HABITAT IMPROVEMENT MANUAL

Interim Report

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HABITAT IMPROVEMENT MANUAL.

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CHAPTER ONE. INTRODUCTION.

1.1) GENERAL INTRODUCTION.

Most rivers in developed countries are intensively managed. Dredging, channelization and impoundment, as well as agriculture (fields are ploughed right up to the river banks and grazing animals range freely along the river and its banks) all change the way in which a river will flow and reduce the habitats that it would support in an unmanaged form. Changes in flow and reduction in habitat diversity directly affect the fauna of rivers usually in a detrimental fashion, reducing abundance, biomass and species diversity.

Modern techniques of river management can, however, be directly used as a method to increase the abundance and diversity of vertebrate and invertebrate species (as long as water quality is not the main limiting factor). (White & Brynildson, 1967). Habitat improvement is the creation and maintenance of conditions more conducive to survival, growth and reproduction of fishes in rivers (Hubbs, Greeley & Tarzwell, 1932). Survival, growth and reproduction require shelter against predators, fertile waters, sufficiency of living space, favourable water temperatures and conditions suitable for spawning. This can usually be achieved by restoration or enhancement of existing riverine habitats, sometimes both (White & Brynildson, 1967).

The purpose of this review is to present and discuss the ideas and methods of habitat improvement and the principles and techniques by which such improvement may be accomplished on lowland rivers in the East Anglian region. The report is divided into five chapters:-

1) Chapter One. Introduction.
2) Chapter Two. A review of improvement devices and methods.
3) Chapter Three. Evaluation of reviewed improvements for use in Anglian rivers.
4) Chapter four. Recommendation of specific improvements for use in Anglian rivers.
5) Chapter five. Planning, installation and management of recommended improvement devices.

CHAPTER TWO. A REVIEW OF IMPROVEMENT DEVICES AND METHODS.

2.1) INTRODUCTION.

The improvement of rivers for fish has been achieved by introduction of habitat improvement devices and by forms of river management. Many different limiting factors affect the fish community within a river and thus many different structures and types of management have been used to counteract these. Management plans and structures have included:-

1) Reduction of the amount of sediment entering the river system and the removal of impounding structures.
2) Cleaning existing riffles and introduction of new ones.
3) Increasing and improving the amount of cover available to fish.
4) The introduction of small dams to diversify both flow and substratum types.
5) The introduction of deflecting devices to diversify both flow and substratum types.

2.2) REDUCTION OF SEDIMENTS AND REMOVAL OF IMPOUNDMENTS.

2.2.1) Introduction.

Sedimentation and pooling in rivers have both found to be limiting factors to fish production (White & Brynildson, 1967). This is because fine sediments tend to fill the pools where larger fish lie and pooling destroys the riffles where some species spawn. Removal of these effects has been accomplished by addition of structural improvements and by changed river management. This type of improvement has included:-

1) Revetment and reduction of channelization.
2) Control of livestock.
3) Removing dams.

2.2.2) Revetment and reduction of channelization.

River channelization led to an increase in the amount of sediment in river systems (Apmann & Otis, 1965). This occurred because as channel length was shortened the river was left with the same amount of energy but with less channel in which to dissipate it; energy was thus expended by erosion of the banks. The additional sediment in the system caused no problems at the site of channelization because the increased energy of the river at this point did not allow particles to settle out. Sedimentation was, however, caused downstream of channel workings. White & Brynildson (1967), Apmann & Otis (1965) and Mih (1978) showed this effect could be reduced if the banks of the worked section of river were protected by revetment in the form of rip-rap. Revetment was found to be particularly useful when associated with fish cover devices (White & Brynildson, 1967; Anon., 1980).

2.2.3) Control of livestock.

Erosion of the riverbed and banks furnishes the current with sediment. Overburdening of the current with sediment leads to siltation and subsequent filling of pools and riffles (Apmann & Otis, 1965). One cause for an increase in the amount of sediment entering a river system has been trampling of the river bank by cattle. White & Brynildson (1967) stated that this problem could be resolved by moving grazing back from the river banks and allowing animals to drink only at specific watering points.

2.2.4) Removal of dams.

Impoundments, such as mill dams, have caused long stretches of river to "pool". These pooled sections are not as good as the natural sequence of riffles, pools and runs either for invertebrate productivity or habitat for fish. Riffles are the most productive sites for invertebrate food and are also the spawning sites for many species of fish, for example chub and dace, thus when this habitat is lost the fishery suffers. In many cases the impoundment that is causing the pooling is an obsolete structure such as an old mill dam. White & Brynildson (1967) and Anon. (1980) stated that removal of such impoundments allowed the river to regain its original character, that is one that included all habitat types, riffles as well as pools.

2.3) IMPROVEMENT OF EXISTING RIFFLES AND INTRODUCTION OF NEW ONES.

2.3.1) Introduction.

Riffles are very important sites for fauna. Fish such as trout, chub, dace and barbel all rely on clean gravel in riffles as spawning sites. Riffles are also the sites of highest production of benthic (bottom dwelling) invertebrates. These clean gravel sites have often been lost in rivers by removal through dredging, siltation or by pooling effects of downstream impoundments (White & Brynildson, 1967). Compaction of gravel beds due to trampling by cattle or by current action has also detracted from their use as spawning sites (Solomon, 1983). The preservation and inhancement of gravel riffle habitats has been achieved by:-

1) Mechanical or hydraulic disturbance.
2) Addition of new gravel riffles.
3) Use of a riffle sifter.
4) Placement of wing deflectors.

2.3.2) Mechanical and hydraulic disturbance of riffles.

Mechanical disturbance involves turning the substratum over and letting the current wash away the finer particles. The most common methods employed involved ploughing the riffle (using a normal farm plough) or turning it over with a specially designed bucket on the end of a dredger.

Hydraulic methods of disturbance have involved jetting the riffle with high powered water and air jets. Mih (1978) wrote

"...a gravel cleaner based on this principle consisted of two rows of 2-inch diameter vertical pipes supported by steel skids on a framework on which a pump could be mounted. A total of 30 pipes each injected 90 gallons per minute of an air/water mix to a depth of six inches in the gravel".

This sort of device washed out the finer particles and left the larger ones behind.

2.3.3) Addition of new riffles.

According to White & Brynildson (1967) this method has been little tried but many of those introduced have been washed away or become silted up. If new gravel was to be added then any upstream additions of sediment must have been reduced and the position and shape of the riffle must have been carefully planned.

2.3.4) Placement of wing deflectors.

White & Brynildson (1967), Everhart, Eipper & Youngs (1975) and Anon. (1980) stated that placement of wing deflectors above or on an area of silted gravel had a cleaning effect. The deflectors constricted and redirected the current thus increasing its speed. The faster water washed out the finer sand and silt particles and left gravel and rock behind.

2.3.5) Use of a riffle sifter.

A machine called a riffle sifter was designed for cleaning gravel riffles. Mih (1978) wrote

"This is a self-powered amphibious vehicle that hydraulically flushes the gravel through 12-inch vertical pipes penetrating the streambed. On the vertical flushing bars there are upward-slotted openings where the water jet forms fan-shaped sprays to act as a water ladder, progressively lifting fine material upward while the flushing bars are raked through the stream gravel. Screen suction intake between each pair of vertical bars collects silt-ladened water to be pumped through a nozzle and jetted out on to the stream bank. During cleaning operations, the machine is pulled slowly downstream by a cable-winch mounted on the machine while the other end of the cable is anchored in the stream".

2.4) METHODS OF INCREASING AND IMPROVING SHELTER.

2.4.1) Introduction.

Places where fish take refuge from floods are commonly referred to as shelter. Areas where they lie to avoid warming by the sun, or to escape predators, are known as cover. Many devices introduced to provide either shelter or cover have supplied both. These words are thus used synonymously in the text.

Shelter is important to fish and invertebrates (Swales & O'Hara, 1980) both in and adjacent to streams because it provides:

A) Concealment for prey and predators.

B) A place of refuge during disturbance or floods.

C) Shading. This helps to maintain lower water temperatures which are favoured physiologically.

Improving the amount and quantity of shelter in rivers has been accomplished in several different ways. The structures and management plans used have included:-

1) The use of artificial overhangs.
2) Brushwood and boulder shelter devices.
3) The placement of artificial reefs.
4) Planting and management of bankside and instream vegetation.
5) Increasing the number of natural overhangs.

2.4.2) Artificial overhangs.

Swales & O'Hara (1980) simulated marginal shelter by using plywood boards that could move up and down with fluctuation in river levels. This sort of cover has also been constructed at a fixed level in the same way as jetties.

White & Brynildson (1967) and Hunt (1969) suggested a modified version of set level cover that looked more natural from the river bank and provided more cover instream. This device consisted of a wooden platform below water level that was covered with rocks and turf that raised it to bank height. The structure worked very well when used in conjunction with deflectors and, due to its construction, tended to deflect the current anyway. The device provided permanent and diverse cover, because it was semi-submerged, and required very little aftercare.

2.4.3) Brushwood and boulder cover devices.

Other suggested methods of increasing shelter have included the use of brushwood (Rodeheffer, 1939; Bossou, 1954; White & Brynildson, 1967; Anon., 1980) and the placement of boulders in the river channel (Hubbs, Greeley & Tarzwell, 1932; Tarzwell, 1938; Ward & Slaney, 1981). Brushwood shelters were made with whole or parts of trees cut from nearby woods or the river bank. This sort of shelter was only of a temporary nature but its advantages were that it was cheap, could be easily removed in times of flood and as easily replaced. Brushwood has also been used as a building block for reefs in lentic waters (Rodeheffer, 1939) and was valuable in increasing fish production, however these tended to rot quickly and thus needed regular replacement.

Placement of boulders in the river provided some cover as well as increasing the diversity of flow pattern (Tarzwell, 1938; White & Brynildson, 1967; Ward & Slaney, 1981). It was found that at the upstream edge, underneath the boulder, the substratum was eroded and an overhang was formed. Such overhangs were often used by sheltering fish. On the downstream edge, behind the rock, a slack was formed in the current. Fish used such slacks as feeding sites, sitting in the region of reduced current and watching for any food floating by on either side.

2.4.4) Reefs.

Artificial reefs serve as concentration points for species of fish and invertebrates in barren areas. They lead to an increase in production and yield. Stroud & Massmann (1966) set out a list of guidelines for the placement and construction of marine reefs:-

1. Reefs should be relatively large and bulky possessing cavities and entrance holes. The building blocks should be piled both vertically and horizontally with a central open space.
2. Devices should be made from durable materials, for example stone or plastic.
3. Reefs should be placed in areas where invertebrate and fish production is low and at a distance from good habitats. The reefs should be well marked using flags (or similar markers) and should be built on a solid substratum.
4. If the substratum on which the reef is placed is soft then pilings should be driven into the bed before reef placement. Reefs are best not placed in areas of very soft substrata or fast current as they will be washed away or buried.
5. Reefs should be situated well away from boats, for example near the beach or only in unnavigable channels.

6. Materials used to construct reefs have to provide sites for algal and invertebrate attachment. Objects with rough surfaces and holes are best.

2.4.5) Vegetation.

White & Brynildson (1967) found that both bankside and instream vegetation were important as riverine habitats. Sturdy turf on the banks led to formation of overhangs whilst bankside and instream plants made ideal places in which fish might lie. Grasses and low bushes were found to be best and it was stated that such plants should be protected from shading out and grazing. Parts of river densely shaded by a tunnel of trees needed to be managed to let light in and so encourage macrophyte growth. Tree management led to lower growing bankside vegetation trailing into the water and growth of macrophytes in the spring, summer and early autumn. Fencing off river banks stopped grazing of both bankside and instream plants.

Low growing plants and willows stabilised the banksides whilst their roots provided excellent cover instream. Larger trees such as alders were good only if the river was wide; the canopy shaded the river, kept temperatures low, trailing branches provided good cover and shading did not completely denude the river bed of macrophytes. In stretches where instream plants were scarce appropriate species were introduced.

2.4.6) Increasing natural overhangs.

White & Brynildson (1967) and Anon. (1980) stated that deflecting devices could be used to increase the occurrence of natural bank overhangs. This was done by placing deflecting devices on bends in the river and thus diverting the current towards one bank. Where the bank was sheer, erosion occurred and this led to the formation of overhangs.

2.5) DEFLECTORS.

2.5.1) Introduction.

Hubbs, Greeley & Tarzwell (1932); Tarzwell (1938), Shetter, Hazzard & Clark (1946), Ehlers (1956), White & Brynildson (1967) and Anon. (1980) found that deflectors could be used to enhance the meander pattern of rivers. This was achieved by placing of devices on alternate banks thus guiding the current sinuously down the river. In already meandering rivers placement of devices at the inside edge of bends enhanced this effect. Current deflectors, used in conjunction with bank protection and cover devices, have been used to create and maintain a deeper channel (with a greater diversity of flow and substratum types) and were also found to be of use in the reinstatement of the riffle-pool sequence of a river. Addition of deflecting devices increased current speed around the structure and caused scouring of bed material; pools were recreated by this scouring and downstream, where the current slackened again, scoured material was deposited and a riffle formed. To enhance this effect researchers placed deflectors every 5-7 channel widths (the natural spacing of riffles and pools). Sand bars were also seen to form at the downstream end of the deflectors.

Placement of deflecting devices and bank protection also led to cleaning of gravel substrata by washing out finer sand and silt particles. Two main kinds of deflecting structure have been used:

1) Wing deflectors-triangular.
   -straight.
2) Mid-channel deflectors.

2.5.2) <u>The wing deflector.</u>

2.5.2.1) Triangular.

This is a triangular structure that extends from the bank (White & Brynildson, 1967; Anon., 1980). The longest side of the triangle is the side angled out at 45° downstream into the current from the bank, the shortest side is the downstream end of the deflector angled away from the apex back to the bank. The third side of the triangle is formed by the bank itself. Wing deflectors of this kind tend not to clog and have the desired effect on the channel, that is formation of riffles and pools. At flood flows the structure turns water away from the banks and back into the main channel due to the angle of the trailing edge. The construction of wing deflectors using logs and rock is best for smaller upper reaches or rivers.

2.5.2.2) Straight.

This type of deflector consists of a single (some times double) log, plank or line of rocks extending downstream, a half to two thirds the channel width and angled 45° from the bank (Hubbs, Greeley and Tarzwell, 1932; Shetter, Clark & Hazard, 1946). Such devices were introduced to form a pool or run at the apex of the device and a riffle downriver of this. Devices were successful in the creation of riffles and pools, however at high flow (when water flowed over the top of the deflector) the structure tended to direct the current towards the bank causing erosion.

Water is directed towards the bank, whenever such structures are completely immersed, because it flows at 90° to the last surface that it hits (White & Brynildson, 1967).

2.5.3) Mid-channel deflectors.

Hubbs, Greeley & Tarzwell (1932) assessed the use of such deflectors in the improvement of Michigan trout streams. All of these types of deflector are constructed in the shape of the letter after which they are named e.g. A, I, Y, V and are made from logs, rocks or gabions. The apex of the A, Y and V structures faced upstream and the I deflector was placed parallel to the direction of flow. The main purpose of this type of deflector was to form pools or runs, on either side of the device, as well as riffles and eventually a point bar on the downstream side. All of the devices were successful to some extent in the formation of these habitats, however all of them were prone to catching drift wood and other debris on the front of the device. This often led to the formation of an impoundment.

2.6) SMALL SCALE DAMS.

2.6.1) Introduction.

Small rock dams on upland streams in North America were first used in the improvement of rivers for fish in the early 1930's. This kind of structure was used only so that water could be stored during the winter months and then released slowly over the summer so as to ensure a year round supply of water to rivers. It was often only the fact that rivers dried up in the summer months that killed fish off (Burghduff, 1934; Cronemiller, 1955). However it became obvious from building of small scale dams that they had other effects on the character of the river channel. In rivers that needed the creation of pools and resting places, and a slackening of the current to reduce channel erosion, small dams were seen as the perfect answer (Tarzwell, 1938).

The addition of small scale impoundments to rivers led to a reduction in gradient and a stabilising of bed materials by reducing the amount of movement possible. Pools formed both above and below these dams; above due to a backing up of water and below due to the force of the water falling over the dam scouring away the river bed. According to Tarzwell (1938) if the dam was built well then the structure also provided shelter (in the form of an overhang). Scouring and washing away of the river bed immediately below the dam led to the deposition of this material, in the form of a new riffle, further downstream of the impoundment. Hubbs, Greeley & Tarzwell (1932) stated the advantages of small scale dams were that they:-

A. Formed pools.
B. Provided cover.
C. Formed a downstream riffle.
D. Reduced water level fluctuation.
E. Led to warming of very cold waters.
F. Aided fishing in swift waters.

The disadvantages included:-

A. Possible over warming of water.
B. The top pool filled with silt and sand.
C. Caused obstruction to migration (trout and salmon especially).
D. Blocked the channel to the passage of boats.

Smith (pers. comm.) found that the river Kym, between Little Paxton and Hail Weston, was backed up six kilometres by three dams none of which were more than a meter high. This observation agrees with the statements of White & Brynildson (1967) and Everhart, Eipper & Youngs (1975) that dams were really only of any use in rivers and streams with a steep gradient. Low gradient rivers tend to already exhibit features that dams create so the additional building of impoundments is detrimental. For example the use of dams in sandy, low banked and warm streams did more harm than good (Hubbs, Greeley & Tarzwell, 1932).

Many different kinds of dam have been used to improve rivers for fish:-

1) Log dams.
2) Board dams.
3) Gabion dams.
4) Loose rock dams.
5) Masonry and concrete dams.
6) Earth dams.

2.6.2) Log dams.

Hubbs, Greeley & Tarzwell (1932) built dams of this sort by placing logs across the stream. These were effective in the formation of small pools both above and below the impoundment. Ehlers (1956) found that, although desired habitat was formed by some logs, many were left dry by end cutting, undercutting or complete washing away of the device.

2.6.3) Board dams.

Everhart, Eipper & Youngs (1975) suggested building such dams in small streams by placing a single plank or board across streams. Tarzwell (1938) suggested construction of a somewhat more complicated device involving an upstream facing ramp (made of planks) resting on top of a log placed across the stream. Construction of both such devices was successful in the formation of pools although the former tended to be badly affected by endcutting, undercutting and washing out.

2.6.4) Gabion dams.

Gabions are wire baskets, filled with rock, and wired together in series to make a strong structure. Everhart, Eipper & Youngs (1975) stated that gabions have been used in the construction of many improvement devices from deflectors to dams because they are easy to install, cheap, flexible, durable, natural in appearance and permeable. Klassen & Northcote (1986) used gabions to build tandem V-shaped dams at sites on a river where there was a predominance of organic material. These dams acted as substratum stabilisers with the organic material settling out and a subsequent build up of gravel behind the structure. Pools and shelter were also formed due the addition of these dams.

2.6.5) Loose rock dams.

Loose rock dams consist of piles of large rocks partially sealed with smaller particles, for example gravel. This kind of dam, however, is very prone to destruction by the current especially if the river experiences high winter flows and has a soft or movable substratum. Both Ehlers (1956) and Warner & Porter (1960) found that this dam lasted less than a year from the time of installation. Ways of increasing the life span of loose rock dams was to build them to incorporate boulders already existing in the river or to build the dam with alternate layers of rock and brushwood (Everhart, Eipper & Youngs, 1975). Brush helped to keep the rocks in place and gave the whole structure a better seal.

2.6.6) Masonry dams.

There is only one report of such a construction by Ehlers (1956). His structure contained a centre pass-box with wings extending out to both banks. By the end of its first year of construction it had been undercut by 13 feet and by a year later the entire middle section had collapsed. Within ten years of construction the entire dam had collapsed and, although it had created a very good pool, the venture had not been worthwhile either financially or from the point of view of continued habitat improvement. He blamed the the dam's failure on the movable substratum on which the structure had been placed.

2.6.7) Earth dams.

Ehlers (1956) reported that this dam was constructed by piling mud, taken from the stream and surrounding area, into the stream and then sealing this by "paddling" (rubbing wet earth, usually clay, together to seal gaps). This structure did not last the year.

CHAPTER THREE. EVALUATION OF REVIEWED IMPROVEMENTS FOR USE IN ANGLIAN RIVERS.

3.1) INTRODUCTION.

All improvement devices (except reefs) and types of management, reviewed in chapter one, were used in high gradient mountain streams in North America to increase the production of trout and salmon species only. This Chapter evaluates the use of these improvements with specific reference to coarse fish in Anglian rivers. Specific construction and management details are stated in Chapter four. In this chapter improvements are evaluated, within each section, from the best to the worst. The sections are:-

1) Reduction of the amount of sediment entering the river system and removal of impoundments.
2) Cleaning of existing riffles and addition of new ones.
3) Increasing and improving the amount of cover.
4) The introduction of dams.
5) The introduction of deflecting devices.

3.2) REDUCTION OF SEDIMENTS AND REMOVAL OF IMPOUNDMENTS.

3.2.1) Introduction.

Some methods already employed to reduce siltation of rivers, such as bank revetment and control of livestock, will be more use in the Anglian region than others, for example reduction of river channelization or removal of impounding structures. The latter has never before been tried as a method of improvement in this region.

3.2.2) Revetment.

Revetment of eroding banks using rip-rap has proved useful in reducing the amount of sediment entering river systems (Apmann & Otis, 1965; White & Brynildson, 1967; Anon., 1980; Anon., 1983). Revetment is a relatively cheap, reliable and easy to install method of improvement. It is, and should continue to be, used in the improvement and maintenance of rivers in the Anglian region, for example the river Nene in its tidal reaches.

3.2.3) Control of livestock.

Fencing off riverbanks (Apmann & Otis, 1965) and providing special watering points (White & Brynildson, 1967) to reduce trampling would be possible only by arrangement with riparian owners. White & Brynildson (1967) suggested that fences should be at least 10m. from the bank as this stopped livestock reaching through to crop bankside plants, and allowed movement of vehicles, for example dredgers, along the riverside. In the Anglian region, however, where land is expensive, 5m. or less would probably suffice. Special watering points should be made in any pasture field that borders a river, especially as they take up little space and are and easy to build.

3.2.4) Reduction of channelization.

Channelization causes downstream sedimentation (Apmann & Otis, 1965). Reduction of this practice would lead to a subsequent reduction in siltation; channelization of rivers should thus be kept to a minimum. This kind of river management, however, is necessary in certain places as it increases drainage of pasture and arable land and reduces flooding, especially in low lying areas.

3.2.5) Removal of dams.

Removing impounding structures, such as fallen trees and old mill dams, is the first step in improving river fisheries (White & Brynildson, 1967; Anon., 1980; Anon., 1983). Before removal of such dams, though, an assessment of their habitat value must be made. For example the pool formed behind an impoundment may be a nursery area for juvenile fish or used as shelter during high water. The existing value of the feature in these respects and as a part of overall habitat diversity may outweigh the known benefits of its removal. Indeed, in special cases, such as the ponding of a low-order stream, the fishery may be wholly dependent on impoundments.

3.3) IMPROVEMENT OF EXISTING RIFFLES AND INTRODUCTION OF NEW ONES.

3.3.1) Introduction.

Improvement of existing riffles is a method little used in this country although it has proved successful in other countries. For example improvements installed in Lawerence creek, Wisconsin by Hunt (1969) increased the amount of exposed gravel by 11%. This, along with other improvements, increased the average number of legal sized trout by 156%. Addition of new riffles to river systems has generally been little tried, subsequently information is sparse on the effects of such improvements.

3.3.2) Mechanical and hydraulic disturbance of riffles.

Mechanical disturbance of riffles is an improvement that can cheaply and easily be put into practice. In low-order rivers and streams local angling clubs can dig riffles over with forks and farmers, that own fishing rights, can clean riffles by ploughing them. In higher-order, or deeper, rivers the N.R.A. could manage riffles on a larger scale using a specially designed dredging bucket.

Hydraulic disturbance is somewhat more complicated than mechanical disturbance because it involves the use of high powered water and air jets. It is, however, probably a more effective method if the equipment is available. Farmers may be able to rig up such a system from a tractor and angling clubs could hire portable high powered jet devices such as those used to clean cars. Larger statutory bodies, for example the N.R.A., may have the resources to build a device like that described by Mih (1978).

This sort of work should be carried out only in the winter, when no fish are spawning, and disturbance should always proceed from the bottom (downstream) to the top (upstream) edges of riffles.

3.3.3) Addition of new riffles.

Placing new riffles in rivers is likely to be an expensive and difficult operation, requiring planning, staff and materials. The construction details and the exact location of a new riffle needs to be planned by somebody who is fully aware of river hydrodynamics and not by well meaning amateurs. Purely dumping a pile of rocks and gravel anywhere in a river is likely to be either detrimental to the fishery or a waste of time and money, as the "riffle" will silt up or be washed away.

It is, however, possible for angling groups to build new riffles in rivers, for example the Norfolk anglers conservation association (N.A.C.A.) have done so on the river Wensum at Lyng. There is a set of guidelines that should be followed for implementation of any such device (see chapter four). Construction of the N.A.C.A riffle was, though, only enabled by donations of rock and gravel from Redland aggregate and the use of a local farmers' tractor and trailer to transport the material. Design and placement were suggested by an environmental consultant.

Implementation of this type of improvement is probably more easily accomplished by larger statuatory bodies, like the N.R.A., as they have greater funds, proper equipment, available staff and knowledge. Examples of artificial riffles, placed by Anglian water, can be found on the river Gwash, Leicestershire.

3.3.4) Placement of wing deflectors.

Shetter, Clark & Hazzard (1946) and Hunt (1969) increased the amount of exposed gravel by placing current deflectors on top of sandy and silty substrata in small mountain streams. The devices led to deepening of the channel through washing out of finer particles; larger particles, such as gravel and rock, were uncovered and remained in place.

Although these deflectors were small, and placed in small streams, there is no reason why scaled up versions shouldn't work on upper reaches of larger lowland rivers in the Anglian region. As long as addition of such devices does not contravene the land drainage and sea defence byelaws (Anon., 1976), they are covered by high flows (Anon., 1980) and they are built well.

3.3.5) Use of a riffle sifter.

The construction and use of this machine was described by Mih (1978). The main problems encountered during its use were that the flushing bars had problems penetrating the river bed and often broke off on large rocks. The cable pulling the machine was also prone to snap. If the device were reconstructed it may well work better in East Anglia than it did in the mountainous streams of North America. This is because the substratum of many Anglian rivers is generally soft, containing few rocks and boulders.

Sifting riffles with such a machine would be vastly preferable to all other methods discussed because fine particles would be removed from the river system all together, rather than just washed downstream. It is for this reason that the N.R.A. has expressed a desire to construct a riffle sifter.

3.4) METHODS OF INCREASING AND IMPROVING COVER.

3.4.1) Introduction.

The comprehensive management of rivers in the Anglian region has left little natural, bankside or instream, cover where fish may shelter from flood flows or avoid warming by the sun. River fisheries have suffered for these reasons. Many methods employed to increase cover in North American streams could also be used in British rivers, without adversely changing land drainage or flood carrying capacity. Others, such as increasing natural bank overhangs, are of little practical use.

3.4.2) Artificial overhangs.

Moveable bankside shelters made of plywood boards (Swales & O'Hara, 1980) are good temporary devices. The device is constructed from plywood boards that float on the river surface. These are held in place via metal rings, screwed onto the boards, that are slipped over the top of metal poles in the banks. The advantage of this device is that the boards can move with fluctuations in river level and thus shelter is available to fish during both droughts and spates. The main problem with the device is that the boards are easily lifted off the poles by floods and washed away, or deliberately removed. These problems can be overcome by attaching the boards more firmly at a fixed level by building what basically amounts to a small jetty. This structure also has problems though, such as being covered during high water and left dry during droughts.

The best type of artificial cover is a fixed level, semi-submerged wood and rock device (White & Brynildson, 1967; Anon., 1980). The advantages of this structure are that it provides diverse instream cover, it doesn't adversely affect river flow (but can be designed to deflect the current where desired), it is natural in appearance, it can be any size and it is a permanent structure that needs little aftercare. This is exactly the sort of improvement device that is needed in the Anglian region, that is to say a flexible design that can be installed almost anywhere without causing problems to land owners or the N.R.A. and subsequently requires little maintenance.

3.4.3) Other cover devices.

Placement of brushwood structures in Anglian rivers is a viable way of increasing cover especially as this sort of device can be used in all orders of river, from streams to tidal reaches. The advantages of using this method are that these shelters are readily available (as they can be cut from nearby), they provide a very natural form of cover, they are cheap and easy to install and can be removed immediately if the need arises. The disadvantages are that the branches rot quickly, debris tends to collect on them and they need management, for example removal and replacement.

Boulder cover can also be employed in the Anglian region. This is best in the upper reaches of rivers where the boulders can protrude above the surface of the water. They provide better cover like this, and are visible. The problem with boulder cover is that unless material can be found on the riverbank, or nearby, then they are very difficult and costly to install. This is certainly the case in East Anglia.

3.4.4) Reefs.

The addition of artificial reefs has never been tried in the Anglian region, but I see no reason why they shouldn't have a beneficial effect. Reefs would probably work best in the broads, as these are lentic waters. Structures made of brushwood could be used (Rodeheffer, 1939) although these would quickly rot. More durable reefs could be made from piles of old breeze blocks, piping or rocks; it may even be possible to cast special concrete structures, containing many sized holes and with a rough surface, if the money is available. These could be made to any size depending on where they would be placed.

It may also be possible to place some kind of reef in the lotic environment of Anglian rivers, especially the larger tidal reaches. Many of these rivers have soft substrata and very little instream cover. There are, however, patches where the substratum is hard, such as the stretch at St.

Bennets Abbey on the Ant. These hard stretches seem to be regions of high invertebrate production and fish concentration. If some kind of reef, for example a layer of breeze blocks or pipes, were placed on the river bed at these sites, invertebrate production and fish concentration might increase further still. Placement of reefs at sites where the substratum is soft, to improve these areas, would seem to make more sense than improving sites that are already good. The problem with this is that anything heavy positioned on top of a soft substratum is prone to sink. Surveying the river would establish regions where a shallow soft substratum overlies a hard one. These may also be good places to build reefs.

The major disadvantage of this type of improvement is interference with boating. Any reef placed in broads and rivers must not protrude too far from the river bed and must be well marked.

3.4.5) Vegetation.

Planting and management of bankside and instream flora gives the best cover. Trees, such as willows (*Salix sp.*) or alders (*Alnus glutinosa*) and macrophytes, such as *Potamogeton spp.*, provide the sort of cover that might exist on an unmanaged river. In areas where the river is completely shaded by trees, inhibiting growth of both bankside and instream vegetation, selective pollarding and removal should be employed to let light in. White & Brynildson (1967) stated that the best species to plant on banks is reed canary grass (*Phalaris arundinacea*) as this grows in mats out into the channel and forms excellent shelter. The main problem, however, with plant cover is that if it is not regularly managed then they can take over. This can lead to complete shading of rivers, formation of impoundments (excessive macrophyte growth or fallen trees) and creation of snags on which debris collects. It is for these reasons that natural cover has been removed and is thus sparse.

3.4.6) Increasing natural overhangs.

Natural overhangs provide excellent shelter as the turf above is often a source of food, and roots may hang down into the water. Placing deflecting devices in rivers, to increase natural overhangs, has proved successful (Anon. 1980, Anon 1984). Where a deflector is installed opposite a sheer bank, erosion occurs at the base of the bank and an overhang may be formed. The erosion continues however, and through a cycle of overhang and collapse the bank retreats - which may conflict with adjacent land-use. This form of improvement is thus discouraged unless riparian owners are willing to allow it.

3.5) DEFLECTORS.

3.5.1) Introduction.

Deflecting devices are used to create pools, deep runs and riffles as well as increase diversity of flow pattern. Bankside wing deflectors are useful but mid-channel devices create many problems. Deflecting devices include wing and mid-channel deflectors.

3.5.2) The wing deflector.

Swales (1982) installed wing deflectors in the river Perry in Shropshire. These had the desired effect on flow and substratum. There thus seems no reason why similar deflecting devices shouldn't work in upper and middle reaches of lowland rivers in East Anglia. Use of such devices in lower stretches is limited by river traffic.

3.5.2.1) Triangular.

The triangular deflector can be constructed from logs, rocks and gabions. The device is made in the shape of a triangle, the longest side of which runs downstream from the bank to about two thirds the channel width at an angle of 45°. This type of device is effective in the formation of a pool and riffle and is best used in conjunction with artificial cover devices (placed opposite). The structure is relatively cheap, easy to build and is a strong and permanent device if properly built. When covered by high water, flow is directed back into centre channel and not onto the banks, due to the action of the downstream edge of the device.

3.5.2.2) Straight.

Straight deflectors can be constructed from either logs, rocks or gabions. These devices are easy to build and have the desired effect on the channel, scouring fine material and producing a pool and riffle. The problem with them is that when covered by high water the current is directed onto the bank (from which it extends). This can be overcome by revetment of the river bank.

3.5.3) Mid-channel deflectors.

These devices are usually made from lines of rocks or logs placed mid-stream and built into the shape of the letter after which they are named. The advantages are that they are very cheap and easy to build and they form two pools, or runs, and two riffles. The major disadvantage is that they tend to clog with debris. If a large amount builds up then an impoundment may form.

3.6) WEIRS.

3.6.1) Introduction.

The term dam, as used in all references, is somewhat misleading because, although the structures are designed to impound flow and form a pool, they are not intended to stop flow altogether. Indeed, formation of a pool below the structure is as desirable as formation of a pool above and are often more permanent. The term weir is a more accurate description and I shall thus refer to such structures as weirs from here on.

Weirs should only ever be installed in rivers and streams with a steep gradient. This means that installation of a weir should cause pooling no greater than 10m in length, that is 10m from the weir to where the impoundment no longer effects the river. The fact that dams can be bad is exemplified by White & Brynildsons' (1967) statement that removal of impoundments in some rivers is the first method by which they can be improved. In the Anglian region the non-use of dam-like structures on low gradients tends to rule this form of management out in most cases. There maybe, however, a few sections on the very upper reaches of Anglian rivers that would benefit from the addition of such improvement, for example the river Wensum at Fakenham. The other way in which weirs could be used is if their installation is planned when the river is dredged. If the channel is made deeper where the dam is to go then pooling effects would be reduced. Pooling is reduced because if the weir is lower than the rest of the river the water level will not have to rise as far before covering the dam and flowing over it.

There are many different kinds of weir structure. Not all of them are suitable for all situations, one type usually being better than an other, depending on the environment in which they are to be built and the type of materials available. Weir types include:-

1) Log weirs.
2) Board weirs.
3) Gabion weirs.
4) Loose rock weirs.
5) Masonry weirs.
6) Earth weirs.

3.6.2) Log weirs.

Log weirs are ideal for upper, lower-order rivers in the Anglian region. This type of device is cheap, easy to build, materials needed are often close at hand and the device is effective in forming pools. The disadvantages are that the logs may rot and, unless the device has been well constructed, the structure is often left dry by end cutting, undercutting or washing out.

3.6.3) Board weirs.

There are two kinds of board weir. The first of these is simply a board or plank placed across the river that impounds flow (Ehlers, 1956). The second type is more complicated and sometimes referred to as the Hewitt ramp (Tarzwell, 1938).

The first of these devices is of use only in very small upland streams, however due to its single plank construction it is not a very strong and is prone to undercutting. The second can be used in larger streams (but is best reserved for use with a very steep gradient) as the structure is stronger and much less susceptible to either end or undercutting.

Simple board weirs are a good type of improvement for upper reaches of Anglian streams especially as wood may be cheaper and more readily available than other materials. The Hewitt ramp is of little use in the region.

3.6.4) Gabion weirs.

If a larger weir is required then gabions are a strong and cheap material with which to build it. Weirs constructed from gabions should be triangular in cross-section because this is a stable and strong design. The use of such large weirs, however, will probably not be needed in the Anglian region unless the river has been especially deepened for the device.

3.6.5) Loose rock weirs.

Loose rock weirs consist of piles of large rocks partially sealed with smaller particles, for example gravel. This kind of weir, however, is very prone to destruction by the current especially if the river experiences high winter flows and has a soft or movable substratum.

Although loose rock weirs are cheap and easy to build where rocks are available this is not the case in the Anglian region and, considering the short life span of loose rock weirs, this sort of device is not recommended

3.6.6) Masonry weirs.

Only one such weir has been used as river improvement before and this lasted less than two years (Ehlers, 1956). Devices of this kind are expensive and difficult to build and too large for use in the Anglian region.

3.6.7) Earth weirs.

Ehlers (1956) found that a weir made of paddled mud didn't last a year. Although this type of weir is very cheap and easy to construct, it does not last long enough to warrant building. Finding the mud may also be a problem in the Anglian region as it would usually be taken from the banks.

CHAPTER FOUR. RECOMMENDATION OF SPECIFIC IMPROVEMENTS FOR USE IN ANGLIAN RIVERS.

4.1) INTRODUCTION.

Implementation of all suggested improvement devices and managements is not possible in the Anglian region. This is because with some improvements, for example introduction of dams, the physical character of the area does not lend itself to placement of such structures. The reason that many improvements cannot be implemented, however, is because they would contravene the land drainage and sea defence byelaws (Anon., 1976) causing flooding or raising the water table.

Recommended improvements for the Anglian region are:-

1) Reduction of sediments and removal of impoundments.
2) Improvement of existing riffles and construction of new ones.
3) Increasing and improving cover.
4) Use of deflectors.
5) Restricted use of weirs.

4.2) REDUCTION OF SEDIMENTS AND REMOVAL OF IMPOUNDMENTS.

4.2.1) Introduction.

There are three methods of improvement that I recommend using within this category:-

1) Revetment.
2) Control of livestock.
3) Removal of dams.

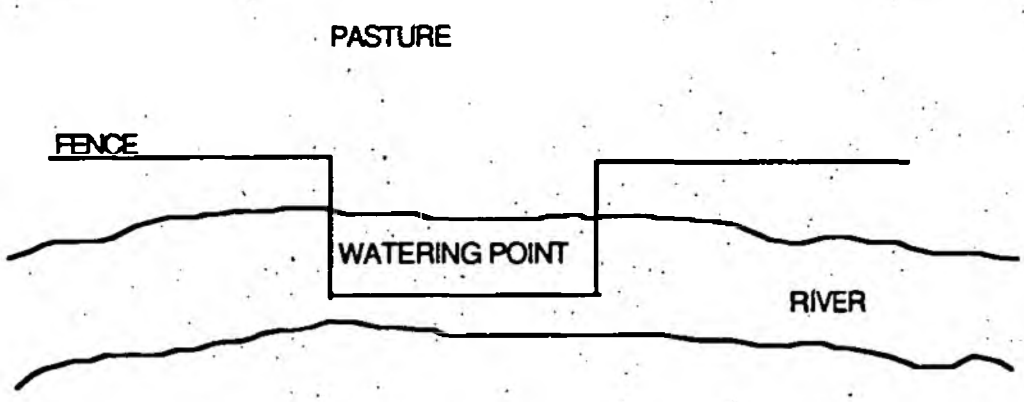
4.2.2) Revetment.

Revetment of banks by rip-rapping reduces the sediment input from bank erosion. Rip-rap is made from stones or wood and should extend from the river bed to the top of the bank. Stones should be built up as a rough dry stone wall and wood should be made into a lattice fencing. The fence is built by driving stakes into the river bank at 1m intervals, branches and sticks are then bent to intertwine between these posts. If the bank is sheer then the fence can be built right up against it, if it slopes then the area behind rip-rapping should be filled with earth, rock or a mixture of the two. One way of increasing the improvement potential of revetment, and reduce erosion even further, is to build rip-rap in conjunction with artificial cover devices.

4.2.3) Control of livestock.

A sturdy fence, constructed of wooden posts, wire fencing and barbed wire should be made alongside the river, about 5m from the bank. At one or two points a special watering point should be made in the fence (Figure one). This is constructed by building a rectangular extension of the fence into the river, enclosed on every side, except the field side. This reduces trampling of the bank as well as disturbance of the riverbed. Such watering points may collect debris, especially at high water, and need regular checking.

1.1) Figure one. A watering point.



4.2.4) Removal of impoundment.

If it is at all possible then dams should be removed slowly so that the water level doesn't fall too rapidly, one foot per week is a reasonable rate. If this is not possible then the stretch of water above the dam should be checked for stranded fish, isolated pools and mud banks. Fish should be returned to the water; isolated pools should either be drained, and the fish returned to the mainstream, or the pool should be connected to the main flow by digging a channel or deflecting the current; bare mud banks should be planted up or dug out.

As this method has never been tried before it is difficult to state specific recommendations, however it is currently being investigated by N.R.A. Anglian region.

4.3) IMPROVEMENT OF EXISTING RIFFLES AND INTRODUCTION OF NEW ONES.

4.3.1) Introduction.

I recommend two main methods for improving existing riffles through physical disturbance and explain how to build new ones.

4.3.2) Mechanical and hydraulic disturbance of riffles.

Riffles can be mechanically disturbed by ploughing, harrowing or digging them over like a garden bed. Each spade full should be turned upside down, broken up and mixed in the current to wash away fine sediments. If a dredging device is available then this can be employed; the operator of one dredging machine scooping a section of the riffle out and placing this into a Gradall 7-foot wide digging bucket on another machine. The front of the second bucket is covered with a fine wire mesh (13mm diameter) and once the bucket is full it is agitated with the gravel in it. Fine particles fall through the holes and are washed downstream on the current. Medium sized particles fall through the holes and began to fill the hole where the scoop was taken. Once all the fine and medium particles are been lost from the bucket the remaining particles are placed back into the hole from which they had come. Hydraulic disturbance can be achieved by jetting riffles with portable high power jets, like those used to clean cars and buildings. The jet should be sprayed into the substrate at an angle, with the jet pointing upstream.

In both methods work should proceed from bottom, downstream, to top, upstream, edge of the riffle. Care should be taken not to compact the already cleaned substratum, for example by walking on it or driving vehicles over the riffle.

4.3.3) Addition of new riffles.

New riffles should be slanted across the river in the direction the current flows. The riffle should be slightly dished in cross-section, with the lowest point in the centre and the higher shoulders towards the bank, as this is their natural shape. The base should be constructed of rocks and boulders and then covered with ungraded gravel. The size, shape and specific dimensions can be determined by looking at riffles that already exist on the river or on a river of similar size, order and character. Any new riffle placed in a river channel must be sited according to the position of existing riffles, that is on top of one already forming or 5-7 channel widths from this or any others.

4.4) METHODS OF INCREASING AND IMPROVING COVER.

4.4.1) Introduction.

There are three methods of increasing and improving cover that I beleive will work in the Anglian region:-

1) Artificial overhangs.

2) Reefs.

3) Brushwood shelters.

4.4.2) Artificial overhangs.

I suggest the device designed by White & Brynildson (1967). Wooden posts are driven about 4ft. into the river bed with the free ends left underwater about 1-2ft. from the water surface. These posts are placed at an angle across the river to where the edge of the shelter will be. Similar posts are driven into the riverbank in holes that render them the same height as the instream ones. Planks, known as stringers are installed which connect the bankside and instream posts, via trenches dug into the banks. The stringers are nailed in place. Planks, running parallel with the bank, are nailed on top of the stringers and gaps are left between each one. All the wood used in this structure should be completely submerged so as to reduce rotting. On top of this wooden framework a layer of rock is placed that brakes the water surface by a foot, the trenches are also filled with rock. The whole structure is then covered with soil and turf so that it blends in with the existing bank.

4.4.3) Reefs.

These should be constructed according to the guidelines laid down by Stroud & Massmann (1966):-

1. Reefs should be relatively large and bulky possessing cavities and entrance holes. The building blocks should be piled both vertically and horizontally with a central open space.

2. Devices should be made from durable materials, for example stone, plastic.

3. Reefs should be placed in areas where invertebrate and fish production is low and at a distance from good habitats. The reefs should be well marked using flags (or similar markers) and should be built on a solid substratum.

4. If the substratum on which the reef is placed is soft then pilings should be driven into the bed before reef placement. Reefs are best not placed in areas of very soft substrata or fast current as they will be washed away or buried.

5. Reefs should be situated well away from boats, for example near the bank or only in unnavigable channels.

6. Materials used to construct reefs have to provide sites for algal and invertebrate attachment. Objects with rough surfaces and holes are best.

I would recommend that they should be made from breeze blocks or the convoluted bricks built for climbing plants, obtainable from garden centres.

4.4.4) Brushwood shelter.

Branches or trunks are attached by cut or root ends and anchored via cables to stakes driven deep into the river bank. The other end of the brushwood is dropped into the river, next to the bank, with what was the growing end facing downstream.

4.5) DEFLECTORS.

4.5.1) Introduction.

Only one deflecting device is recommended, this is the wing deflector. General and specific construction details are given.

4.5.2) General construction details.

One of the main problems with deflectors is that they are prone to endcutting; this is where the current erodes its way around the end of the structure. Soft low banks, made of loam and with a low rock content are especially prone to this kind of erosion. So as to counteract this any structure placed into a river should have all parts, at right angles to the current, well embedded into the river bank, at least 2-3m. The banks at the ends, and up and downstream of improvement devices, should be protected with rip-rapping. The downstream side of the structure should be well braced, with these extending into the banks or riverbed, or built only where natural bracing already exists. The main body of devices should extend into the river bed as well as the banks by digging trenches across the channel. Once the trenches have been made some of the structure should extend down into this and the rest of the structure built on top. The top of a deflector should always just clear the water surface at normal flows and be covered by floods. They should extend one third to one half the channel width and be at an angle of 45° to the bank in a downstream direction. Deflecting structures are designed to guide, rather than force (or at worst impound) the current.

4.5.3) <u>The wing deflector.</u>

This a triangular structure that extends from the bank. The longest side of the triangle should be the side that is angled out at 45° into the current, the shortest side is the downstream end of the deflector that is angled away from the apex back to the bank. The third side of the triangle is formed by the bank itself. One of the most common ways of constructing this device is to embed a log (or logs) 2-3m into the bank, angle it downstream at 45° and extend it to about half the channel width. This is then braced on the downstream side by placing another log, angled from the main one, downstream back to the bank where it is also embedded. The gap between these two logs is then filled with rocks to give added strength. The bank opposite this structure should be protected by rock rip-rapping so as to stop the formation of meanders if this is not desired. The construction of wing deflectors using logs and rock is best for upper and middle reaches of rivers. If deflecting devices are desired in larger lowland rivers then I beleive that construction of wing deflectors using gabions is the best option. The gabions should be used to form the basic triangle and this should then be filled with rocks.

4.6) WEIRS.

4.6.1) Introduction.

Two types of weir will work in the upper reaches of low-order rivers in this region. These are the log weir and the simple board weir. General construction details are stated, these apply to any small scale weirs, and specific details of the two recommended devices are given under their respective headings.

4.6.2) General construction details.

One of the main problems with weirs is that they are often left dry by endcutting; this is where the current erodes its way around one or both ends of the structure. Soft low banks, made of loam and with a low rock content are especially prone to this kind of erosion. So as to counteract this any structure placed into a river should have all parts, at right angles to the current, embedded at least 2-3m into the river bank. The banks at the ends, and up and downstream of improvement devices, should be protected with rip-rapping. The downstream side of the structure should be well braced, with the braces extending into the banks or riverbed, or built only where natural bracing already exists, tree roots for example. The main body of devices should extend into the river bed as well as the banks by digging trenches across the channel. Once the trenches have been made some of the structure should extend down into this and the rest of the structure built on top. Weirs should always be built in a pyramidal fashion, with the base of the structure wider than the tip, and the top should also always just clear the water surface at normal flows and be covered by floods. A spillway of some description should also be included. This usually involves building the centre section somewhat lower than the sides and encourages water to flow centrally over the dam thus digging out a pool in the middle of the river below the structure; the spillway also reduces endcutting as water is drawn away from the banks. The main problem with all weir structures is that the pool behind the impoundment tends to eventually fill with sediment, this is difficult to avoid unless the pool is dredged. Even when the pool above the weir fills, the pool below continues to be eroded and thus maintained, their function is thus never completely lost.

4.6.3) Log weirs.

This sort of weir can be as simple or as complicated as desired. The simple log weir is made from just one log placed across the stream, resting in a trench, with either end fixed into the river banks. This is held in place by four stakes and wire. The wire is run over the log, between the upstream and downstream stake, and is pulled tight as they are driven into the river bed. Modified versions of this type of weir can be employed. The first of these is where the main log is placed on two notched sills sunk into the river bed and then securely fastened to these sills. The structure can also be covered with rock and a spillway created by notching the top of the rock or making the rock covering lower in the middle. This type of construction is ideal for streams of no more than 1-2m. wide. If a stronger device is needed then this can be converted into a K-weir by the addition of downstream braces between the log and the bank. The gaps between the braces and the log should be filled with rocks. For deeper stretches of water this weir can be made larger by using more than one log. Logs can be placed directly on top of one another or built into a pyramid, with the remainder of the building the same as for the single log weir.

4.6.4) Board weirs.

This consists very simply of a board (or boards nailed together), some 3-4 inches thick, placed on its edge across the stream. These are held in place by extending them 2-3m into the banks and by stakes. The stakes are placed on either side and driven deep into the riverbed right next to the boards, the top of these should be level with the top of the board to give added strength. A spillway can be created by cutting a few inches out of the top edge, for about a foot or two, in the middle of the weir.

CHAPTER FIVE. PLANNING, INSTALLATION AND MANAGEMENT OF RECOMMENDED IMPROVEMENT DEVICES

5.1) INTRODUCTION.

When river habitat improvement schemes are employed the sequence of events in which such improvements occur should always be the same:-

1) Planning.
2) Installing.
3) Monitoring.
4) Maintaining.

5.2) PLANNING IMPROVEMENT.

5.2.1) Introduction.

The careful planning of habitat improvements is essential to the eventual success of any management. Many projects that have been set up with much of good intention and little actual planning have come to rapid ends, usually being washed away by the current.

5.2.2) Where to improve?

Bodies in charge of a stretch of water, for example an angling club or the regional National Rivers Authority (N.R.A.), will be aware of where the fishing "hot spots" are, where production is high and where the survival of juveniles is good. The opposite of this, stretches of water where the fishery is bad, are potential sites for habitat improvement. If the river, however, is lacking in nutrients, or is polluted, and it is these factors that are limiting biological production then habitat improvement may be futile. Sites should only be chosen for management if both physical and biological surveys show that there is a good prospect of increasing the year -round carrying capacity of the river (White & Brynildson, 1967). Carrying capacity is the maximum number of fish that the river has the resources to sustain over a given time.

There are four questions that need to be asked before management is initiated.

1. What is the present capacity for growth and natural reproduction of fish in the river?
2. What is the present carrying capacity?
3. What are the potential carrying capacities of the river at different levels of management?
4. What are the unique qualities of this river?

5.2.3) Surveying sites, determination of limiting factors and prescribing improvements.

The whole river and its catchment should be considered. This is because it does little good to install deflectors and dams at one point if the upstream erosion on the watershed fills the pools and riffles or if a downstream "hot spot" is altered and so lost. The only way to be sure that there will be no such sideffects is to survey the river. The survey should take the form of a comprehensive study of both physical and biological aspects of the stretch of water. The information set out in **5.2.3.1** and **5.2.3.2** should be compiled in every survey (from Hubbs, Greeley & Tarzwell, 1932; Hazzard, 1948; White & Brynildson, 1967; Solomon, 1983).

5.2.3.1) Physical considerations.

A) History of land and water use and future uses. What has the river, and the land bordering it, been used for in the past, for example has there always been pasture? Are there any plans for the future, building for example?

B) Present status and history of fishery. Is the fishing on the river good at the moment, has it ever been better?

C) Geology of area. What are the major rock and sediment types in the area?

D) Type of surrounding land. Is the surrounding land arable, pasture or built up?

E) Number and position of tributaries flowing into the river.

F) Topography of banks. Are there any river cliffs or bank overhangs?

G) Riffle-pool spacing. How many riffles and pools are there in the stretch of river and what is the spacing between them? Does this agree with the 5-7 channel widths rule?

H) Amount and type of cover and visual obstruction. What are the predominant plant species bankside and instream and do these provide any cover? Are there any other features that provide cover, for example fallen trees?

I) Average water temperatures for winter and summer.

J) Average speed of flow in winter and summer.

K) Maximum and minimum depth.

L) Substratum type.

5.2.3.2) Biological considerations.

A) Water quality. Do any effluents run into the river? Is the river naturally unproductive?

B) Amount and availability of spawning grounds. Are there any areas of clean gravel in riffles? For example this habitat is used by chub and dace for spawning. Are there any roots hanging into the river? For example this habitat is used by roach for spawning.

C) Amount and species of weed. Is there a lot of macrophyte growth and what are the main species present?

D) Age, size and species of fish.

E) Food type and availability. Is there high invertebrate and macrophyte production? Are these sources of food available to fish?

F) Is there protection from depletion of the fishery?

Through surveys, covering the factors laid out above, it is possible to identify limiting factors. A limiting factor is one which stops the river from reaching its carrying capacity, for example a lack of gravel bed riffles or a preponderance of predatory species. Once limiting factors have been identified improvements can be suggested, each improvement scheme being tailored for each specific problem.

5.3) INSTALL IMPROVEMENTS.

5.3.1) Introduction.

There are certain guidelines that must be followed when installing any device, irrespective of the particular improvements to be implemented:-

1) Legal approval.
2) Choice of device and materials.
3) Choice of site.
4) When to work.

5.3.2) Legal approval.

Legal approval for implementation of improvements must be sought once the part(s) of the river that need to be improved, the limiting factors and the type of structure required have been identified. No work should ever commence without the written permission of the relevant bodies these include; British Waterways Board, National Rivers Authority, local landowners, Water Authority etc.

5.3.3) Choice of device and materials.

The sort of improvement needed will be entirely dictated by the factors that are limiting the fishery and by the nature of the river. As White & Brynildson (1967) pointed out habitat improvement is basically a biological not an engineering problem. Rather than trying to improve on nature, management should open up the possibilities for nature to improve the stream itself, for example by encouraging meandering or erosion of fine sediments. Materials used in construction will also be determined by the environment into which it is to be introduced, for example if the river is large and is subject to high winter flows then any construction must be made solid. Materials used should always be ones that are readily available, for example logs from a local wood, rocks from a quarry and should be as natural as possible.

5.3.4) Choice of site.

The exact position of any habitat structure will be dictated by the lie of the river. For example it is fundamental to install riffles and pools 5-7 channel widths from one another, or from already existing ones, because this is the natural spacing of these features. Construction of improvements should avoid backflooding existing pools or riffles and must not destroy other riverine features. Structures should not block the channel (unless that is the desired effect of the improvement) and should not be built in a fashion that might lead to blocking; certain devices, used in the past, are now not recommended for this reason e.g. A and I midstream deflectors.

5.3.5) When to work.

When installing devices or management plans all work should take place in late summer, out of the spawning season. Working at this time of year not only avoids disturbing spawning fish but also has other advantages; the current is not as strong, water is warmer and the height of the river at low flow can be seen. The height at low flow is very important because the framework for all devices should remain below water level at all times as this preserves any wood used in the design. The worst bits of the river should be improved first so that the better areas are not disturbed unduly. All structures should be built for permanence and with angling in mind. The natural appearance of any structure is as important as the way in which it modifies the river (Hubbs, Greeley & Tarzwell, 1932; White & Brynildson, 1967; Anon., 1980).

5.4) MONITOR IMPROVEMENTS.

5.4.1) Introduction.

The best way to monitor the effects of river management is to survey the site before and after the addition of the improvements. To get a good idea of the actual changes the structures have on the fauna, on top of the seasonal and yearly changes that occur in rivers anyway, the sampling needs to start at least two years before implementation of improvement devices. This can only be done if the project is planned well ahead of the actual work. The alternative to this is to compare the improved stretch of river with a control (a similar stretch that hasn't been improved). The improved reach and the control should both be sampled at the same times; any variation seen in the fauna of the control is natural variation and this can be taken into account when the changes caused by the improvement device are measured. This sort of monitoring is more feasible when no "before" sampling has been done.

The differences between improved and unimproved streams and rivers can be measured by three main methods:- Intensive creel census, quantitative studies of invertebrates and the determination of fish growth rate by electric-fishing with the examination of fish scales (Tarzwell, 1938). The later two may only be possible if improvements are implemented by the N.R.A. or other such body.

5.4.2) Creel census.

To secure complete and reliable data a record must be made for every fishing trip that is made to the river. The best way to do this is by catch returns, forms should be handed out to fishermen to be filled in and returned. In the survey any fish taken home, or of reasonable size, should be counted, weighed, measured (length) and the number of each species recorded. For smaller fish, or for those caught and immediately returned to water, the average size, number and species of the fish should be noted. The time spent fishing and the bait used should be noted in each case.

5.4.3) Quantitative studies of bottom organisms.

Samples should be taken from the major habitat types at improved and control sites, these may either be substratum types or larger habitat features, for example riffles and pools. Quantitative samples should be taken at different times of the year so as to take account of seasonal variation. Invertebrates can then be identified to order or group, counted and the volume measured. The volume gives an idea of the amount of food available to fish.

5.4.4) Growth rate studies.

Improved and control sections of the river can be netted off and electric-fished. Scales taken from individuals at each sampling occasion give an idea of the age and average growth rate of fish. Age is determined by counting the number of lines on the scales and growth rate is determined by the distance between these lines. This allows the production of the fishery to be calculated and thus any change in the number or size of fish in the river can be seen.

5.5) MAINTENANCE OF IMPROVEMENT DEVICES.

Any device that is artificially placed into a river system will suffer wear and tear as well as damage due to the action of the current. However there are times that damage is more likely to occur than others. Improvement structures should thus be checked and repaired:-

1) In the spring.
2) At the end of every fishing season.
3) After any flood.

No structure, however well built, will survive intact without regular management. Aftercare usually only involves replacing odd stones or logs but sometimes complete reconstruction may be needed.

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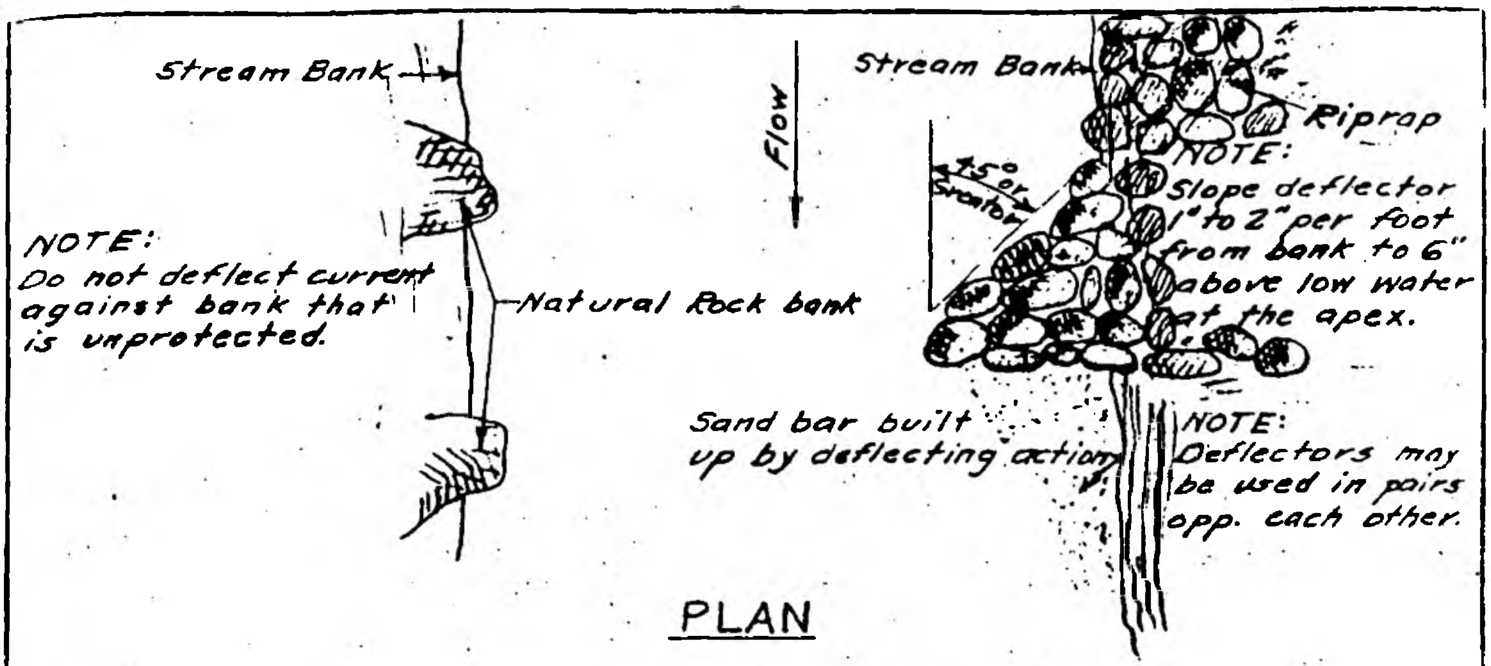
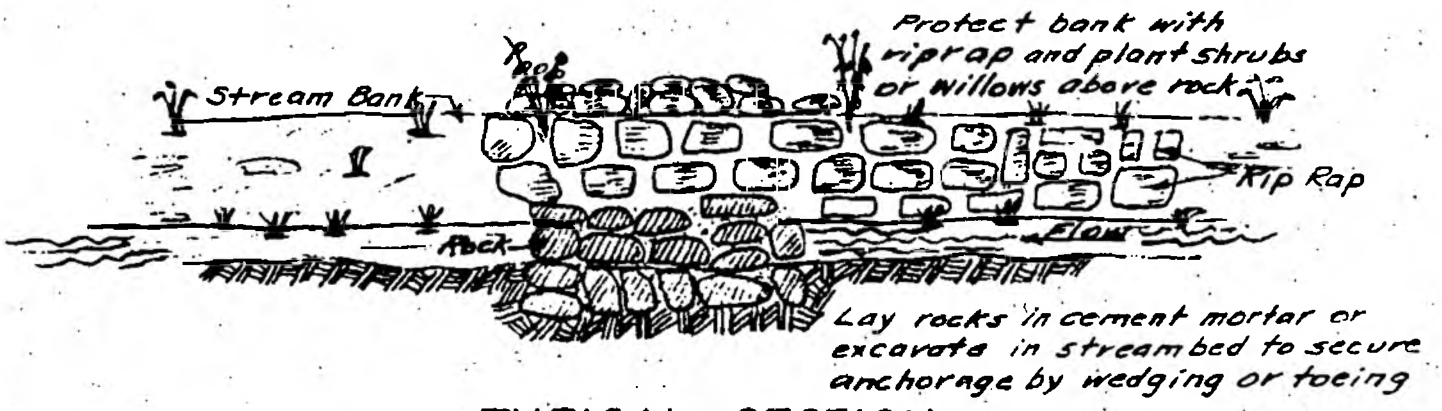
APPENDICES

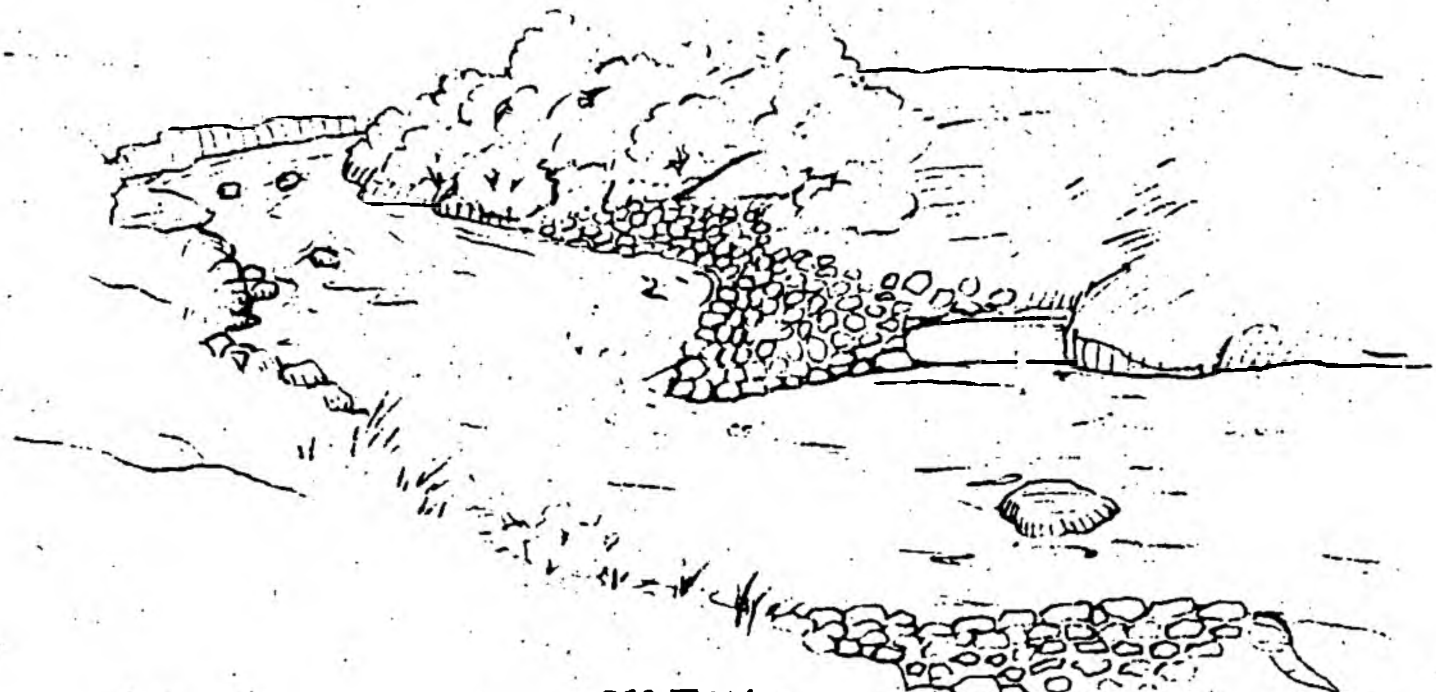
REVETMENT.



PLAN



TYPICAL SECTION



VIEW

ROCK DEFLECTOR AND RIPRAP

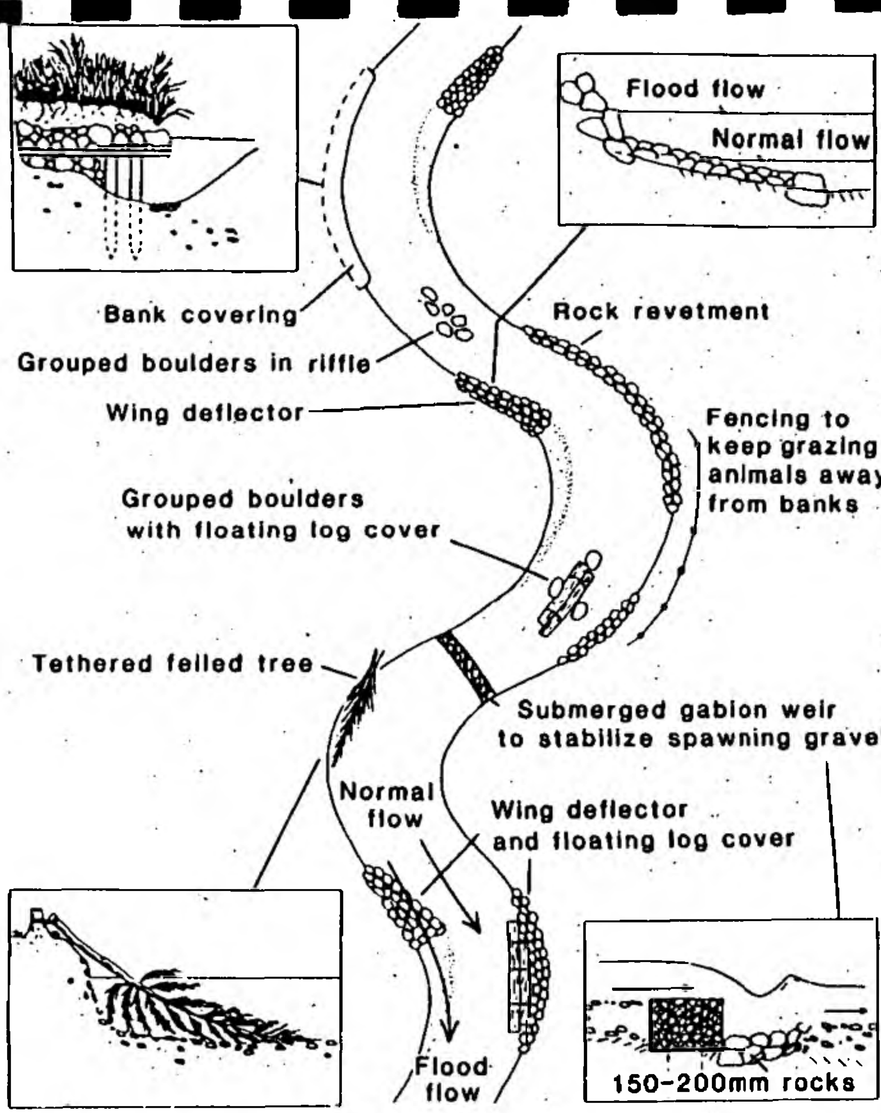


Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

Stream enrichment is likely to be useful only where nutrients are naturally very low, and there may be some objection to its widespread adoption. It is effectively changing the very nature of oligotropic streams and may be resisted on conservation grounds.

6. STOCK MANAGEMENT

6.1 General

A widespread view on the west coast of North America, where stock enhancement practices are being widely developed and utilized, is that one of the most effective techniques is the proper management of spawning escapement. In practical terms this means regulation of exploitation by individual species and individual river and tributary stocks.

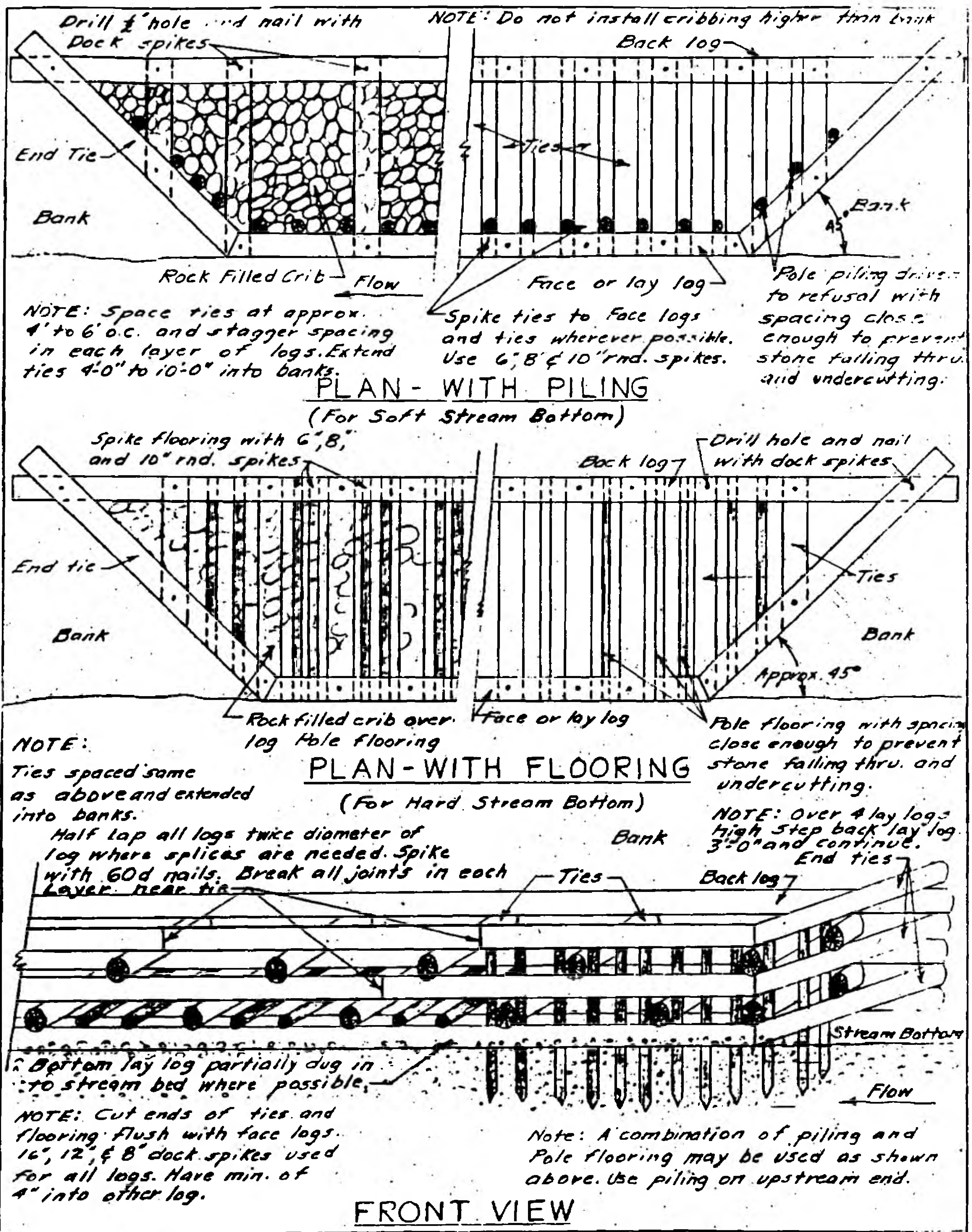
6.2 Regulation of commercial fisheries

Most commercial exploitation of Pacific salmonids takes place outside river mouths, and there are thus to an extent mixed-stock fisheries. However, an increasing knowledge of migration patterns and stock characteristics is allowing a degree of separate management. One of the best examples is that of the Fraser River in BC. This system supports vast stocks of pink and sockeye salmon, with smaller but nonetheless valuable stocks of coho, chinook, chum and steelhead. Some of the stocks are greatly enhanced (e.g. for pinks and sockeye by spawning channels, others by hatcheries) while others are naturally maintained. There are marked cycles of abundance, every four years for sockeye and every two years for pinks. The stocks are exploited by fishermen from both Canada and the US as they pass through coastal waters. Stocks fell during the earlier part of the century for various reasons, but have recovered in recent years due to careful management and stock enhancement. Commercial catches of pink and sockeye salmon average over 7 million fish per year. Clearly, the Fraser River salmon represent an extremely valuable, but difficult to manage, resource. Management of the pink and sockeye salmon is the responsibility of the International Pacific Salmon Fisheries Commission, established by Canada and the US in 1937. There is a wide range of complex regulations governing time, place and method of fishing, which are adjusted each year according to the expected abundance of various stocks. In addition, emergency orders are passed to 'trim' exploitation according to a detailed analysis on an almost daily basis. For example, the following emergency orders were among many that were issued in 1982 (International Pacific Salmon Fisheries Commission, 1983):

"<u>30 July</u> In order to secure additional escapement of summer-run sockeye the Commission approved the following regulatory changes: (1) That Area 29 of Canadian Convention Waters open to gill nets and trollers on 3 August for 1 day of fishing. (2) That the scheduled fishing in United States Convention Waters be delayed 1 day for 1 day of fishing in the week commencing August 1.

<u>19 August</u> In order to harvest additional Chilko River sockeye the Commission approved Area 29-7 and 9 to 17 of Canadian Convention Waters to gill nets on 20 August for 12 hours fishing.

<u>1 September</u> In the interest of protecting delaying Adams River sockeye the Commission approved that Area 7A of US Convention Waters be closed to fishing effective 3.00 pm 1 September.



LOG BANK CRIBBING

CONTROL OF LIVESTOCK

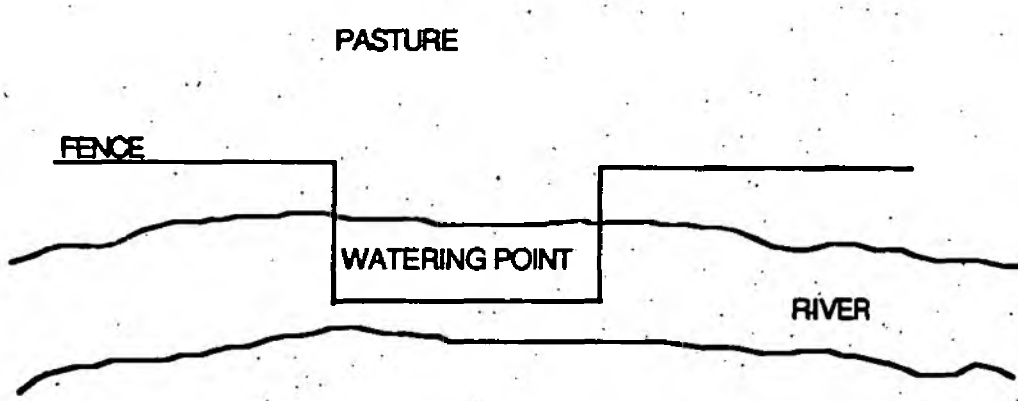
No serious bank erosion on Anglian rivers

two. One way of increasing the improvement potential of revetment, and reduce erosion even further, is to build rip-rap in conjunction with artificial cover devices.

4.2.3) Control of livestock.

A sturdy fence, constructed of wooden posts, wire fencing and barbed wire should be made alongside the river, about 5m from the bank. At one or two points a special watering point should be made in the fence (Figure one). This is constructed by building a rectangular extension of the fence into the river, enclosed on every side, except the field side. This reduces trampling of the bank as well as disturbance of the riverbed. Such watering points may collect debris, especially at high water, and need regular checking.

1.1) Figure one. A watering point.



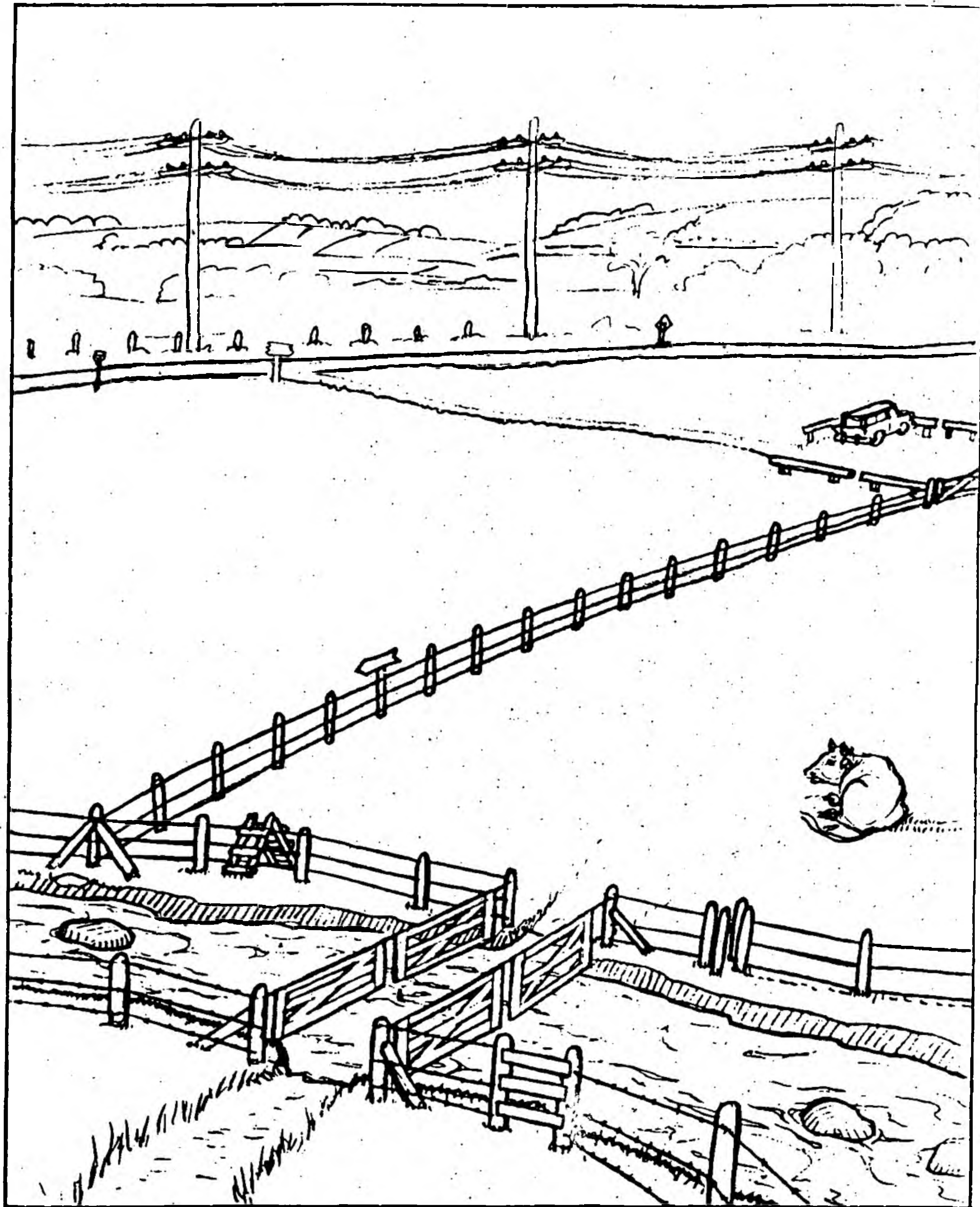
4.2.4) Removal of impoundment.

To prevent bank further need slow flow to be drawn down slowly

If it is at all possible then dams should be removed slowly so that the water level doesn't fall too rapidly, one foot per week is a reasonable rate. If this is not possible then the stretch of water above the dam should be checked for stranded fish, isolated pools and mud banks. Fish should be returned to the water; isolated pools should either be drained, and the fish returned to the mainstream, or the pool should be connected to the main flow by digging a channel or deflecting the current; bare mud banks should be planted up or dug out.

As this method has never been tried before it is difficult to state specific recommendations, however it is currently being investigated by N.R.A. Anglian region.

Unlikely — as ponded section often dredged.



FENCING, ACCESS TRAILS AND FENCE STILES

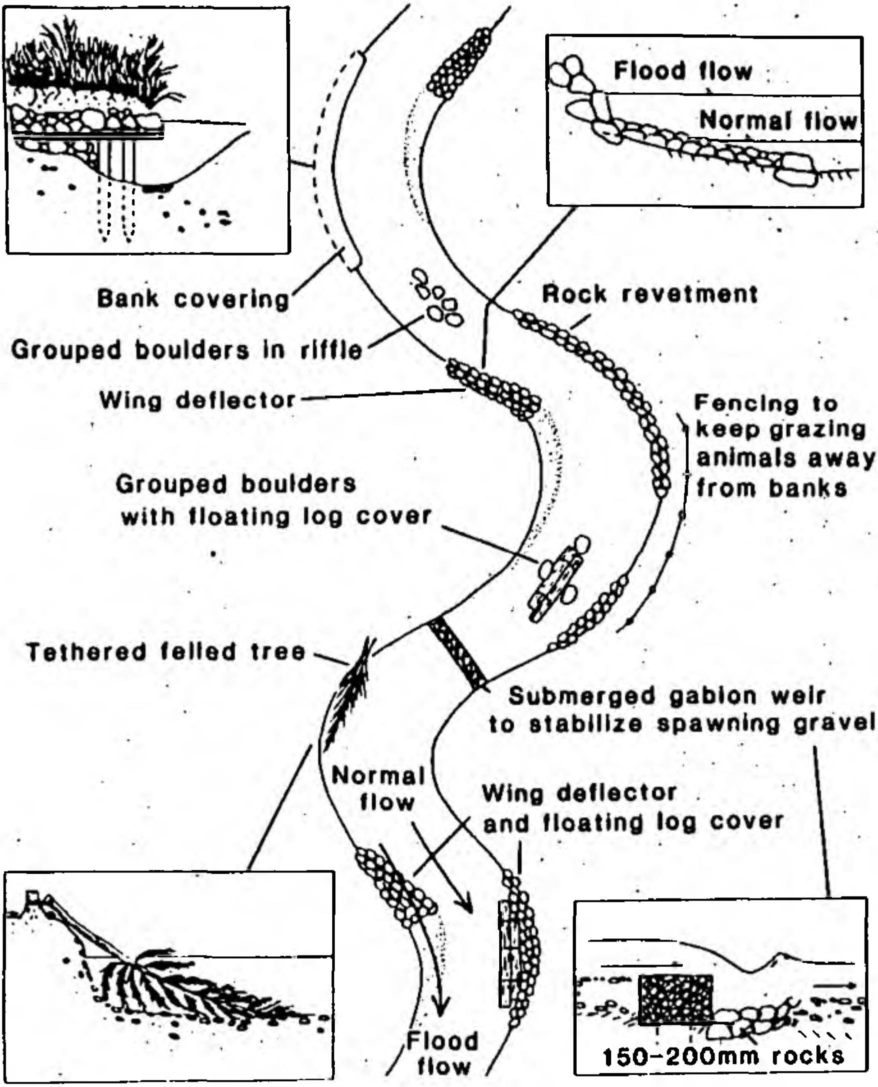


Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

Stream enrichment is likely to be useful only where nutrients are naturally very low, and there may be some objection to its widespread adoption. It is effectively changing the very nature of oligotropic streams and may be resisted on conservation grounds.

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Build fences well back from the stream bank.

strands of barbed wire across the stream. String the lowest strand high enough to allow debris to pass beneath during normal flow. Such crossings are not intended to withstand floods; after each flood they will have to be restrung. Locate cattle and machinery crossings, if possible, where the stream bottom is firm and where the banks slope gently. If you must pave the bottom with gravel, dig it out first so that the finished level will not protrude above the normal stream bottom to form a dam. Bevel the path leading down the stream bank into the crossing and pave it if it is so steep that it will erode. Build crossings wide enough that livestock do not bunch up, panic and become injured when crossing during high water. Several references on fence construction are listed in the Bibliography.

Cattle crossing with floodgates to allow debris to pass downstream during floods.

Floodgates performing during a flood.

A cattle watering area which can be folded back out of the way of floods when cattle are not in the pasture.

MECHANICAL AND HYDRAULIC DISTURBANCE OF RIFFLES.

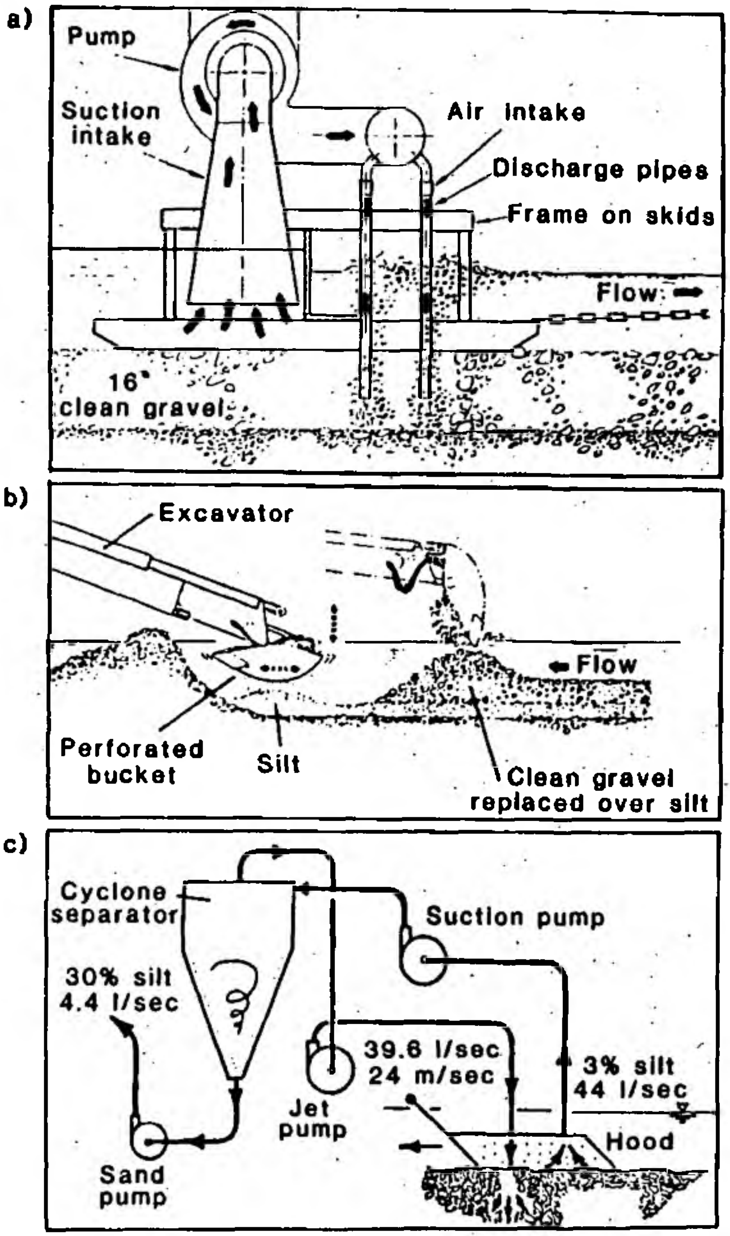


Figure 4.1 Spawning-gravel cleaning machines (section 4.3). (a) Air-water jet system for spawning channels, used with little success in natural streams (Andrew, 1981); (b) Andrew's (1981) 'vibrated bucket' method for natural streams; (c) silt separating system which discharges the slurry onto the bank (Allen, 1981).

holes; numbers of spawners have increased by 2.3 and 6.3 in the two streams. Occasional maintenance is required on the newly-created riffles mainly because the fish themselves displace gravel downstream while spawning.

The greatest interest in spawning substrate improvement has been on the west coast of North America, with a series of developments culminating in very successful (and expensive) spawning channels for Pacific salmon. These are unlikely to be a realistic development in the UK because rivers could not support such gross production of young fish of species with a significant riverine life history stage; channels are predominantly used for pink and chum salmon (which migrate to sea as fry) and sockeye (which migrate to lakes as fry). However, many of the other developments involving substrate improvement are of interest.

One of the main problems with gravel cleaning is that the silt is removed downstream, where it tends to resettle and perhaps cause degradation to other gravel. The 'vibrating bucket' method used on the Fraser River catchment (Andrew, 1981) overcomes this problem by burying the fines under the cleaned gravel. An excavator with a finely perforated bucket is used to remove a volume of gravel. This is then vibrated in the water to wash out the fines, which settle into the hole from which the gravel was removed. The gravel is then replaced to give a clean layer of about 30 cm over the fines. The estimated full economic cost of this technique is calculated at Can. $1.25 per yd² (1981).

Andrew also describes a gravel cleaning machine, developed for cleaning spawning channels but used with limited success in rivers. It operates by jetting an air and water mixture into the gravel through pipes projecting 22 cm into the gravel, at 30 cm centres. Major problems arose with boulders, and dispersion of the fine material. The conclusion was that it had little potential for cleaning natural gravels, and that the vibrating bucket technique was more effective.

A gravel cleaning machine described by Allen et al. (1981) overcomes some of the drawbacks of Andrew's gear by recycling the silt/water mixture and removing most of the silt in a cyclone separator. About 70 gallons per minute of a slurry containing 30% silt is sprayed on to the bank well away from the stream. Again boulders were a major problem, and there were a number of other 'teething troubles' with the prototype under test, but the conclusion was that there was some significant potential for the equipment.

In deciding the viability of any approach to gravel cleaning, one must take account of the cost of the exercise, the immediate benefit, and the longevity of any beneficial effects. The obvious immediate benefit is the use of cleaned areas by an increased number of spawners. However, if these fish would otherwise have spawned successfully elsewhere, one must consider the stream as a whole, and also evaluate survival of eggs to emergence of the fry. The duration of beneficial effects is very limited in some situations; Carling (1979; in press) reports very rapid re-incursion of fine material into graded gravels and gravel winnowed by redd digging, in a river with high suspended solids loads. However, a number of North American studies have indicated reasonable life-span of ameliorating effects. Andrew (1981) found that siltation was much more rapid at the upstream end of a cleaned 2 300 ft length of stream than at the downstream end, indicating that the gravel was acting as a bedload collector. After a year the upper 200 ft contained a similar level of fines as uncleaned gravel. About 400-500 ft from the upstream end about

DEFLECTORS.

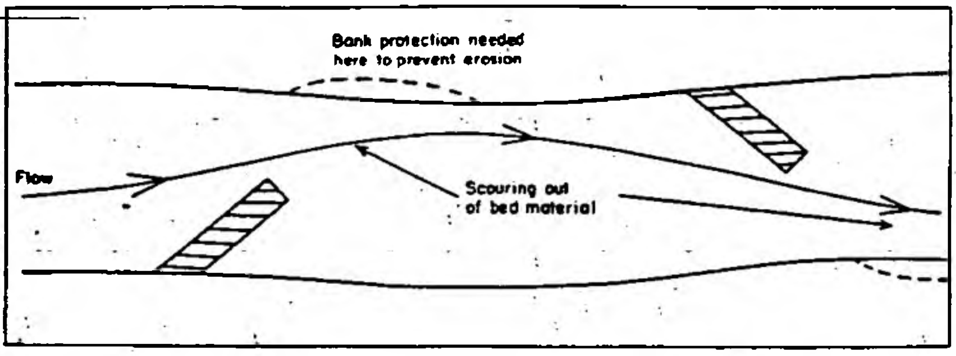


Figure 1. The effects of current deflectors on current flow and channel morphology.

ctors may lead to reduced egg survival (Burns, 1970; Cooper, 1965; Gammon, 1970; nsen, 1971; Hausle and Coble, 1976; Hynes, 1973; Peters, 1965, 1967; Saunders and nith, 1962). Consequently, any reduction in the amount of sediment in gravel beds ads to an improvement in fish habitat.

Stuart (1959), working on a trout stream in Scotland, noted that there often exists a gular, periodic spacing of pools and riffles in natural gravel bed rivers. Following the ss of this pattern due to river dredging, Stuart succeeded in recreating pools and riffles directing that piles of gravel be left on the stream bed at intervals appropriate to fles. Since then, geologists have confirmed that this spacing is generally consistent at ve to seven channel widths (Leopold *et al.*, 1964). Since current deflectors partially create the habitat characteristics associated with pools and riffles, they should, where ssible, be installed at between five and seven stream widths apart, imitating the natural er pattern.

Pools and riffles, however, are only present in a river if the channel gradient and bstrate particle size are of the correct order. Even if pools and riffles are not present, thalweg, or line of maximum depth, moves downstream in a sinuous pattern with a avelength of between five and seven stream widths (Leopold *et al.*, 1964). Thus, if flectors are alternated from one bank to the other at a distance apart of between five d seven stream widths, the current is conducted on a sinuous path resembling the atural channel flow pattern (Figure 1).

If current deflectors are to function correctly, they must be installed in areas where er flow, depth and substrate are suitable. The construction and installation of the uctures must be adapted according to the nature of the stream and the desired effect. variety of construction materials can be used, but wire gabions filled with rubble and nber are most frequently employed. Further information regarding the construction d installation of improvement devices can be obtained from Hunt (1969), Borovicka 1968), White and Brynildson (1967), and Everhart *et al.* (1975).

One of the longest term improvement studies which has incorporated current flectors has been that carried out by Hunt on the Lawrence Creek, Wisconsin (Hunt, 969, 1971, 1976). In his studies, Hunt obtained data on fish population abundance, iomass and production over a period of 11 years, including a three-year pre-habitat provement period, and an eight-year post-development period. Although mean nual biomass of trout, mean annual number of legal sized trout, and annual production creased significantly during the three years following development, improvement ntinued, and maximum number and biomass did not occur until five years following mpletion of development.

to pass freely through the sack material, binding the sacks into a solid wall. In this v although the structures were sturdy and capable of withstanding high discharges, th cc readily be removed from the river in the event of their constituting a flood risk.

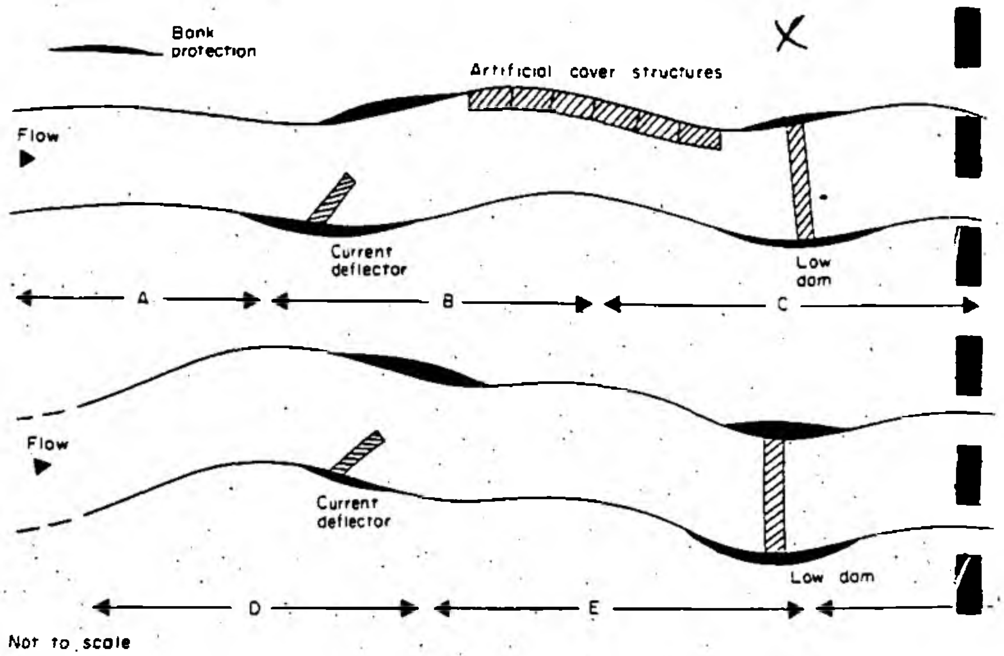


Fig. 2. Layout of improvement structures at the study site, showing the extent of sections A–F.

The first stage in installing both low dams and deflectors involved using a hydr excavator to dig out the river bank at the site of their installation to a depth of 2-3 l structure could then be extended into the river bank and the possibility of erosion the outside of the device so reduced.

The current deflectors were built by constructing a wall which extended from to half of the width of the river and a few centimetres above the surface of the angled downstream at around 45° to the bank. The low dams were built so that their was wider than their apex, so making the structure more stable. Since the river bed composed of compacted gravel it was not necessary to excavate the substrate to firm base for the dam in order to prevent under-cutting. However, bank protectio rubble and concrete sacks was needed in the vicinity of each improvement structu prevent erosion damage through increased water flow and turbulence (see Fig. 2).

In August 1978 further improvement structures in the form of floating artifici devices were installed at the study site. These were designed to simulate the shelter norr provided by such features as overhanging bank vegetation and undercut banks. The st were constructed simply by linking together end-to-end sheets of marine plywood m 2 m X 0.75 m X 0.5 cm. The sheets were installed along the margins of two bends in the as shown in Figs 2 and 3, where they were anchored to stakes in the bank. Floating on the surface of the water, these devices were able to remain in position with flu

Fig. 7. Action of the current deflector in section D.

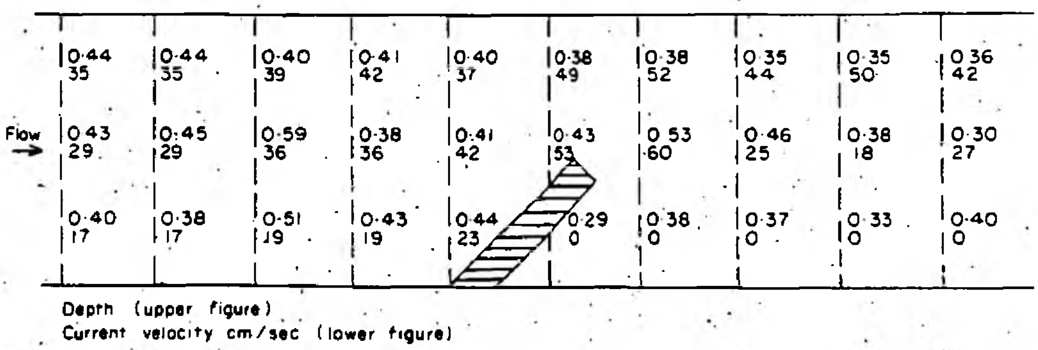


Fig. 8. Effects of the current deflector in section D on water depth and current velocity.

is no information available on the form of the river before this work was carried out. It is unlikely that the area has been completely restored to its 'natural' condition since the extent of the programme was necessarily limited. However, it is probable that a more extensive improvement programme would be capable of fully restoring a damaged area of river, as has been demonstrated in studies carried out in North America (Barton & Winger, 1973; Lund, 1976; White & Brynildson, 1967).

The use of improvement structures to rehabilitate fisheries damaged by channel works may, however, be said to be detrimental to land drainage interests. By their action, improvement structures often impede flow and raise water levels, and can therefore recreate the conditions which originally lead to channel works being carried out. A possible way

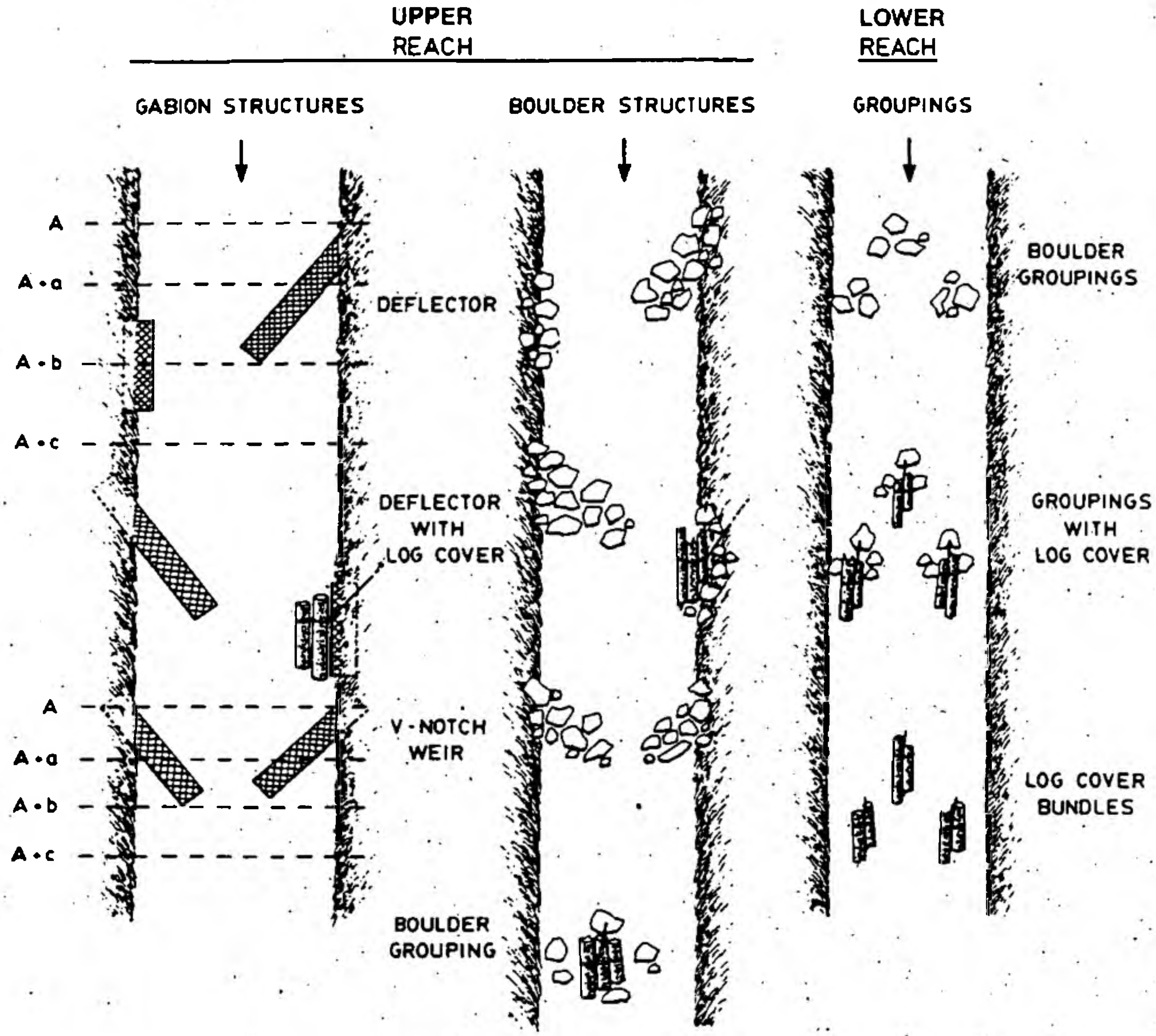


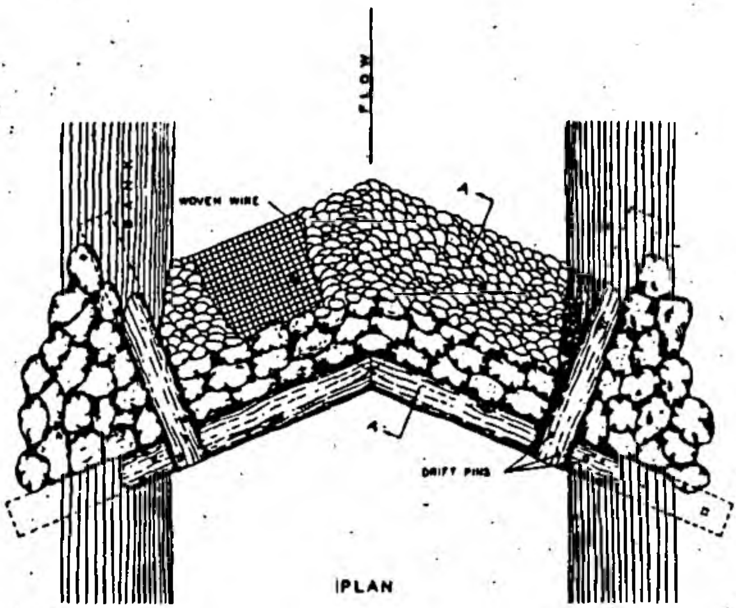
FIGURE 1. *Designs of boulder and gabion structures installed in the Keogh River (simplified).*

rearing areas for both coho and steelhead, were compared to detect natural fluctuations in salmonids before and after treatments.

Results

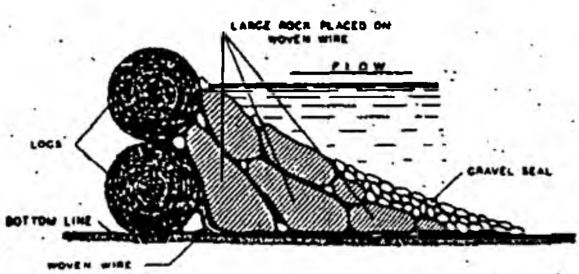
Hydraulic Effects in the Keogh River

Cross-sectional measurements in treatment sites in the upper reach indicated differing responses to floods. Small changes (10 cm) in depth occurred in boulder V-notch weirs and boulder groupings, but not in the other designs after the first year. Further changes in mean or maximum depth or 'wetted width' were insignificant or undetectable in the second year after placement of structures. Changes in



PLAN

FIGURE 4



SECTION-AA
(LARGER SCALE)

FIGURE 5

WEDGE DAM

cheap and effective way of providing cover and small pools. This method of improvement has the advantage of being relatively permanent and it adds to rather than detracts from the natural beauty of the stream.

Another practice which adds to the natural beauty of a stream as well as improves the habitat for fish is the fencing of stream bottoms to exclude domestic stock. This practice has greatly improved many southwestern streams as the vegetation which has become established on the stream banks has prevented bank erosion, kept the streams narrow, provided shade and cover, and increased the supply of terrestrial food.

EVALUATION OF THE RESULTS OF STREAM IMPROVEMENT

Although a good deal of stream improvement work has been done in many sections of the country during the past four years, investi-

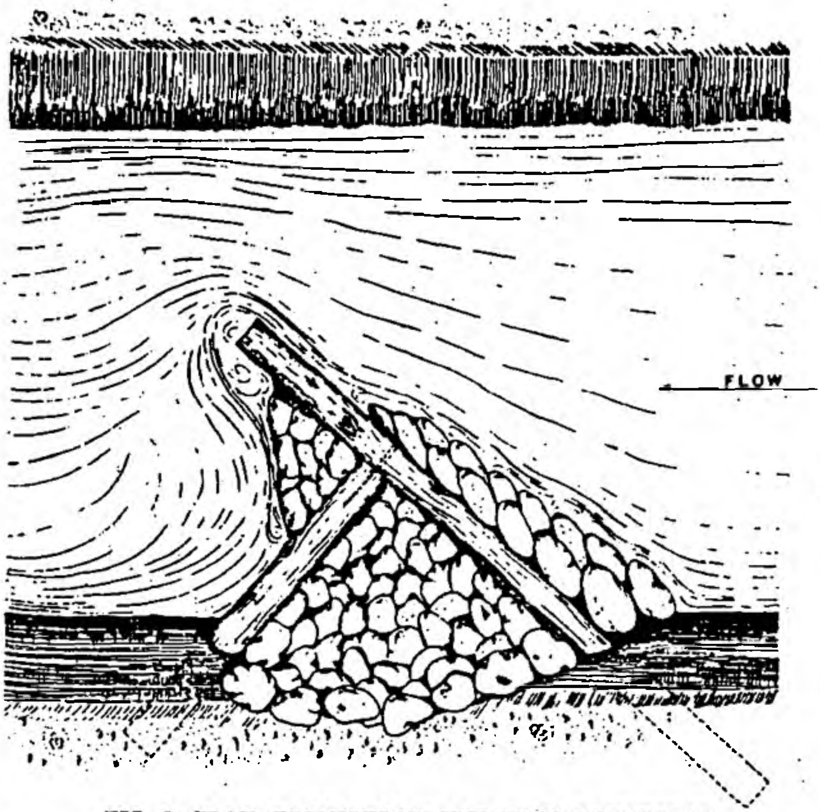


FIG. 6—PLAN, TRIANGULAR CRIB-WING DEFLECTOR

basing these inferences upon observed weaknesses in the remaining structures.

At the time of the original Forest Service survey of the area, the river flow was about four to five cubic feet per second. Cassel (1935) found 44 pools in the one and one-quarter mile section where the improvement work was to be carried out. He defined a pool in this stream as ". . . any place where the three measurements taken at least two feet apart reveal minimum depths of 12 inches or over". Despite the

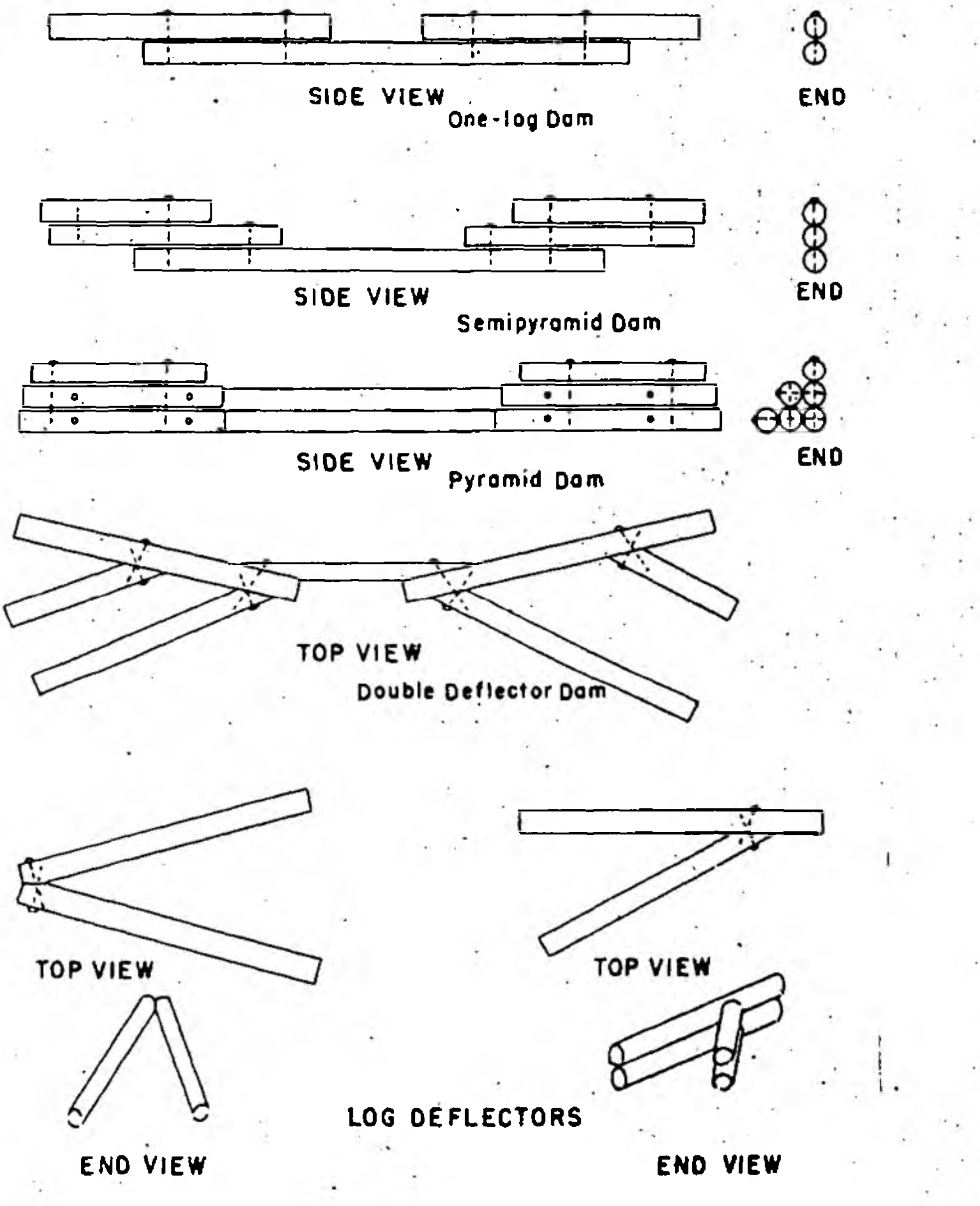


FIGURE 1. Types of log stream improvement structures employed.

large number of natural [redacted], he [redacted] instr[redacted]ns t[redacted]all [redacted]heck dams and, accordingly, 11 loose-rock dams (no masonry used), 15 log dams, 2 rock and log dams, 5 log deflectors, 2 earth dams, 1 wire crib dam, 1 masonry dam, 1 board dam, 1 double deflector, 1 underpass deflector, and 1 rock deflector were constructed under his supervision. The types of devices utilizing logs are shown in Figure 1.

Following the completion of the dams, Cassel observed, ". . . I have rated all 5 log deflectors as good, 10 of the dams as good, 17 structures as average, and 9 as poor. . . . . . It may be some of the structures will do more harm than good but only future surveys can reveal how and why they are harmful."

On October 26, 1936, and again on September 17, 1937, Mr. Bartholomew visited the improvement area to determine the condition of the devices and to make any needed repairs. Measurements of pool depths above and below the structures were made, and a discussion of maintenance needs and general success of the improvements was included in his reports to the United State Forest Service for the two years. Bartholomew and his crew spent about six days repairing the structures in 1936. In his 1937 report he stated, "The amount of maintenance work needed, due to the effects of high water, was approximately double the work done in October, 1936."

The number and types of devices functioning successfully during the check periods are shown in Table 1. The table reveals that the earth dams did not last even one year. Several of the rock dams were damaged severely during the winters of 1935 and 1936, but repairs were made which restored them to use. No repairs of any kind were made between 1938 and 1953.

TABLE 1

Summary of the Success of Improvement Devices

Type of structure	Number present and operating				Total present 1953†
	1935	1936	1937	1953*	
Rock dam	11	10	9	0	1
Crib dam	1	1	1	0	0
Log dam	15	15	15	6	9
Earth dam	2	0	0	0	0
Masonry dam	1	1	1	0	1
Board dam	1	1	1	0	1
Rock and log dam	2	2	2	0	0
Log deflector	5	5	5	2	5
Rock deflector	1	1	1	0	0
Double deflector	1	1	1	1	1
Underpass deflector	1	1	1	1	1
Totals	41	38	37	10	19

* Includes only those which are operating in their original locations.
† Includes nonfunctional structures also.

HISTORY OF TYPICAL STRUCTURES

Precipitation in the Sierra Nevada at the elevation of these structures occurs mainly in the form of snow. Peak flows result from occasional fall and summer thunderstorms and abnormal warm rains [redacted] [redacted] 2: [redacted] s [redacted] n [redacted] de. [redacted] de. [redacted] th [redacted] most [redacted] the [redacted] flow goes under the dam, the structure does maintain a good pool. Although undercut, this dam is solidly attached to both banks, well anchored by willows, and shows no evidence of deterioration.

5. *Structure 38.* One-log dam with 12-foot port. Holes under the dam in both 1936 and 1937 were repaired in a total of ten and one-half hours. Gravel filling in the pool above may be largely responsible for the fact that the dam has remained intact and operating. A good pool below is the result of water falling 10 inches from the dam crest. This dam is in no danger of washing out because a dense mat of willow roots winds through and around the ends of it. The willows are most effective anchors, as well as sources of food and cover for fish in the stream below.

Log Deflectors

Five devices of this type were built in 1935, and five were present in 1953, although not all were operating. Structures 17, 18, and 19 are shown in Figure 9. They are still in excellent condition. Some repairs were made during 1936 and 1937, when trampling by cattle threatened to break down the banks. However, little change has occurred here since 1936 insofar as damage to the structures is concerned. Two of the devices are operative only in high water. All are on a bend in the stream and successfully retard bank erosion during peak winter flows.

FIGURE 9. Three log deflectors in 1953. Structure 17 is in the foreground and has largely diverted the stream to the left. Structure 18 in the middle distance and 19 in the background have been undercut and have lost some of their effectiveness. Photograph by the author.

In Figure 10 another deflector can be seen performing the task of sod and bank protection. A threatened washout in 1936 was prevented by filling the structure with rock, digging a cutoff channel around the

FIGURE 10. Structure 35 in August, 1953; a log deflector filled with rock. The rock protector is visible in the foreground. The success of this deflector is the result of careful anchoring. *Photograph by the author.*

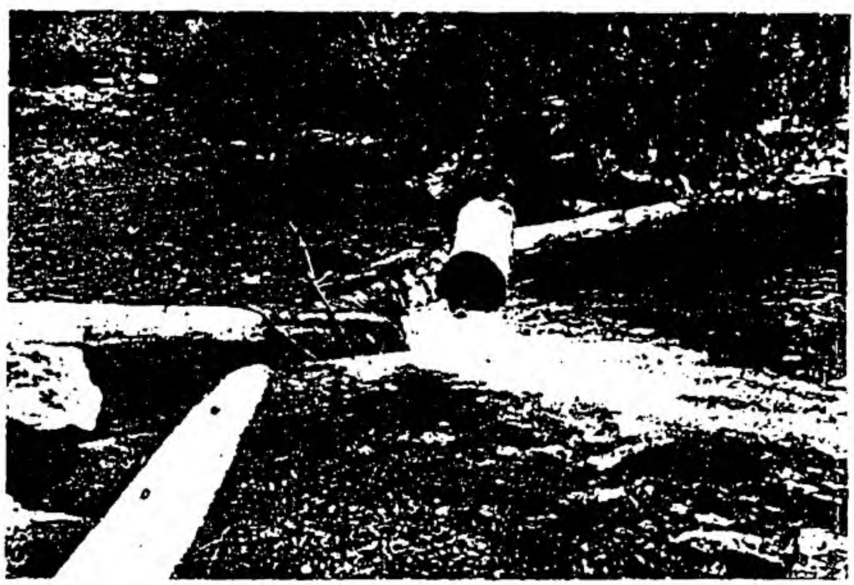


FIGURE 11. Structure 36, a double-log deflector on the downstream side. The V-type of construction restricts the flow to the center. A cross log in the V gives eight inches of fall and prevents undercutting in the spill. *Photograph by W. A. Dill, August, 1953.*

4. Even though fish passage facilities are provided, problems can arise if they are inadequate and poorly designed. Young fish, moving downstream, must pass over or through the dam frequently suffering high mortalities. Fish may eventually pass the obstruction but any delays can be costly, and many times, as on the Columbia River, a series of dams obstruct migration.
5. Reservoirs may flood-out spawning and nursery areas, the lake-type environment created can influence the migration of young fish, and undesirable fish may become established.
6. Predation becomes a problem in the tailraces where weakened migrants are exposed to large concentrations of predators.

Care should be taken in recommending the removal of natural barriers, as these may be maintaining a balance between populations above and below the obstruction. Natural barriers may also prevent the spread of an undesirable fish into headwater areas. Beaver dams are a problem where they obstruct fish movement. The dams may also change the general ecology of the flowage area by warming the water, silting the bottom, and changing the aquatic fauna of the stream bed. Ordinarily a beaver colony remains in an area about three to five years depending on the availability of food and water. After the colony migrates, the dam, unattended, may wash away; occasionally, however, dams remain as stream obstructions.

Many lakes depend on inlet and outlet streams to provide the necessary spawning and nursery areas to hatch and rear the young fish that constantly restock the lake. And, if populations of anadromous and adfluvial fishes are to be maintained, the fish must be assured of easy access to their spawning grounds. Even a log, formation of a sand or gravel bar, or exceptionally low water may prevent fish from entering spawning and nursery areas.

Deflectors

Although much more complicated devices are used in stream improvement than the simple deflector, more and more projects are discarding the complicated, hard-to-build-and-maintain devices in favor of deflectors that are primarily designed to speed up the current, thus washing out silt and providing graveled riffle areas. Increasing the speed of the current gives the water less chance for long exposure to the sun and helps to maintain the usually desired low temperature. Some deflectors in general use are described below.

The single *boulder deflector* is intended for speeding up the current in wide, shallow pools. The boulders may be placed in rows, their proximity depending on the depth of water that is to be piled up in the area behind. The boulders are arranged in lines, or they may be placed haphazardly in the stream bed. In general, the boulders speed up the current and also produce eddy currents which tend to scour the bottom and provide more movement in the pools. They are also advantageous in preventing silting.

A *boulder deflector*, when large boulders are handy in an area, if placed correctly, is one of the easiest of the improvement devices to construct and one of the most rewarding. A trench is dug in the stream bottom so that the foundation layer will be secure in the bottom. A large boulder is used to anchor the stream end of the boulder deflector.

A *log deflector*, consisting of a main log or logs, mud sill, and brace, may be constructed where sufficient boulders are not present. Trenches

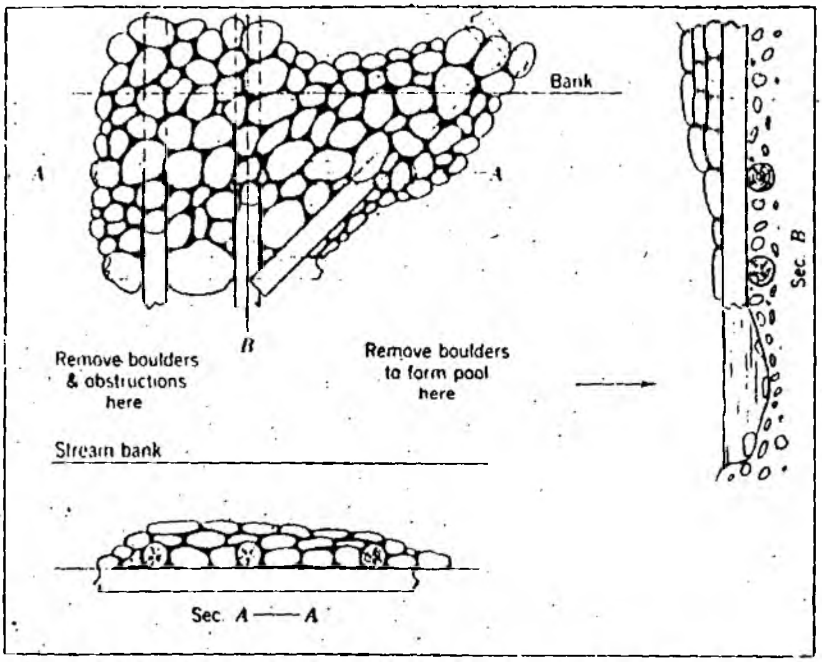


Figure 12-1. Log deflector. Courtesy of Lloyd L. Smith and John Moyle, 1944, Minnesota Dep. Conserv., Tech. Bull. 1:147-164.

are dug to receive the mud sill and the main log. The face and bank and stream ends are protected with boulders.

Cement blocks can be used as deflectors. In one instance, two-foot-square cement blocks weighing approximately 520 kg were cast at the site of the project in reusable wooden forms. An iron ring was anchored in each block for ease in handling. Although the weight of the blocks is a distinct disadvantage, they are adaptable to most situations. If the water is deep, they can be piled on top of one another. If, after the device is finished, evidence suggests the advisability of alterations, the blocks can be shifted easily.

The *triangular crib deflector* is a solidly built device consisting of a main log slanting at the desired angle downstream and anchored well back in the stream bank. A brace running from the back (downstream

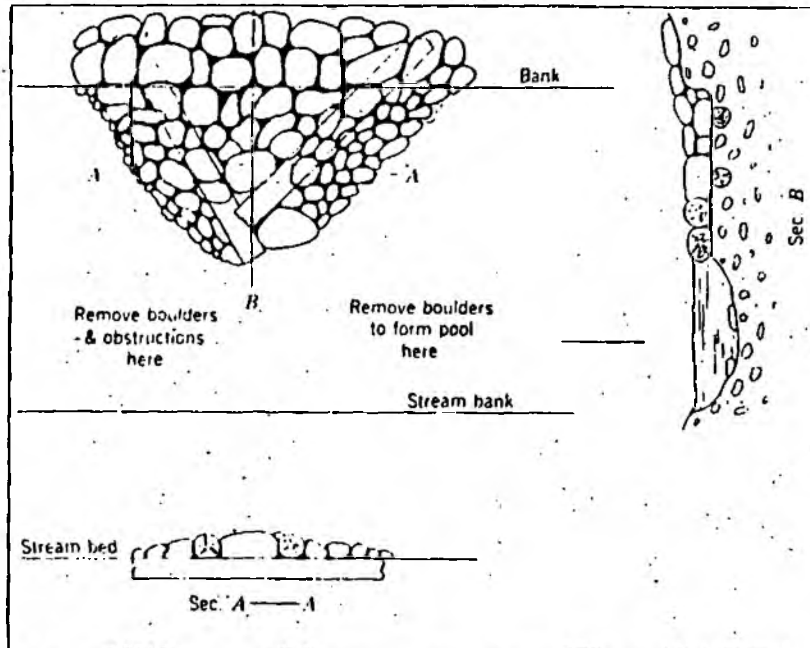


Figure 12-2. Triangular crib deflector. Courtesy of Lloyd L. Smith and John Moyle, Tech. Bull. 1; above.

side) to the bank provides additional support and makes a crib which is filled with rocks or boulders. The front and back are also lined with blocks.

When sections of the stream are too wide to be affected by bank deflectors or in sections where silt deposits have built up, the *triangular rock-filled deflector* may be employed to speed up the current, wash out the silt, and in general narrow the width by dividing the current. In some cases several of these may be placed in a row in the center of the stream. Three logs are merely joined together in a triangle and securely fastened to the bottom. The entire structure is then filled with rocks.

The *underpass deflector* is intended to "blow out" the silt and the soft bottom in an effort to provide a pool. It is constructed with the main log set a few centimeters off the bottom so that the water will be forced to pass under the main log and in this manner dig the pool.

The *double-winged deflector* has been developed in Michigan especially for use on larger streams with low gradient.

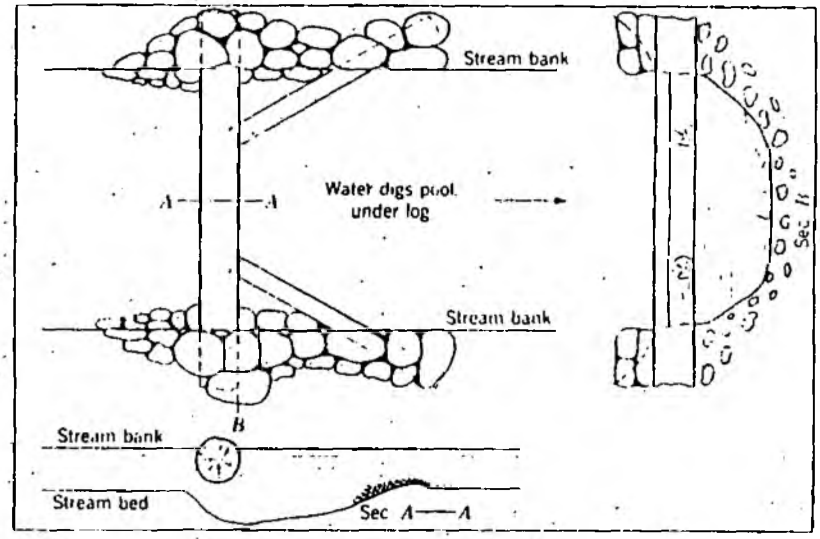


Figure 12-3. Underpass deflector. Courtesy of Lloyd L. Smith and John Moyle, Tech. Bull. 1, above.

Dams

When the gradient of a stream is too steep, where pools are desired, or where it is necessary to impound a large volume of water to insure a steady flow of water throughout periods of low rainfall, dams can be employed with success as improvement devices.

A *rock and boulder dam* takes advantage of the already existing supply of rocks and boulders. The fewer that are taken from the stream bed proper the better (except where a pool is indicated), since it would certainly be unwise to destroy already existing habitats in an attempt to create new ones. Frequently, advantage can be taken of an already existing large boulder which may be used as a keystone around which

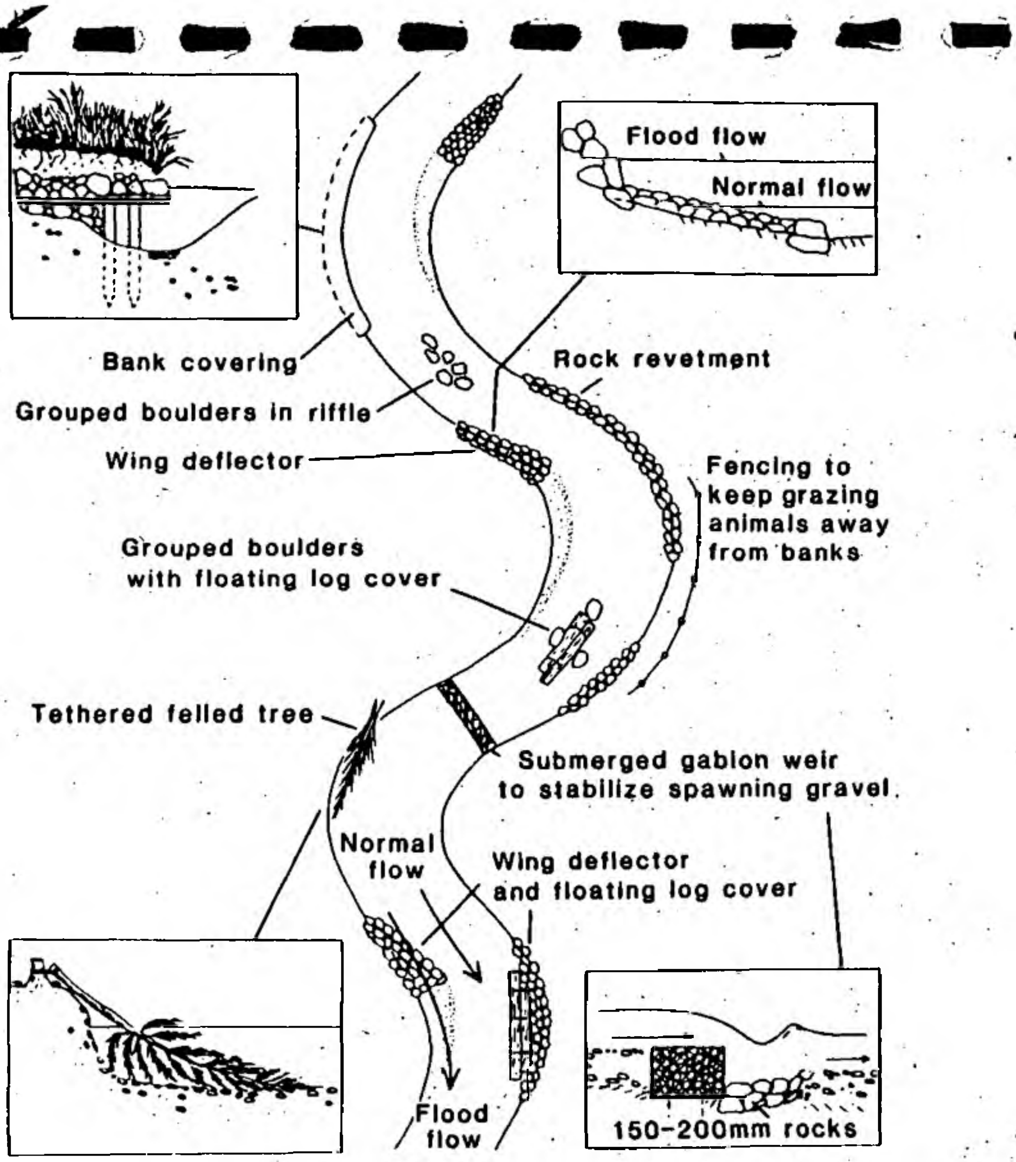


Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

Stream enrichment is likely to be useful only where nutrients are naturally very low, and there may be some objection to its widespread adoption. It is effectively changing the very nature of oligotropic streams and may be resisted on conservation grounds.

6. STOCK MANAGEMENT

6.1 General

A widespread view on the west coast of North America, where stock enhancement practices are being widely developed and utilized, is that one of the most effective techniques is the proper management of spawning escapement. In practical terms this means regulation of exploitation by individual species and individual river and tributary stocks.

6.2 Regulation of commercial fisheries

Most commercial exploitation of Pacific salmonids takes place outside river mouths, and there are thus to an extent mixed-stock fisheries. However, an increasing knowledge of migration patterns and stock characteristics is allowing a degree of separate management. One of the best examples is that of the Fraser River in BC. This system supports vast stocks of pink and sockeye salmon, with smaller but nonetheless valuable stocks of coho, chinook, chum and steelhead. Some of the stocks are greatly enhanced (e.g. for pinks and sockeye by spawning channels, others by hatcheries) while others are naturally maintained. There are marked cycles of abundance, every four years for sockeye and every two years for pinks. The stocks are exploited by fishermen from both Canada and the US as they pass through coastal waters. Stocks fell during the earlier part of the century for various reasons, but have recovered in recent years due to careful management and stock enhancement. Commercial catches of pink and sockeye salmon average over 7 million fish per year. Clearly, the Fraser River salmon represent an extremely valuable, but difficult to manage, resource. Management of the pink and sockeye salmon is the responsibility of the International Pacific Salmon Fisheries Commission, established by Canada and the US in 1937. There is a wide range of complex regulations governing time, place and method of fishing, which are adjusted each year according to the expected abundance of various stocks. In addition, emergency orders are passed to 'trim' exploitation according to a detailed analysis on an almost daily basis. For example, the following emergency orders were among many that were issued in 1982 (International Pacific Salmon Fisheries Commission, 1983):

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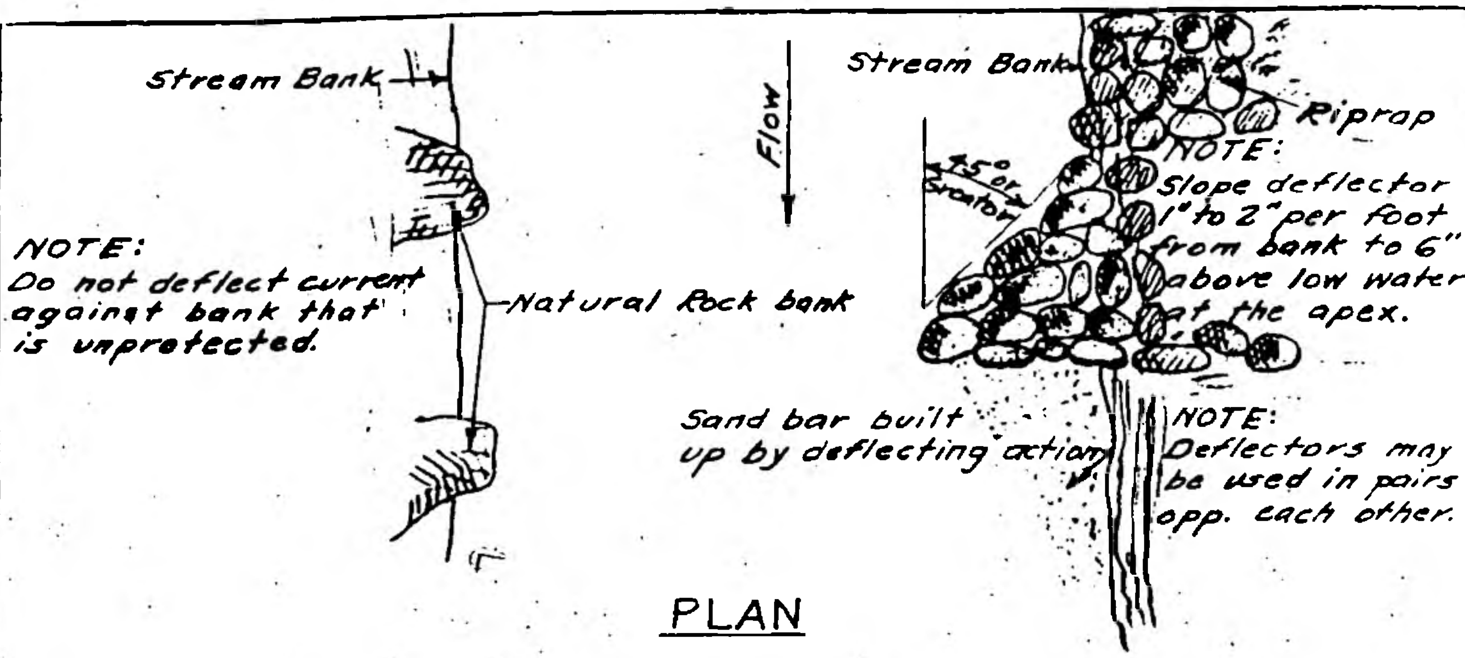
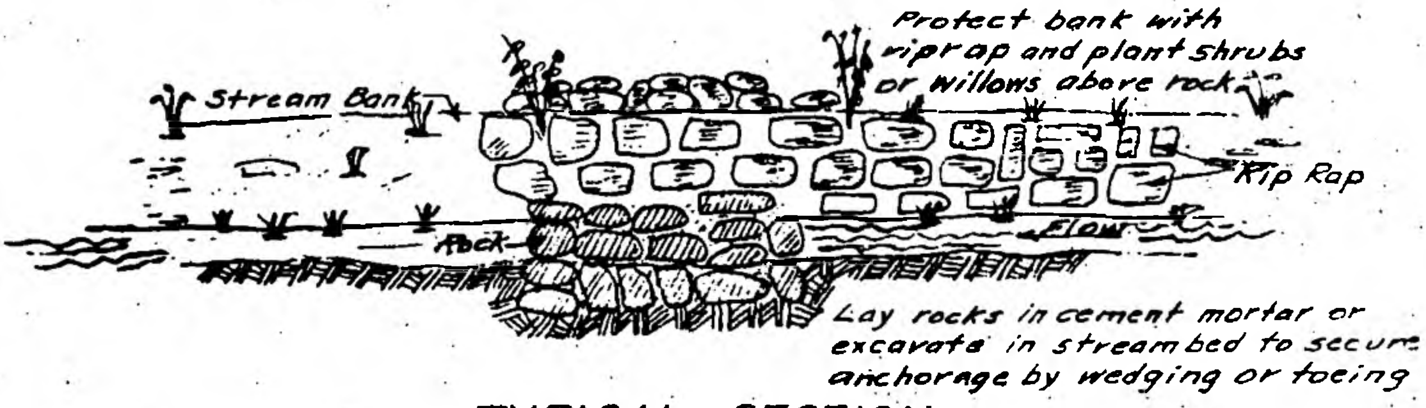
19 August In order to harvest additional Chilko River sockeye the Commission approved Area 29-7 and 9 to 17 of Canadian Convention Waters to gill nets on 20 August for 12 hours fishing.

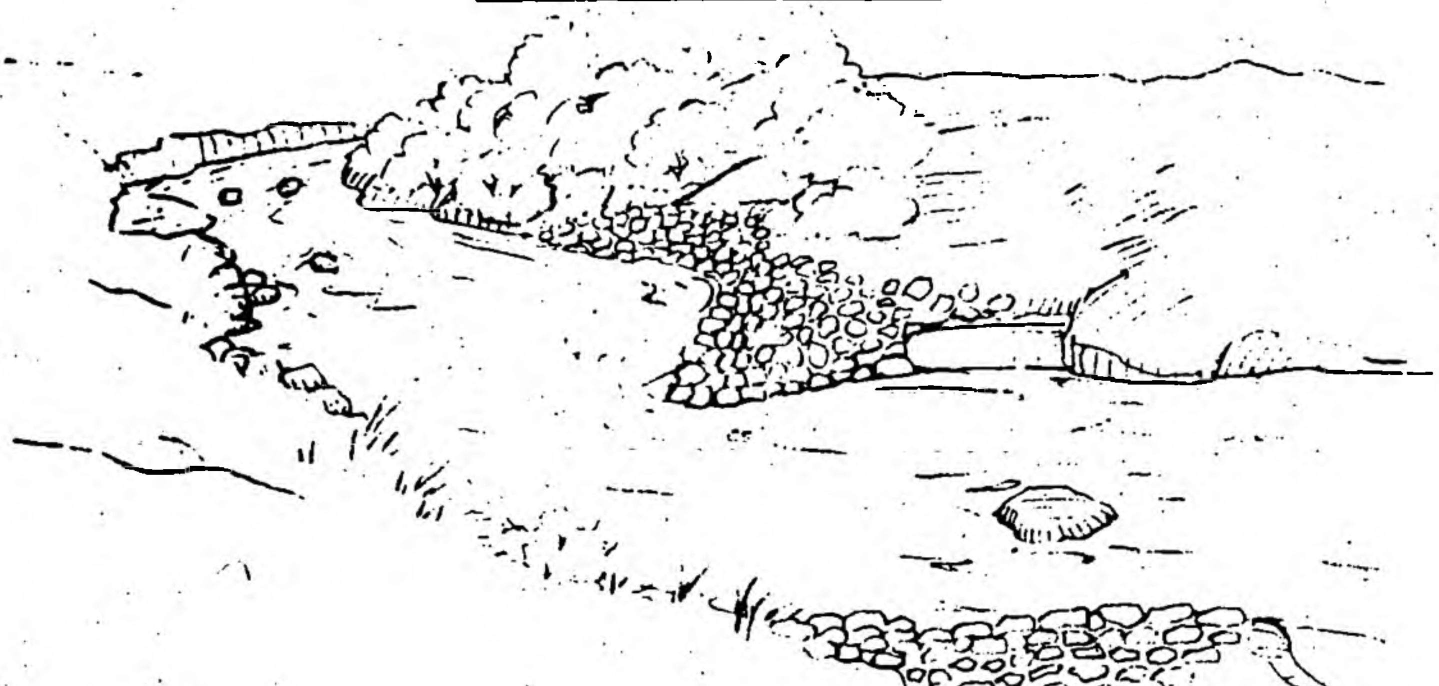
1 September In the interest of protecting delaying Adams River sockeye the Commission approved that Area 7A of US Convention Waters be closed to fishing effective 3.00 pm 1 September.



PLAN

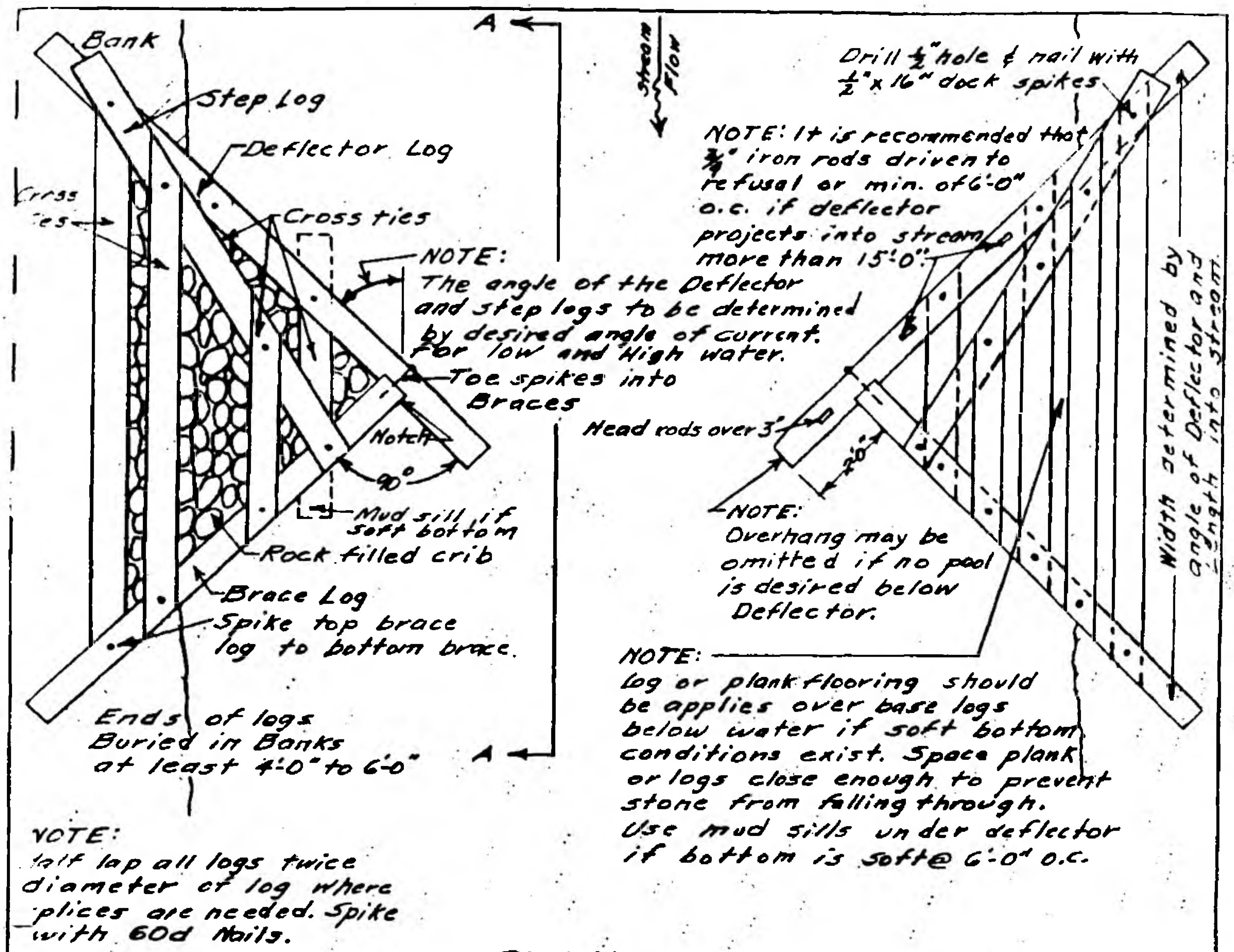


TYPICAL SECTION



VIEW

ROCK DEFLECTOR AND RIPRAP



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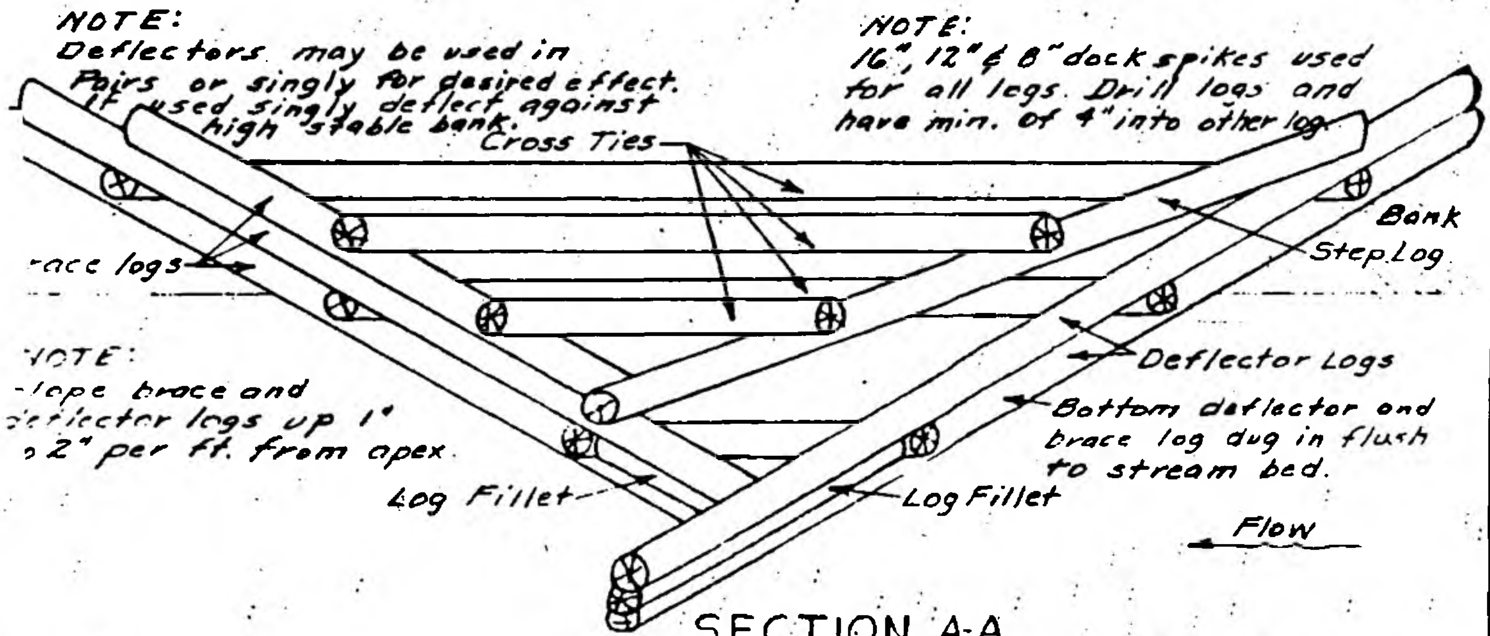


SECTION A-A

LOG DEFLECTOR

Again, avoid unnecessarily obstructing flow in lowland streams; do not build debris-catching structures.

Wing-Deflectors

These are the best all-around devices for modifying channels. Basically, they are artificially abrupt and erosion-resistant upper or leading edges of "point bars" (see Glossary, Appendix C). A well-constructed system of wing-deflectors is durable and inconspicuous. Such an alternating series keeps the current moving swiftly and the channel moderately deep. It makes the current scour deeper pools at bends. The sand and silt scoured off the stream bed will be collected in point bars off the ends of wings downstream. Such a series of deflectors, because they are placed alternately on each side of the stream, conducts the current in a sinuous course. This not only looks natural, but is natural channel pattern.

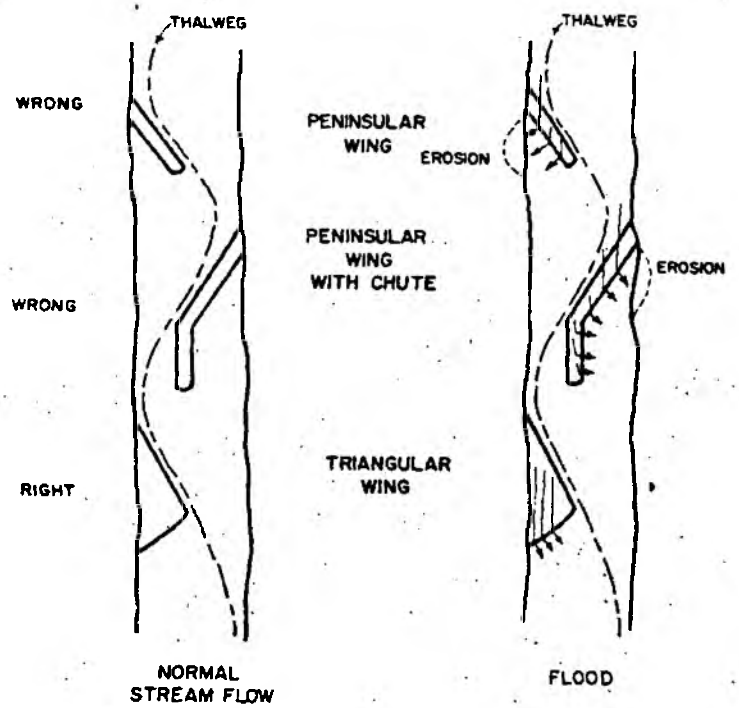
Build deflectors in a roughly triangular shape solidly filled with rocks and soil, rather than in a peninsular shape (such as also achieved with single logs or sheet piling). This is to protect the stream bed and banks against damage by high water. Since water spills off an obstruction at right angles to the last surface it touches, downstream edges of triangular structures conduct high water back into the stream. On the other hand, peninsular structures cause high water to plunge toward the stream bank eroding holes between wings and bank. These holes become dead water pools when the water recedes. They become badly heated in summer and often harbor undesirable fishes.

When designing deflectors, observe two important principles: (1) They should guide the current rather than dam it, and (2) They should have no protrusions on which drifting debris can accumulate.

Flimsy construction does not pay ten years later. Simply deflecting the current with plank wings wasn't enough. The bank has been eroded back several feet and winter ice formations have lifted the structures (see especially the plank in the background). Now most of the current goes under or around the structures and the stream remains wide and shallow.

Any device that impedes the flow of the current and collects floating debris is a hazard to trout habitat in our low gradient streams. In effect, a debris-collecting device is, or eventually will be, a dam. Deflectors should gently guide the current into a self-deepening, scouring action. There is no "correct angle" for a deflector (though some

Wing-deflectors in a stream, showing alternating pattern.



Performance of various kinds of wings under normal streamflow and flood conditions. (Water course straightened to simplify the diagram.)

stream improvement manuals may advocate a 45° angle). Suit the angle and length of wing to the velocity of water and depth desired.

Do not build deflectors at crests of riffles; there they will dam the stream more than if built part way down the riffle, at its foot or in slack water beyond. The crest of the riffle already impounds the pool above it. Rather, deepen pools by deflecting current into them.

Build deflectors low enough to allow the bulk of abnormally high stream flow to pass over the top. High deflectors concentrate floodwater, hence tend to erode stream bed materials excessively and to damage the wings. Let your guide be the water level during early summer base flow in a year of normal rainfall. Deflectors should not protrude more than about 10 inches above this level.

Bank Covers

Bank covers are artificial, overhanging ledges, at the outside of bends where the current sweeps along the bank. They make ideal hiding places for larger trout — and for smaller trout if root tangles or brush are woven into them.

The fish manager has several choices in constructing bank covers and wing-deflectors: (1) a series of alternating isolated wing-deflectors; (2) the above plus isolated bank covers at each intervening stream bend; and (3) a combined construction of bank cover and wing-deflector, the wing being an extension of the bank cover.

Silt and sand collect at a point bar extension of a wing-deflector. The view here looks downstream from one deflector. Brush is placed along the convex bank at this point to help tie down the fine sediments. Grass will soon cover the bar and make it a permanent part of the stream bank.

Constructing Devices to Maintain Sufficient Channel Depth and Cover

A deep channel protects trout from many terrestrial and aerial predators. Deep areas in the stream bed, or pools, occur naturally as parts of the meandered channel pattern of even slow-flowing streams as well as in the pool-riffle undulation of steeper stream beds. Both the meandered pattern and the pool-riffle sequence can be enhanced to create protective cover for trout. Modify the meandered pattern with deflectors and bank revetments to create a deeper channel. These same devices can also be used effectively to enhance the pool-riffle conformation. In streams of relatively high gradient, certain types of low dams (less than about 3 feet high) can also be used to deepen pools.

In constructing devices in low gradient streams, avoid damming the water — and be sure the devices do not destroy riffles; riffles are essential for spawning and are desirable for food production. A good rule of thumb is to maintain a depth of 8 inches in "protected water," that is, water which has ample rocks, vegetation or other hiding cover. Open water should be at least 18 inches deep. Upon elimination of grazing or excess shade, vegetation will often achieve this deepening by narrowing the stream. If not, use single-wing deflectors and revetments of large rock to scour deeper runs and pools. Do not create pools longer than a distance equal to five channel widths; this appears to be an approximate limit of pool length under natural conditions, since pools or riffles are normally repeated every 5 to 7 channel widths. To set 4 or 5 channel widths as the maximum pool length in habitat manipulation may help avoid creating the deep, quiet waters that often serve mainly as habitat for suckers.

Dredging, digging, and blasting do not have long-lasting effect in removing light sediments from streams. Only where the bottom is composed of rock, rubble or peat could digging or blasting be used effectively to deepen the channel. If light sediments clog a stream channel, it is because the current is insufficient to carry them away. If sand or silt are dug out of the stream without removing the downstream obstacles that prevent more rapid flow, new sediments will drift in from upstream to fill the newly deepened channel. Use deflectors and revetments to control sediments present in the channel. These devices put the current to work.

In construction, build solidly. Use durable materials having a natural appearance. Rock is the preferable material for in-stream structures. Take care in selecting the rock to be used above water. Certain limestones, and perhaps other rocks soon crumble due to freezing and thawing. Keep woodwork completely under water or it will rapidly rot. Avoid weak, soft or readily rotted woods. Use oak when possible.

A shallow, sandy, spread-out stream ...

... was narrowed and deepened with wing-deflectors and bank covers. Note the dark protective pool in the bend at the left (below).

USE OF A RIFFLE SIFTER.

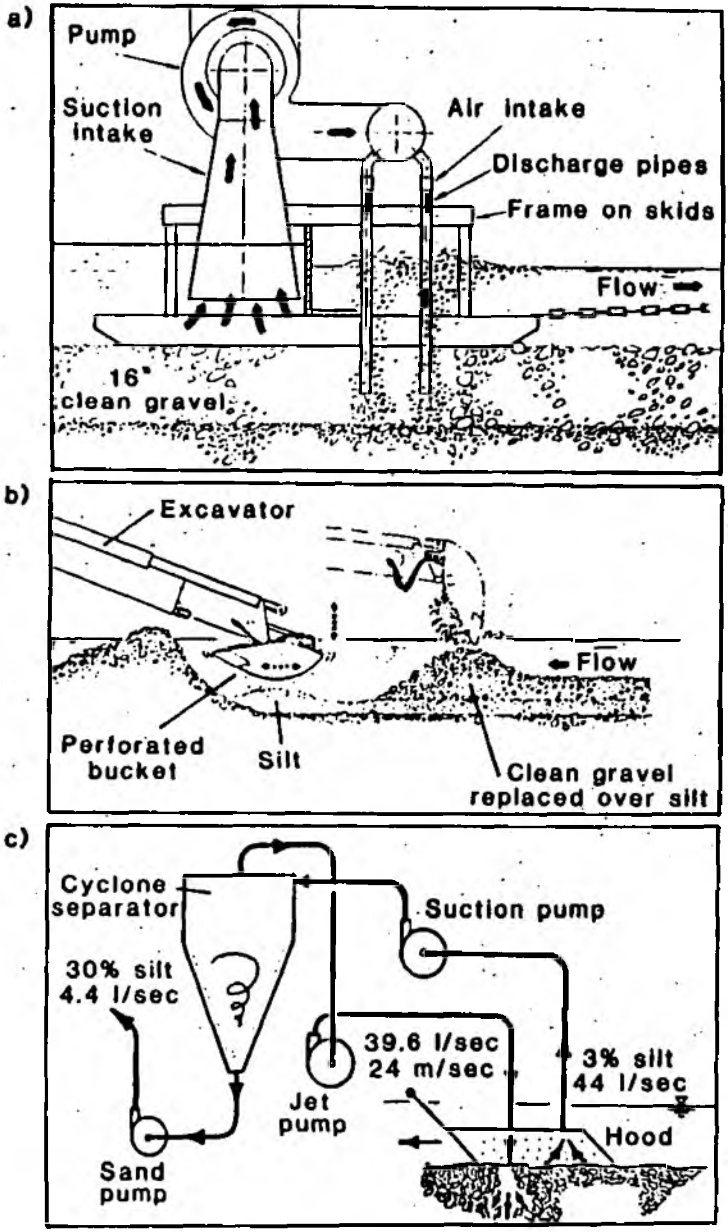


Figure 4.1 Spawning-gravel cleaning machines (section 4.3). (a) Air-water jet system for spawning channels, used with little success in natural streams (Andrew, 1981); (b) Andrew's (1981) 'vibrated bucket' method for natural streams; (c) silt separating system which discharges the slurry onto the bank (Allen, 1981).

holes; numbers of spawners have increased by 2.3 and 6.3 in the two streams. Occasional maintenance is required on the newly-created riffles mainly because the fish themselves displace gravel downstream while spawning.

The greatest interest in spawning substrate improvement has been on the west coast of North America, with a series of developments culminating in very successful (and expensive) spawning channels for Pacific salmon. These are unlikely to be a realistic development in the UK because rivers could not support such gross production of young fish of species with a significant riverine life history stage; channels are predominantly used for pink and chum salmon (which migrate to sea as fry) and sockeye (which migrate to lakes as fry). However, many of the other developments involving substrate improvement are of interest.

One of the main problems with gravel cleaning is that the silt is removed downstream, where it tends to resettle and perhaps cause degradation to other gravel. The 'vibrating bucket' method used on the Fraser River catchment (Andrew, 1981) overcomes this problem by burying the fines under the cleaned gravel. An excavator with a finely perforated bucket is used to remove a volume of gravel. This is then vibrated in the water to wash out the fines, which settle into the hole from which the gravel was removed. The gravel is then replaced to give a clean layer of about 30 cm over the fines. The estimated full economic cost of this technique is calculated at Can. \$1.25 per yd^2 (1981).

Andrew also describes a gravel cleaning machine, developed for cleaning spawning channels but used with limited success in rivers. It operates by jetting an air and water mixture into the gravel through pipes projecting 22 cm into the gravel, at 30 cm centres. Major problems arose with boulders, and dispersion of the fine material. The conclusion was that it had little potential for cleaning natural gravels, and that the vibrating bucket technique was more effective.

A gravel cleaning machine described by Allen et al. (1981) overcomes some of the drawbacks of Andrew's gear by recycling the silt/water mixture and removing most of the silt in a cyclone separator. About 70 gallons per minute of a slurry containing 30% silt is sprayed on to the bank well away from the stream. Again boulders were a major problem, and there were a number of other 'teething troubles' with the prototype under test, but the conclusion was that there was some significant potential for the equipment.

In deciding the viability of any approach to gravel cleaning, one must take account of the cost of the exercise, the immediate benefit, and the longevity of any beneficial effects. The obvious immediate benefit is the use of cleaned areas by an increased number of spawners. However, if these fish would otherwise have spawned successfully elsewhere, one must consider the stream as a whole, and also evaluate survival of eggs to emergence of the fry. The duration of beneficial effects is very limited in some situations; Carling (1979; in press) reports very rapid re-incursion of fine material into graded gravels and gravel winnowed by redd digging, in a river with high suspended solids loads. However, a number of North American studies have indicated reasonable life-span of ameliorating effects. Andrew (1981) found that siltation was much more rapid at the upstream end of a cleaned 2 300 ft length of stream than at the downstream end, indicating that the gravel was acting as a bedload collector. After a year the upper 200 ft contained a similar level of fines as uncleaned gravel. About 400-500 ft from the upstream end about

ARTIFICIAL OVERHANGS.

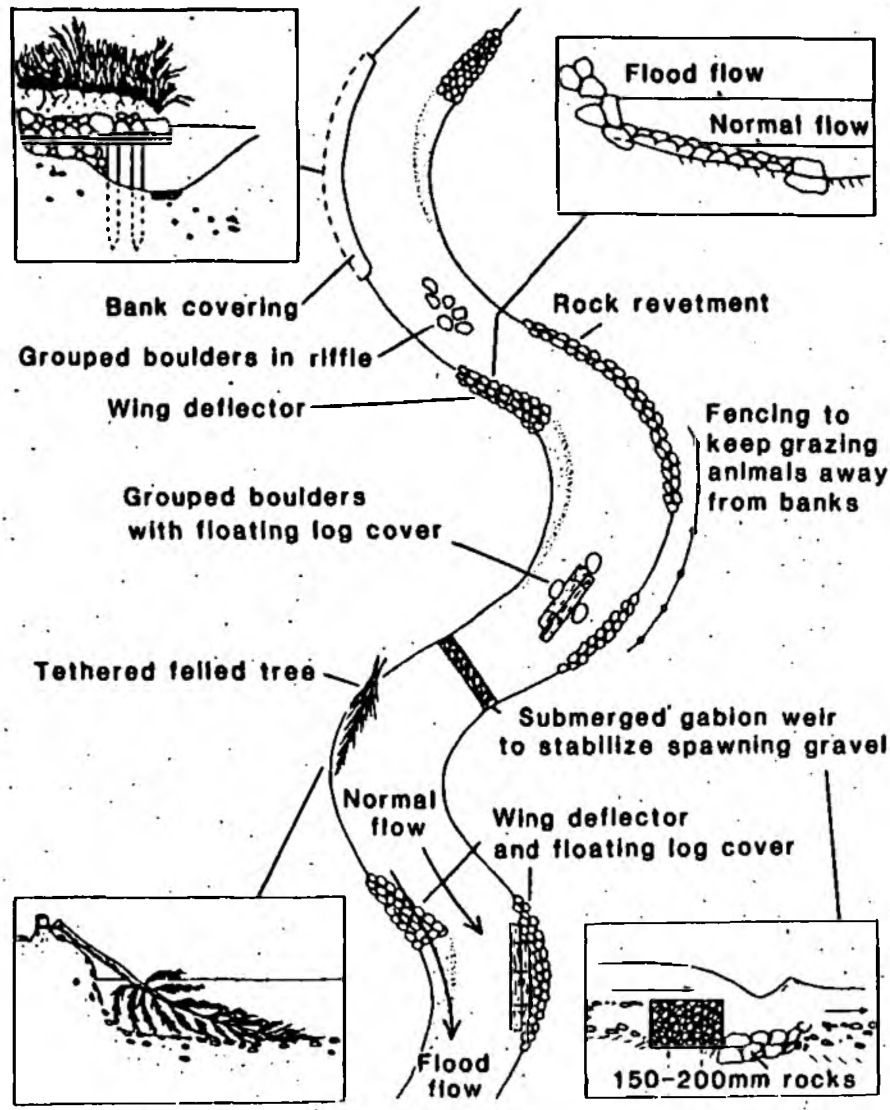


Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

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1 September In the interest of protecting delaying Adams River sockeye the Commission approved that Area 7A of US Convention Waters be closed to fishing effective 3.00 pm 1 September.

discharge and water level. The total area of extra cover provided by these devices was 40 m^2. This form of artificial shelter is not very sturdy and was consequently not intended to be a permanent installation, but was however suitable for this short-term experimental study as it is relatively inexpensive and easy to install. White & Brynildson (1967) and Hunt (1971) describe a more permanent form of cover device which takes the form of a wooden platform installed along the margins of a river and supported by pilings driven into the bed of the river.

Fig. 3. Floating artificial cover structures.

Physical measurements
River widths and channel depths were measured directly in the field. Current velocity was determined using an 'Ott' current meter positioned at 0.6 of the channel depth (Leopold *et al.*, 1964). All other data on physico-chemical environmental characteristics were obtained from information supplied by the Severn-Trent Water Authority.

RESULTS

Effects on channel morphology and hydrology

Low dams. The immediate effect of both low dams was to increase water depth and reduce current velocity immediately above the impoundment, with a corresponding decrease in water depth and increase in current velocity downstream. Also, the fall of water over each dam greatly increased water turbulence and caused scouring out of bed material. The changes in flow conditions produced through the action of the dam installed in section E are illustrated in Figs 4 and 5.

Detailed measurements of water depth and current velocity recorded at three equidistant points across transects at 1 m intervals above and below the dam in section E, recorded

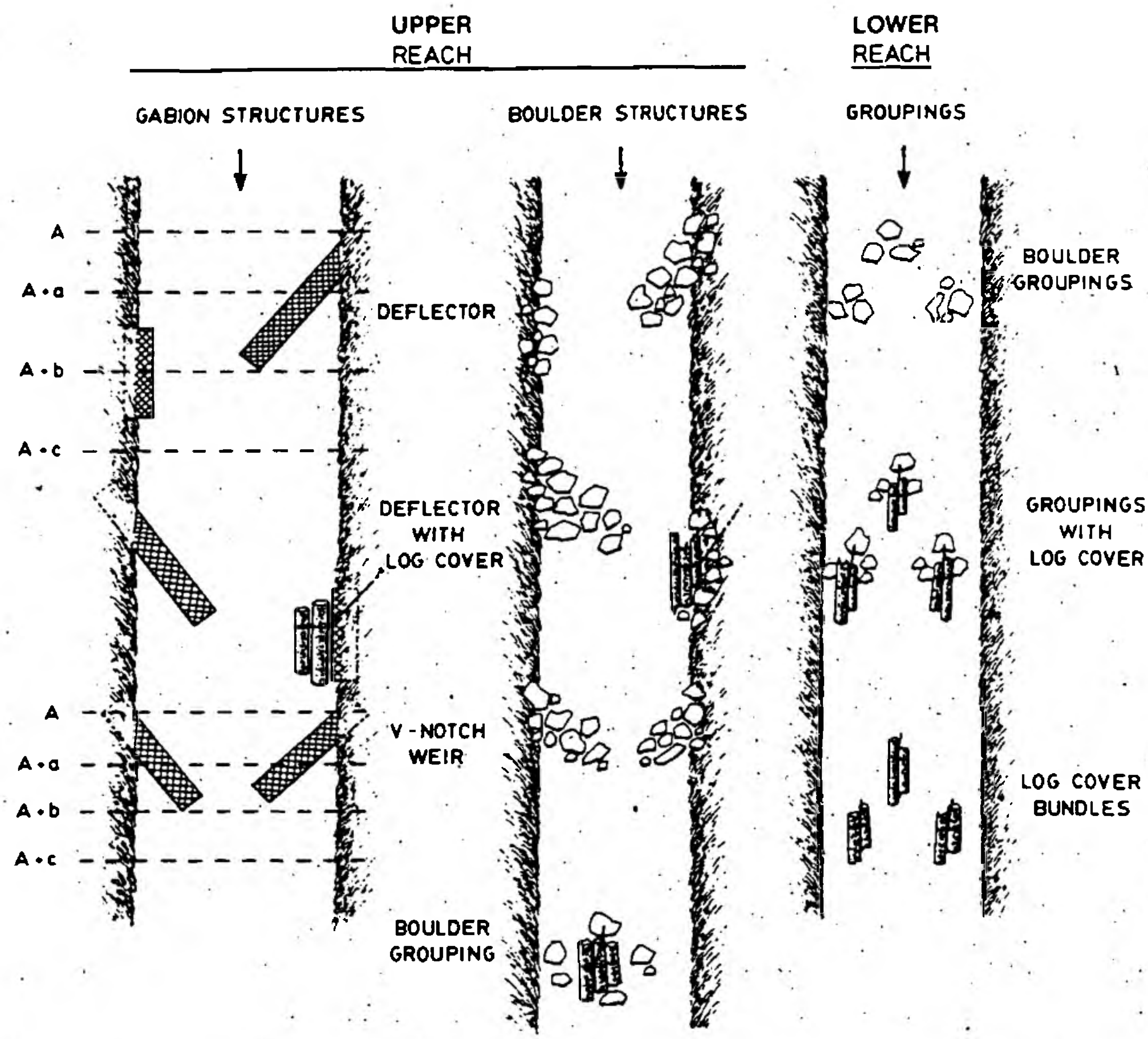


FIGURE 1. *Designs of boulder and gabion structures installed in the Keogh River (simplified).*

rearing areas for both coho and steelhead, were compared to detect natural fluctuations in salmonids before and after treatments.

Results

Hydraulic Effects in the Keogh River

Cross-sectional measurements in treatment sites in the upper reach indicated differing responses to floods. Small changes (10 cm) in depth occurred in boulder V-notch weirs and boulder groupings, but not in the other designs after the first year. Further changes in mean or maximum depth or 'wetted width' were insignificant or undetectable in the second year after placement of structures. Changes in

A more detailed discussion on the importance of shelter in stream ecosystems has recently been made by Marzolf (1978).

The evidence is strong that shelter in streams is of great importance to fish populations. In a study on Trout Creek, Boussu (1954) showed that the removal of overhanging vegetation and undercut banks decreased the numbers and biomass of "legal sized" trout by 40% and 33% respectively, while the addition of artificial vegetation cover increased the total biomass of trout in four experimental sections by 258·1%. Similarly, Gunderson (1968), working on a Montana stream, showed that an ungrazed section of stream had 76% more cover per acre of stream than a grazed section. Brown trout were estimated to be 27% more numerous and to weigh 44% more per acre in the ungrazed section of the stream than in the grazed section.

Artificial cover may be designed to simulate overhanging vegetation and undercut banks, or may take the form of materials installed directly into the river to act as submerged shelters.

3.2.1. *Artificial bank cover devices*

Artificial cover is generally designed to serve the same function as overhanging bank ledges or bank vegetation, in that it provides both shelter and shading. The cover may take the form of a platform constructed above the water surface and held in position by means of pilings driven into the stream bed, as described by White and Brynildson (1967) and Hunt (1971) (see Figure 3a). Alternatively, it may consist of overhanging platforms which float on the water surface, and which stay on the surface as river discharge fluctuates (Cooper and Wesche, 1976) (see Figure 3b).

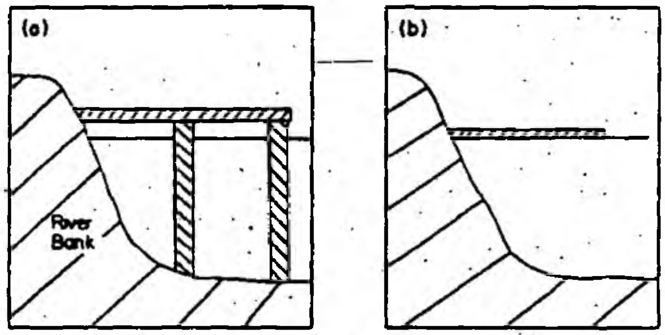
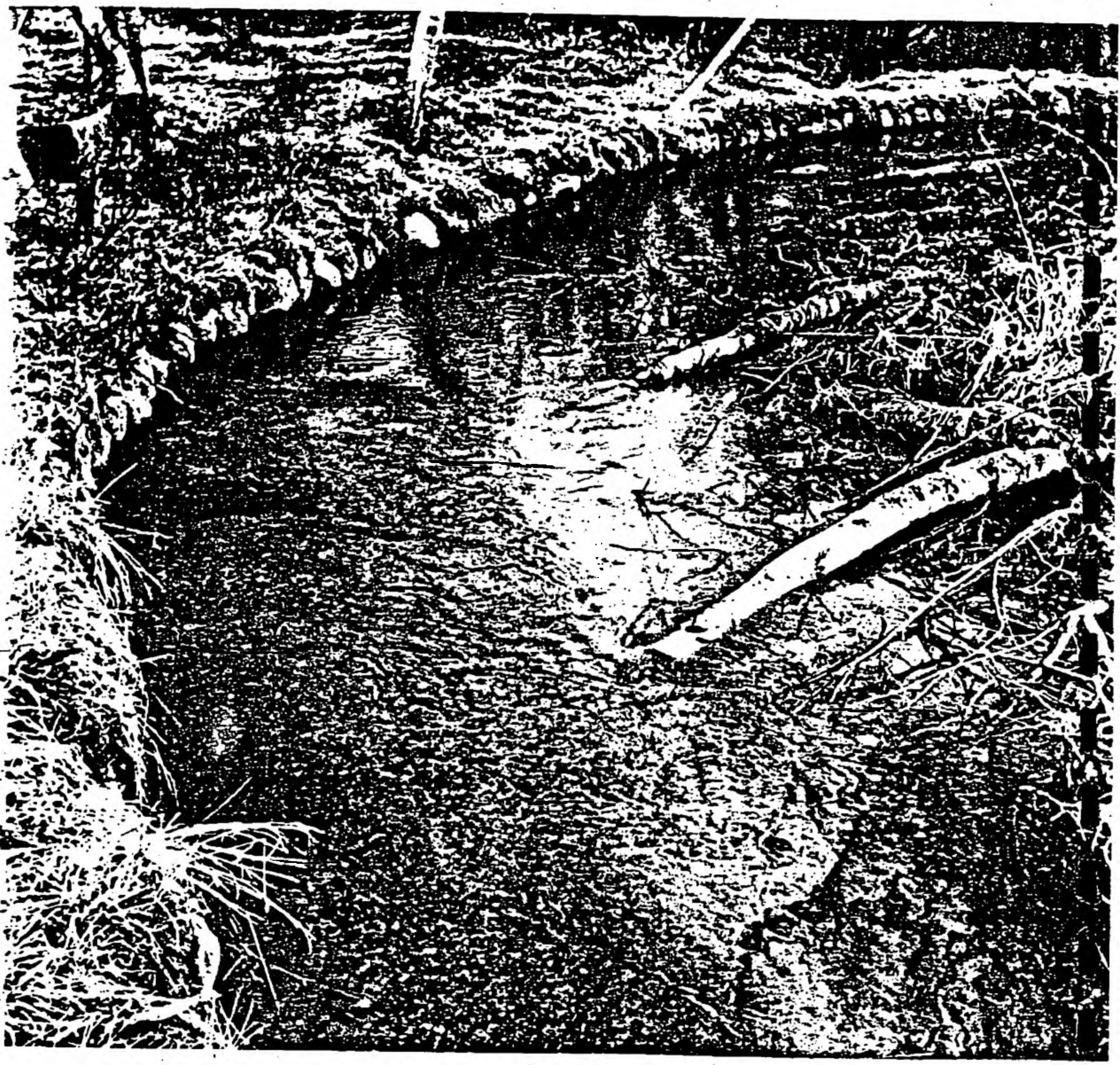


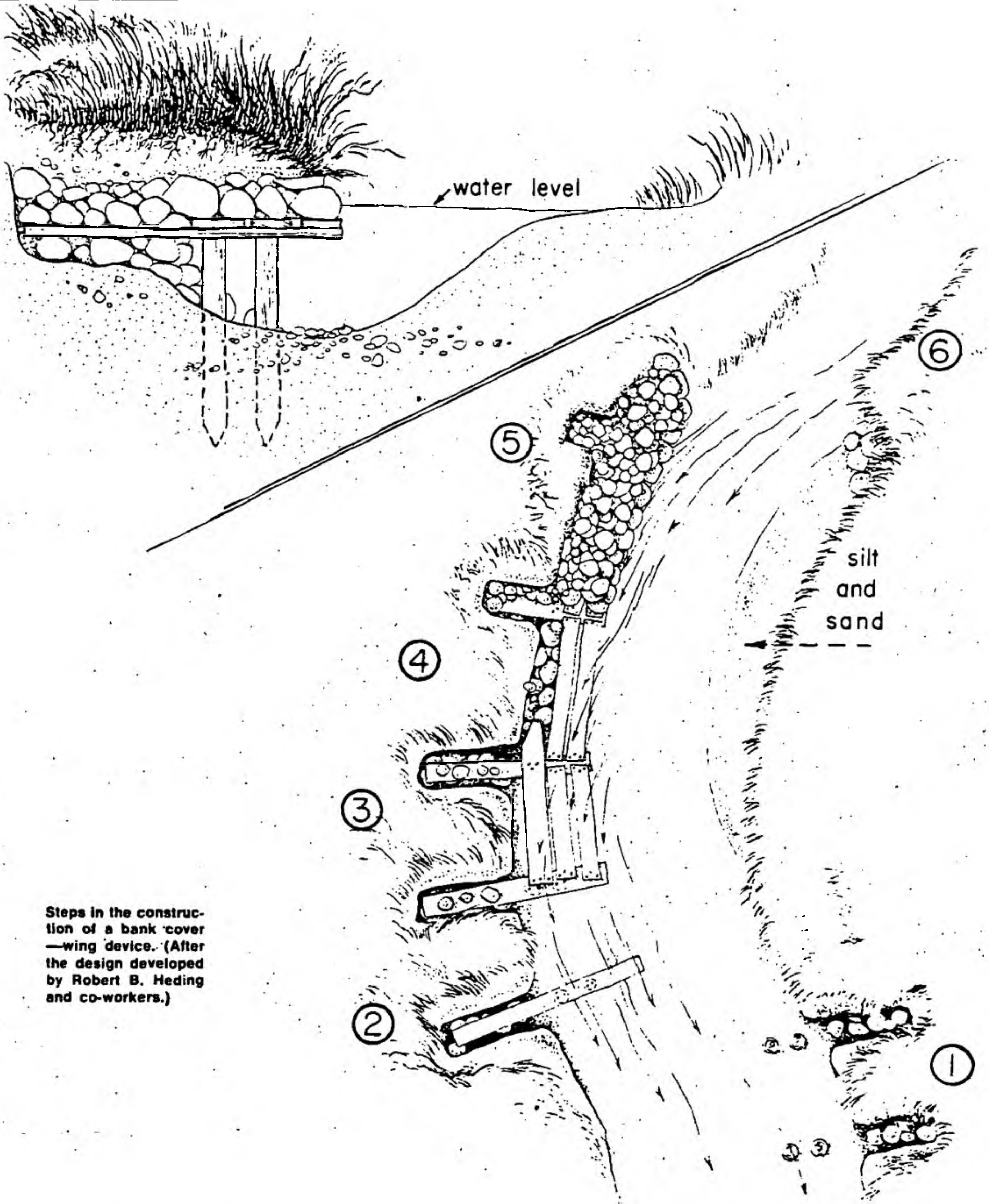
Figure 3. Artificial cover devices. (a) Fixed; (b) floating.

If artificial cover structures are used in conjunction with current deflectors, it is possible to use the deflectors to guide the river flow towards the cover, eventually resulting in an increase in water depth beneath the cover caused by the scouring action of the river flow (White and Brynildson, 1967). Alternatively, cover structures can be placed around the outside of bends where the current scours against the bank (Figure 4), and water depth is consequently greater.

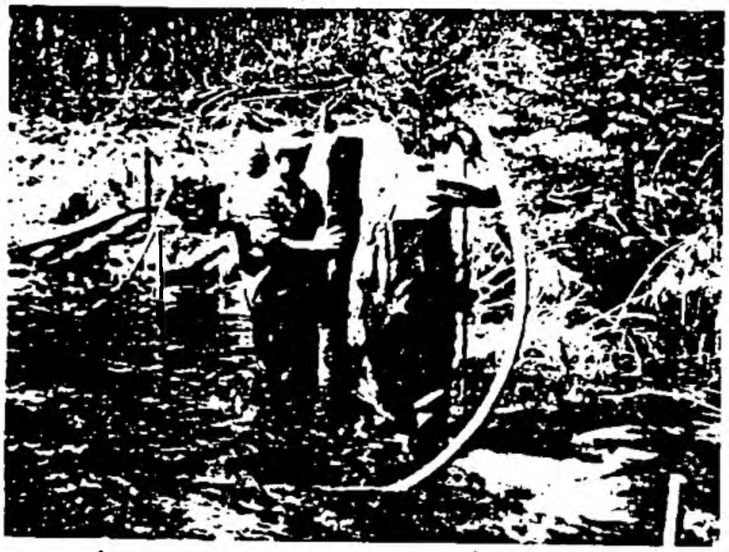
Hunt (1976) found that, following the incorporation of fixed artificial cover into a river improvement scheme, distribution of trout over 6 in was highly correlated with bank cover, and that the number of trout increased by an average of 101% during the three years following development. Other studies detailing the successful use of artificial bank cover include Boreman (1974), Hale (1969), Saunders and Smith (1962), and White (1975).



Bank cover



Steps in the construction of a bank cover—wing device. (After the design developed by Robert B. Heding and co-workers.)



1 Jetting the pilings.

2 Laying the stringers.

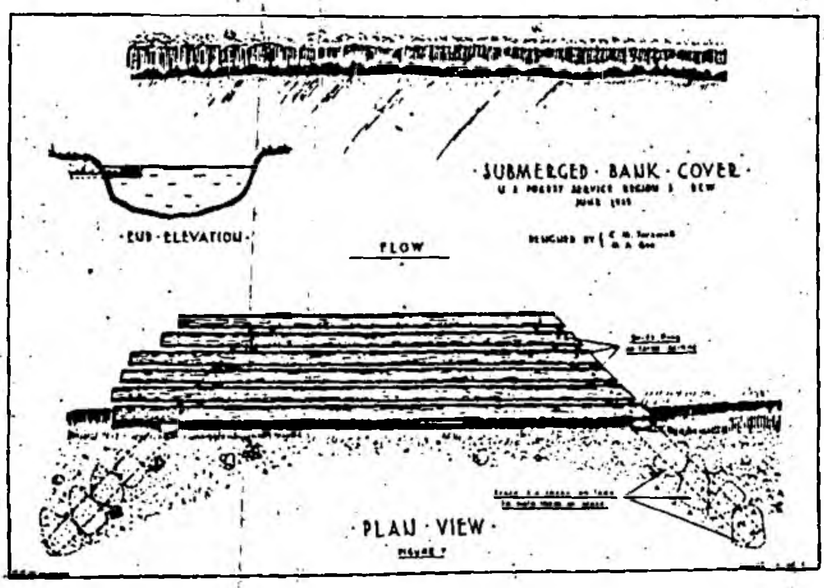
3 Spiking down the longitudinal planking.

4-5 Revetting with rock behind the overhang and covering with rock.

6 Covering finished device with soil and sod.

gations to determine the effects of the various types of improvements and to determine the value of the results of the improvement work have been largely neglected. Perhaps this is largely due to the fact, as pointed out by Eschmeyer (1936) that it is easier to install a so-called improvement than it is to determine whether or not it is beneficial. With the exception of the author's work in Michigan (Tarzwell, 1936) little evaluation work has been done and practically no results from investigations as to the value of stream improvement have as yet been published.

Due to the fact that environmental improvement was a new undertaking in the mountain streams of the Southwest, the Forest Service thought it advisable to carry on studies to determine the effects of stream improvement and to evaluate its results. Since the mountain streams of the Southwest are very different from Michigan streams it was clear that the results obtained there would not be applicable, in fact some believed that it would be impossible to increase the food supply in such streams (Davis, 1936). It was apparent that some knowledge of the value of stream improvement in mountain streams should be secured before the work was continued or expanded to any extent. Therefore, the Forest Service decided to make such investigations in conjunction with the stream surveys being conducted in the Region.*



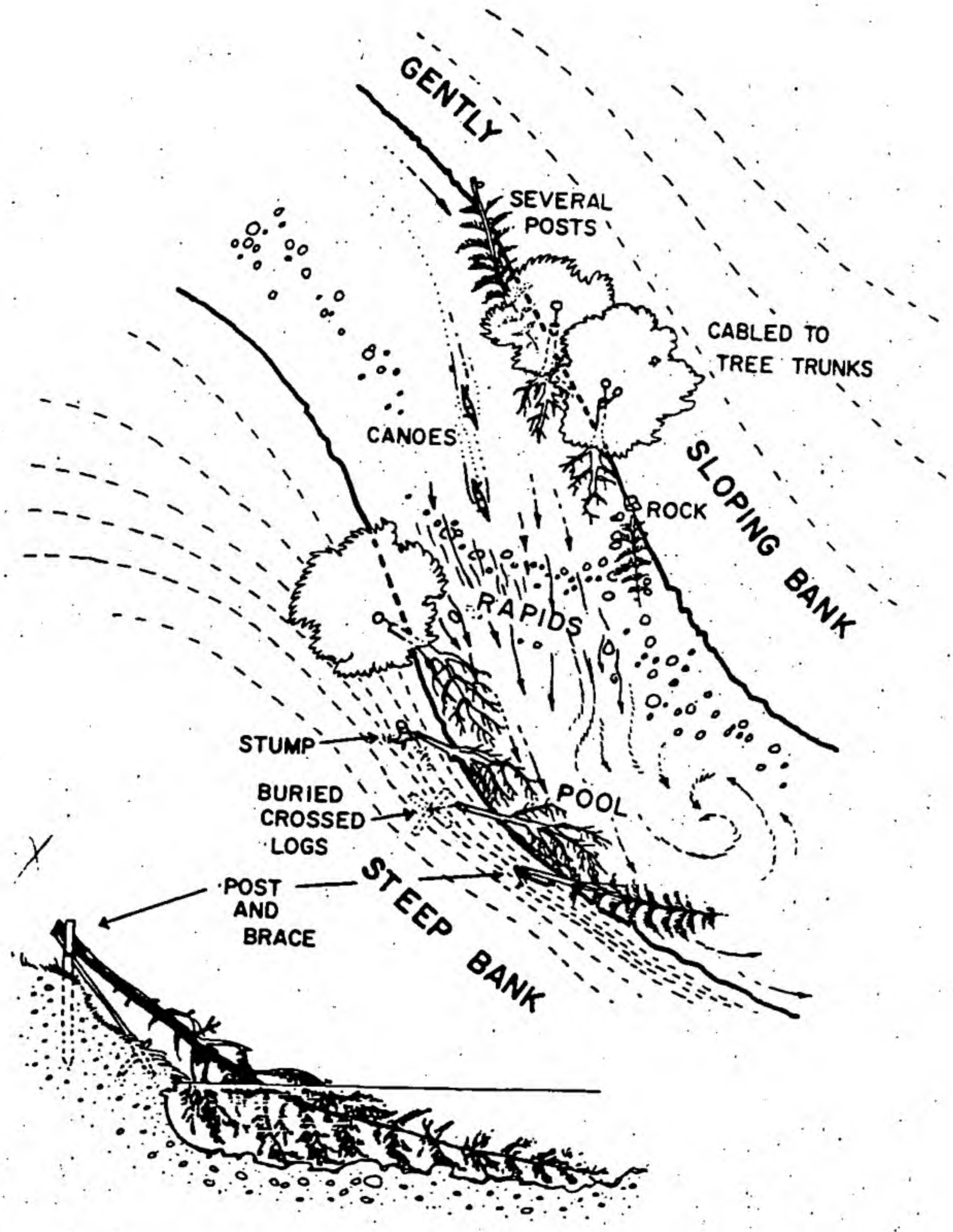
*These surveys and investigations were conducted by Mr. M. A. Gee and the author, of the U. S. Forest Service.

FIG. 8—LOG DAMS—HORTON CREEK, ARIZONA

This photo shows the stone riprapping on the ends of the dams and the use of secondary dams to back the water up under the main dam.

FIG. 9—BANK COVER—HORTON CREEK, ARIZONA

The log bank cover shown in this photo has been covered with rocks and forest litter to give it a more natural appearance. Many persons never notice this is an artificial cover although the span under it is 6x15 feet and gives excellent cover for trout.


GENTLY
SEVERAL POSTS
CABLED TO TREE TRUNKS
CANOES
SLOPING BANK
ROCK
RAPIDS
STUMP
POOL
BURIED CROSSED LOGS
POST AND BRACE
STEEP BANK

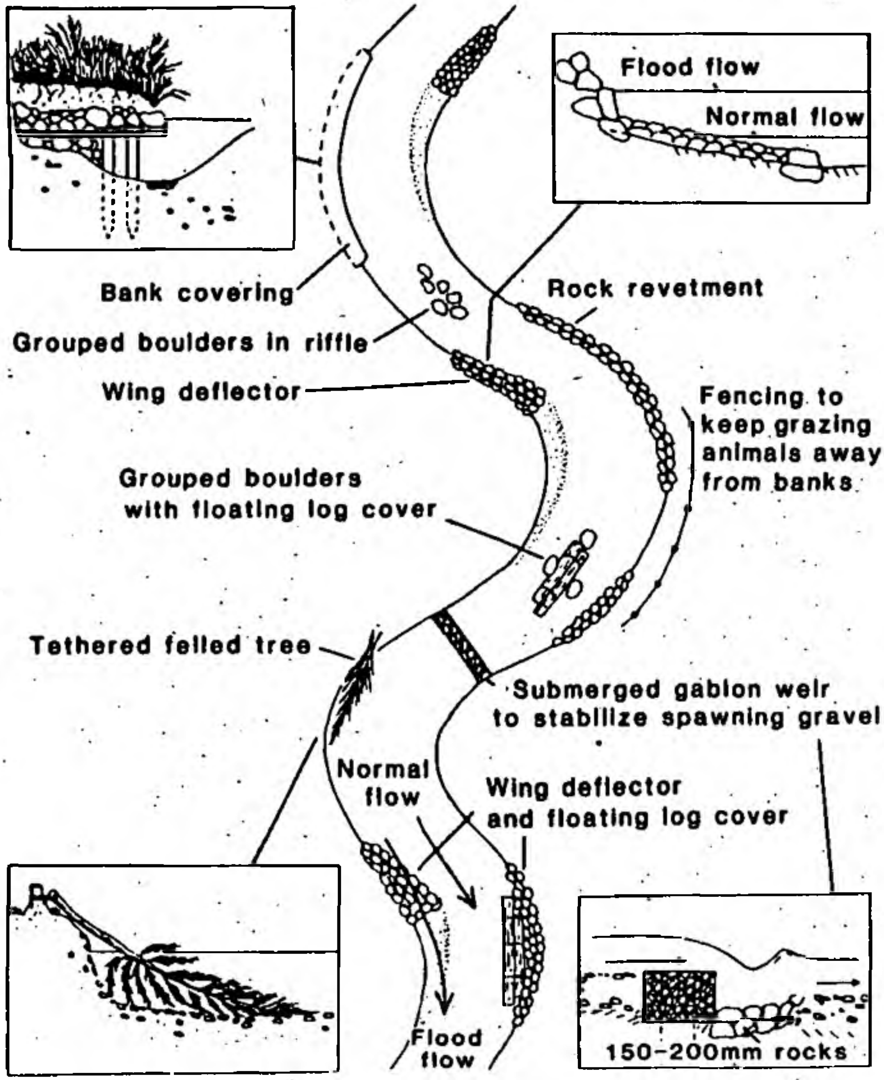


Figure 5.2 Stream structures to improve spawning and rearing habitat, recommended by several studies. Based on White and Brynildson (1967) with additions.

Stream enrichment is likely to be useful only where nutrients are naturally very low, and there may be some objection to its widespread adoption. It is effectively changing the very nature of oligotropic streams and may be resisted on conservation grounds.

6. STOCK MANAGEMENT

6.1 General

A widespread view on the west coast of North America, where stock enhancement practices are being widely developed and utilized, is that one of the most effective techniques is the proper management of spawning escapement. In practical terms this means regulation of exploitation by individual species and individual river and tributary stocks.

6.2 Regulation of commercial fisheries

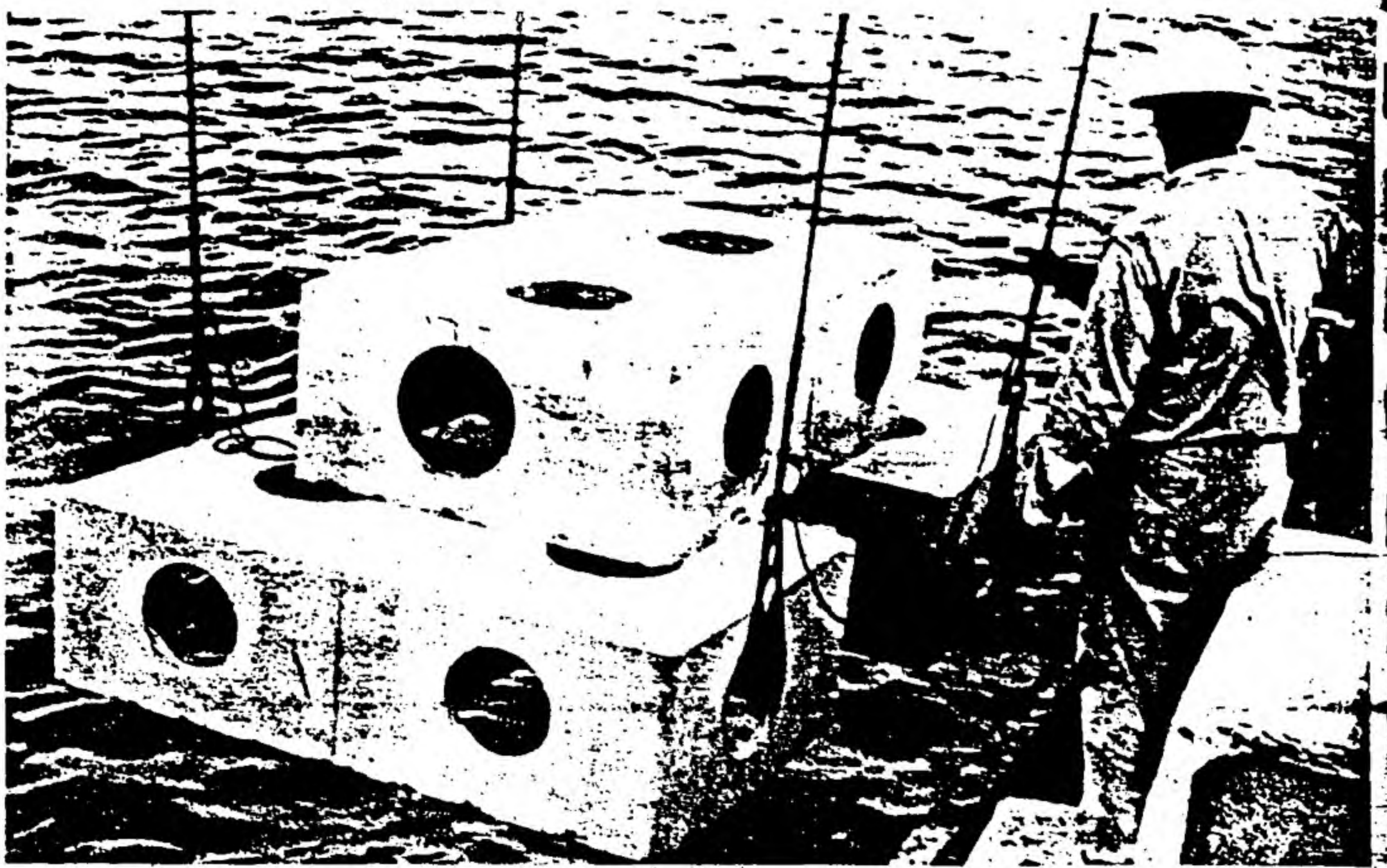
Most commercial exploitation of Pacific salmonids takes place outside river mouths, and there are thus to an extent mixed-stock fisheries. However, an increasing knowledge of migration patterns and stock characteristics is allowing a degree of separate management. One of the best examples is that of the Fraser River in BC. This system supports vast stocks of pink and sockeye salmon, with smaller but nonetheless valuable stocks of coho, chinook, chum and steelhead. Some of the stocks are greatly enhanced (e.g. for pinks and sockeye by spawning channels, others by hatcheries) while others are naturally maintained. There are marked cycles of abundance, every four years for sockeye and every two years for pinks. The stocks are exploited by fishermen from both Canada and the US as they pass through coastal waters. Stocks fell during the earlier part of the century for various reasons, but have recovered in recent years due to careful management and stock enhancement. Commercial catches of pink and sockeye salmon average over 7 million fish per year. Clearly, the Fraser River salmon represent an extremely valuable, but difficult to manage, resource. Management of the pink and sockeye salmon is the responsibility of the International Pacific Salmon Fisheries Commission, established by Canada and the US in 1937. There is a wide range of complex regulations governing time, place and method of fishing, which are adjusted each year according to the expected abundance of various stocks. In addition, emergency orders are passed to 'trim' exploitation according to a detailed analysis on an almost daily basis. For example, the following emergency orders were among many that were issued in 1982 (International Pacific Salmon Fisheries Commission, 1983):

"30 July. In order to secure additional escapement of summer-run sockeye the Commission approved the following regulatory changes: (1) That Area 29 of Canadian Convention Waters open to gill nets and trollers on 3 August for 1 day of fishing. (2) That the scheduled fishing in United States Convention Waters be delayed 1 day for 1 day of fishing in the week commencing August 1.

19 August In order to harvest additional Chilko River sockeye the Commission approved Area 29-7 and 9 to 17 of Canadian Convention Waters to gill nets on 20 August for 12 hours fishing.

1 September In the interest of protecting delaying Adams River sockeye the Commission approved that Area 7A of US Convention Waters be closed to fishing effective 3.00 pm 1 September.

REEFS.



When quarry rock is not readily available and is thus relatively expensive, due to high transportation costs from distant sources, prefabricated concrete "shelter" units may prove preferable as component elements of artificial reefs. Although reefs constructed of such concrete units are known to attract substantially more fish than quarry rock, as well as lasting indefinitely, they turn out to be more costly than rock when quarries are close to the reef site (photo courtesy California Department of Fish and Game).

in Chesapeake Bay by an angler's club, failed to produce better fishing than an adjacent bare area.[11]

Nevertheless, when sufficiently extensive, oyster reefs are well known to be good fishing grounds where sea trout, drum, croakers and other species tend to congregate. Consequently, the Texas Parks and Wildlife Department has supervised construction of 15 commercial oyster reefs varying in size from 6 to 33 acres (191 acres total) so as to assure that they will properly double as angling grounds.[12]

Three types of reefs were involved in the California D-J project evaluating various materials for artificial marine fishing reefs, begun in 1958. One was made of auto bodies (Paradise Cove), one of streetcars (Redondo Beach), and one of artificial rocks (Huntington Beach). Three replication reefs were constructed (Santa Monica Bay), for double-checking purposes. The Standard-Humble Oil platforms Hazel and Hilda at Summerland, Richfield Oil Island at Rincon, Monterey Oil Platform at Seal Beach, and Texaco Oil platform at Gaviota, were also studied.[13]

[11] *Elser, H. J. 1961. A test of an artificial oystershell fishing reef, Maryland, 1960. Md. Dept. Res. & Ed., Ref. No. 61-16:11 pp.; 14 tables (Mimeo).*

[12] *Stroud, R. H. 1964. Guide to Texas fishing reefs. SFI Bulletin, 150:4 (May). Sport Fishing Institute, Washington, D. C.*

[13] *Carlisle, J. G., Jr., C. H. Turner, and E. E. Ebert. 1964. Artificial habitat in the marine environment. Fish Bul. 124 (93 pp.). Res. Agency of Calif., Dept. Fish & Game, Sacramento.*

The auto body reefs proved to have a high attraction potential for fish. The streetcars proved to be somewhat less attractive. The life of these reefs was only 3 or 4 years, after which they disintegrated into a pile of rubble, when fish attraction was greatly reduced. The most successful reef was constructed of concrete shelters—but quarry rock was also utilized extensively and was considerably less expensive.

The concrete units are modified pontoons (designed for supporting boat slips and docks). They were secured from a company that already possessed forms for building pontoons and had merely to set in wooden plugs (to be knocked out later) to form the holes. Each shelter is 5 x 8 x 2½ feet and the holes are 15 inches in diameter. The side walls taper from 2 inches at the bottom to 1½ inches at the top, and there is a partition in the center, for strength. The proper mix for the shelters is 6½ sacks of cement to the cubic yard of concrete, and crushed rock or expanded shale aggregate should be used.

The six-sided shelters cost $75 apiece. Including transportation, a 1,000-ton barge load of quarry rock (2- to 3-ton chunks) cost $4,800 dropped in three locations. The concrete shelters (132 units), equal in cubic footage to the 1,000 tons of rock, cost $7,920. To this must be added the cost of rental of a barge and tug for at least a day at about $750 to transport the shelters—$8,670 in all. This lower cost for the rock was prob-

New York angling groups have commenced utilizing small concrete building blocks with many small holes in construction of the "captree" reef, as in the barge load being towed to reef site, in 1964. Forty concrete "fish havens," similar to the units employed earlier in California, have since been employed by New York marine fishery biologists in construction of an experimental ocean reef near Fire Island. (Photo by New York Bureau of Marine Fisheries, courtesy D. H. Wallace.)

at least one-half mile from existing reefs. [Artificial reefs cannot compete with natural reefs in attracting fish.]

2. Quarry rock is the most satisfactory material for artificial reefs. [The 8 x 5 x 2½-foot concrete blocks attracted 18 per cent more fish, but rock was cheaper and easier to handle.]

3. Reefs should be constructed in the form of a circle or a square with a central open area not exceeding 50 or 60 feet across. [The open area maximizes the edge, or boundary area, and is suitable for both rock bottom and sand bottom fishes.]

Part of the effort to construct reefs in New Jersey waters has involved the dumping of rubble and broken masonry wastes, or other small-size low-profile objects. Later underwater search of one such dumping area (in exceptionally clear water), pinpointed by Loran-fix, revealed no trace of these materials. Evidently, the rubble and masonry wastes were either washed away or were sanded over. Subsequent New Jersey activity has involved the sinking of weighted old wood boats (40 to 75 feet in length). *Toredo* attacks were expected to curtail their effectiveness as reefs in a comparatively short time.

Construction of a huge rubble-and-debris reef in 70 feet of water two miles off Fire Island, New York, was begun in August, 1962, when 3,000 cubic yards of broken masonry rubble and rocks were deposited on the ocean floor. The reef, a cooperative project among various angling interests, was planned to extend 1¼ miles with a height of 10 to 14 feet. Some 72,000 cubic yards of rock (about 100 barge loads) would be needed to complete the reef, as planned (at an estimated cost of $8,000).

Sport fishing in the area was said to have been poor before the reef was started, and limited to some small bottom prominences. Soon, however, party boat captains fishing out of Captree Boat Basin, close to Fire Island Inlet, began to report increased catches over the new reef compared to adjacent areas away from it. For example, on June 2, 1963, about 300 anglers fishing on the reef in 65-foot boats and ten smaller boats caught "several thousand" ling (a kind of hake) and an estimated 3,000 sea bass. One boat reported a catch of 120 sea bass, while another boat reported 500 sea bass taken the same day; two fishermen caught over 100 sea bass between them. By mid-July, both the ling and sea bass had dropped off, while porgies increased in abundance in the catches, suggesting the possibility that a species visits the reef for a time and then moves on to be replaced by another form.[16]

Although such reports seem encouraging, a recommended improvement is to construct reefs with a high profile, using hollow components having many large openings. This design has been found elsewhere to be superior to low-profile structures having few holes and cavities. The New York Bureau of Marine Fisheries is now utilizing "fish havens" of such design for experimental marine sport fishery management.[17] The new steel-reinforced concrete "havens" are 8 feet long by 3⅓ feet wide with 20-inch portholes, similar to some used successfully off California. Forty of these two-ton structures have been located in the Fire Island area. (Too, New York angling groups have recently begun construction of the "captree" reef utilizing small concrete building blocks with many holes.)

Catches from these "fish havens," when compared with catches from the previously constructed rubble-and-rock reef, should demonstrate which is the better type of artificial reef for that area. Presently, there is a dearth of information to indicate what is the best kind of fishing reef for the conditions and species characteristics of Atlantic coastal waters. Therefore, the New York project has considerable implication for marine sport fishery management in North Atlantic waters.

Helpful Reef Building Principles Emerge. These collective recent experiences in U. S. waters appear to

[16] *Wallace, D. H. 1963. Personal communication. Dir. Mar. Fish., Div. Fish & Game, N.Y. Cons. Dept. (July 12).*

[17] *Wallace, D. H. 1965. Notes on marine programs. N. Y. Fish News, 20:6-10 (June).*

VEGETATION.

Ideal turf on a stream bank.

Protecting and Managing Stream Bank Vegetation

When vegetation binds the stream banks they erode less rapidly and the current digs a deeper stream channel—one that protects trout better. A sturdy turf will often form overhangs. These are excellent shelter. In any case, plants on the stream bank together with emergent plants such as watercress, can form an ideal fringe of hiding places for trout at the water's edge. Grasses and low brush are best for this; they should be protected from shade and grazing.

Trees and high brush shade out the plants composing this beneficial turf. Like other parts of a forest floor under a dense canopy of foliage, a heavily shaded stream is nearly barren. It produces little food and is often wide and shallow. It lacks channel-constricting in-stream aquatic vegetation and cover-providing stream bank vegetation. Trees also damage small streams by toppling across them, making debris-catching obstructions and tearing up the bank in the process. Trees in the wet soil along streams have shallow, weak root systems (willows are an exception.) Remove trees shading the water and banks of those streams which will not be excessively warmed by the sun; that is, those receiving a sufficient inflow of spring and seepage water.

Do not plant trees — except where there is reasonable evidence that summer water temperatures are lethally high

Nearby section of the same stream just after fence was put up. Although photographed in spring when conditions were at their worst, heavy grazing had, in previous years, prevented development of vegetative cover much beyond what is shown here.

A densely shaded stretch of Mt. Vernon Creek with a raw, continually eroding mud bank for most of the year.

The same stretch of bank developed a turf after the trees were removed and banks sloped. The grass is still in the first spring of growth, has not yet attained its full length and value as hiding cover, but has already withstood a spring flood.

Stream bank tree tipped back away from channel. Its plate-like root system heaved many feet of shoreline. Thus, shallow "wide-spreads" result, or the course of the channel may be changed drastically. Such events ruin wing-deflectors and other installations — another reason why trees should often be removed at the outset of a stream improvement program.

for trout and that temperatures can only be reduced by shading with trees. Discourage persons engaged in reforestation from planting trees beside trout streams.

Controlled burning of stream bank vegetation holds promise as an important tool to hinder trees and promote grasses and other low plants. The methods for applying fire as stream bank management are, however, not yet developed. The hand-held mechanical brush cutter is at present a useful tool. Selective use of herbicides is being explored as a means of controlling brush on stream banks.

Protect the stream and its banks from grazing and wallowing livestock. They not only eat plants, but trample them and in the process also cave in trout-protecting overhangs of the bank. Fencing cattle away from our streams is one of the primary needs in managing Wisconsin's trout resource. It is an inexpensive way of letting nature take its own course to improve habitat for trout.

Grasses mixed with broad-leaved annuals appear to be best for development of food-producing turf on the bank. In streams less than 15 feet wide, rely on grasses and annuals exclusively to provide hiding cover and bank protection; keep the brush out. On streams 15 to 30 feet wide, very low bushes will not cause damage, but high bushes such as alder should be cut regularly or eliminated.

Reed canary grass, *Phalaris arundinacea* is proving to be a highly important grass for stabilizing the soils of Wisconsin stream banks and for providing overhanging cover for trout. It has long been used to protect waterways in Europe and much of the seed for stands in this country was imported from Sweden, though some varieties of reed canary grass are native to North America. Reed canary grass grows in dense, continuous stands 2 to 8 feet in height. At all seasons a bank-lining fringe of it drapes into the water; even in winter and early spring when brown and withered, this fringe remains durable. The tough system of roots and runners hinders erosion and traps sediments washed downstream during high water. Reed canary grass withstands a wide range of moisture conditions, even grows under water for extended periods. Best growth is attained on moist cool sites, but this grass will also thrive on upland soils. That it is one of the earliest grasses to begin growth in springtime is a further advantage—many other shelter-providing plants do not develop until much later. Reed canary grass can be cut to prevent excessive growths without damaging the turf; however, it will not withstand

Controlled burning holds promise.

Protect stream banks from grazing.

Reed canary grass provides good shelter at the edge of a stream. J. M. Conrader

heavy grazing. Heavy stands of this grass in the upper reaches of streams sometimes hinder angling during late summer, but its superiority in protecting an overwinter trout population for good fishing the next spring and early summer may often outweigh the seasonal inconvenience to some anglers. Reed canary grass sometimes dams extremely small channels. Therefore, do not seed this grass along streams less than 4 feet wide.

Sedges (*Carex* sp.) appear to be less beneficial. In many areas they seem to provide patchy cover because their moisture tolerance range is relatively narrow, and hence provide less protection against stream bank erosion. However, since many species of sedges exist, perhaps useful ones can be found and utilized in stream bank management. Low-growing types would be especially desirable in the narrow headwaters of creeks, for they would not obstruct fishing or choke small waterways as does reed canary grass.

Bluegrass (*Poa pratensis*) with its short blades and weak, shallow root system, is even less desirable. This native of the Old World makes at best only a scanty fringe of hiding cover for trout; its turf is too weak to protect even moderately steep banks against washout. Rapidly eroding and slumping outer banks of stream bends characterize creeks in bluegrass meadows.

Willows (*Salix*) have proven to be useful bank protectors and providers of hiding places for trout, *if periodically controlled by basal pruning.* The leaves, branches and twigs of willow can be counted on to furnish little cover for trout; it is the roots that are important. Willows are our most aquatic tree. Many types of willows maintain relatively deep, tough root systems when growing on stream banks. The dense mass of roots forms a bank with many inverse ledges and grooves that trout can hide beneath. These root systems are effective in preventing bank erosion; you can often find willow root banks that have borne the surging water at a stream bend for several decades.

But to develop and maintain the dense stands of saplings necessary to have a continuous "root-revetment," willows require basal pruning. According to Tesch (1962), writing of German streams where this is a highly developed practice of bank protection, basal pruning should be done at intervals of about 3 years.

Large willow trees on the other hand, can damage a trout stream. By their own shade they prevent themselves from growing in dense continuous stands—and their shade inhibits in-stream vegetation. The roots of these lone trees provide only short patches of cover for trout. Limbs easily split off of large willows, fall into the stream and cause detrimental dams. A dense stand of low willow brush binds the stream bank better, but does not slough limbs into the streams and does not overshade the stream.

Many kinds of willows grow in North America. Some may prove to be very helpful in stream management; others, useless. An investigation should reveal types suited to various purposes and conditions, as in Kirwald (1964).

A dense stand of low willow brush binds the stream bank, and does not shade the water.

Limbs of large trees split off and dam up the stream. Spawning grounds become covered with silt.

The large willow with wide-spreading branches shaded both banks, leaving them barren of vegetation. Note the good growth of grasses in the foreground outside of the shaded areas.

On the same stream, a similar stream bank illustrates a good job of management. The willow on the right has been cut back. Removing shade produced by willows is a major part of the overall management of this part of the stream. Note resprouting of willow stumps on the right after two years of growth. They will need pruning soon.

The lower branches of young alders are alive and drape into the water, providing good trout cover.

Alders that have grown too high have long stems that completely arch a stream 25 feet wide, creating dense shade and providing no hiding cover.

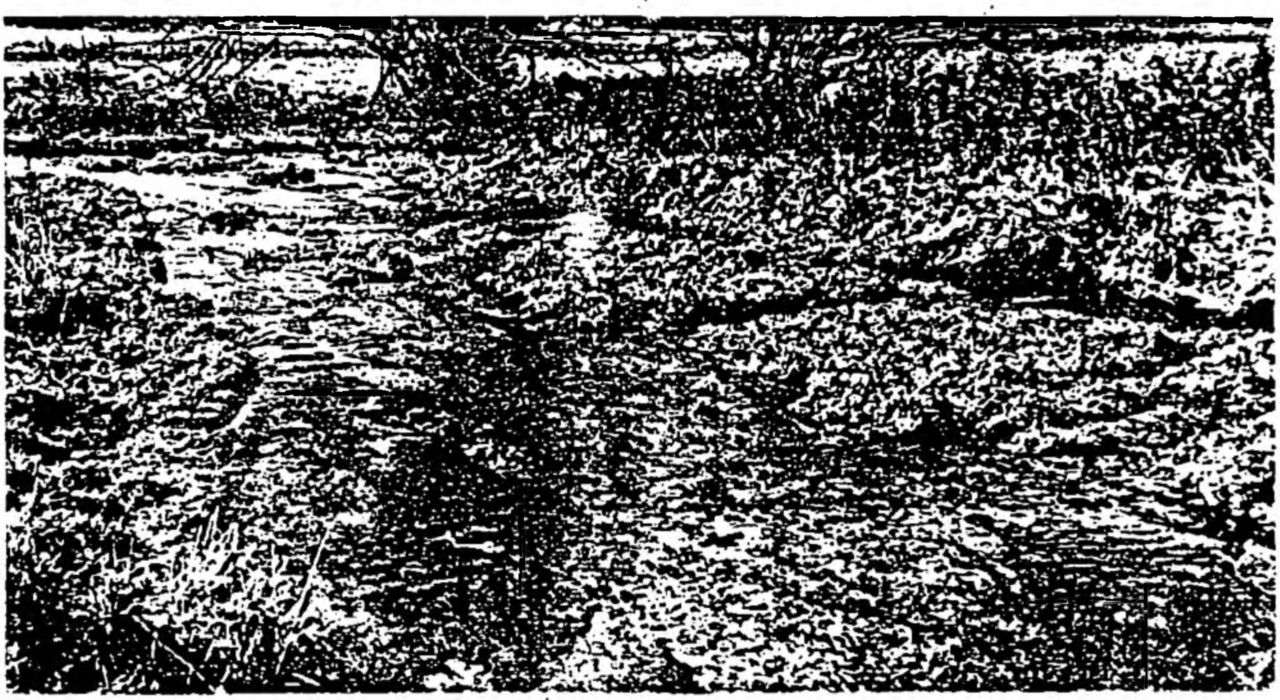
Alders (*Alnus*) serve as submerged hiding cover only when their branches actually drape into the water. Alders are ideal shelter only on streams wider than 40 feet. On smaller streams they give too much shade to the stream bed and shade out their own lower branches, the ones which would serve as shelter. Even on larger streams, the beneficial lower branches of alder are often missing because the ice encasing them in winter has torn them away. Prevent alders from forming dense, continuous thickets along small trout streams.

The protection of stream bank vegetation from shade and livestock will also protect aquatic plants in the stream. These provide excellent hiding cover for trout, but unfortunately most of these plants die out in winter and do not flourish again until mid or late springtime. Watercress (*Nasturtium officinalis*), an import from Europe, is a principal aquatic plant important as trout shelter. This plant occurs in the hard water streams of western, southern and eastern Wisconsin, but is at best sparse in the north. In summer and autumn when it flourishes, it provides in many streams the principal cover for trout — and substrate for animals that trout eat. But cress withers and drifts away in November or December leaving the channel barren until it starts growing again the next spring.

Submerged aquatic plants such as *Elodea*, *Veronica* and water buttercup (*Ranunculus*) likewise cannot thrive in shade. These appear to provide less desirable hiding places than watercress, but they are more dependable as year-round cover. They flourish in summer, and often do not die out completely in winter.

A small book: "Gewasserpflege" (Management of Waters) by E. Kirwald (1964) is to our knowledge the only general reference on control of stream-, river-, and lake-bank vegetation and its uses in stabilizing soils and landscaping. Although written primarily for the highway engineer, the farmer and the forester, it would also be of aid to the fish manager. It is presently available only in German, but possibilities for an English edition are being investigated.

Watercress along the bank, *Veronica* and *Elodea* in the middle of the stream. In protected streams, a variety of plants can grow.

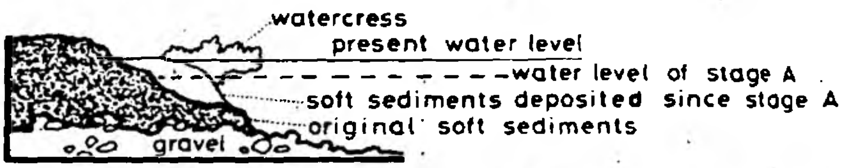


Some stages in natural development of a fertile lowland Wisconsin trout stream from overgrazed (A) to very productive (D-E-F) to overforested (G&H) when protected from grazing. A hypothetical 14-foot wide cross-section plus adjacent bank shown.

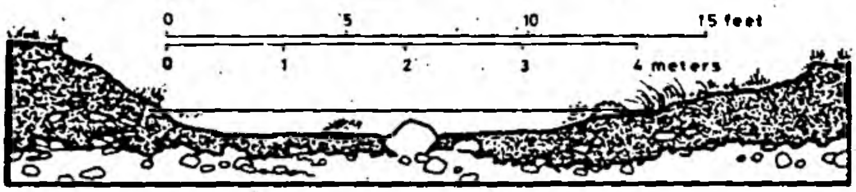
The complete sequence from stage A to stage E-F has been observed on Black Earth and Mt. Vernon Creeks near Madison.

Later succession — stages G and H with many intermediates — is to be seen on other streams. Details of this succession vary from stream to stream, especially after stage E-F, but the passage from predominantly herbaceous to predominantly woody vegetation generally has the same detrimental effects. Good management for trout — and other wildlife — would be control of vegetation to maintain stages D-E-F.

KEY

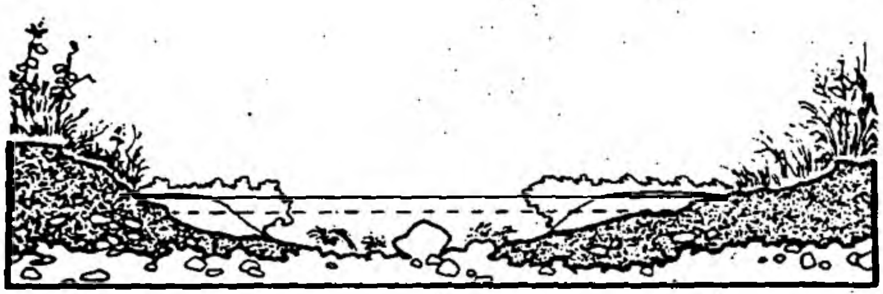


A



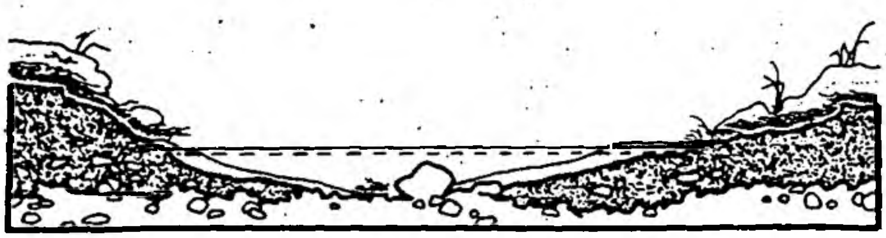
MIDSUMMER CONDITIONS UNDER HEAVY GRAZING BY LIVESTOCK:
Bank vegetation and watercress grazed and trampled. Banks eroding, and stream bed mostly covered by shifting silts. Submergent plants grow poorly. Whole surface of water and stream bed exposed to sun. Greatest depth in cross-section only 9 inches (22 cm). These conditions offer trout no shelter, no place to spawn, little food, and frequently unfavorable temperatures.

B



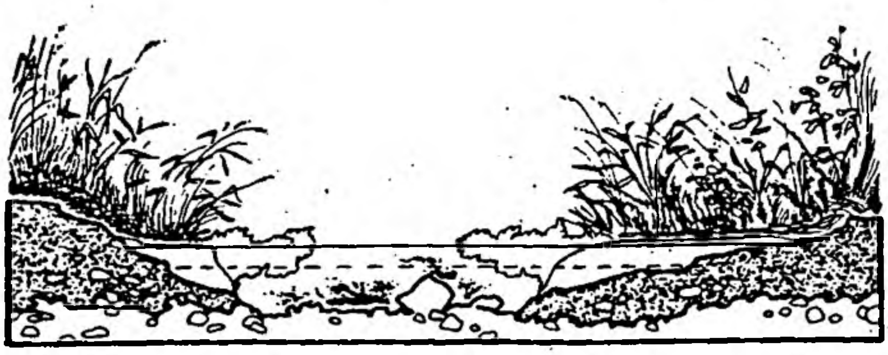
MIDSUMMER CONDITION AFTER 2 TO 4 YEARS OF PROTECTION AGAINST GRAZING:
Bank vegetation forming a turf. Abundant watercress at edges of stream constricts channel, thus deepening and speeding water. Soft sediments scoured from much of stream bed and trapped in cress beds. Submergent plants thriving. Only about half the former stream width exposed to sun. Greatest depth about 20 inches (50 cm). Trout have ample shelter beneath watercress, beside rock, and among submergent plants. Firm stream bed and many plants provide substrate for many animals that trout eat. Newly exposed gravel is a place to spawn.

C

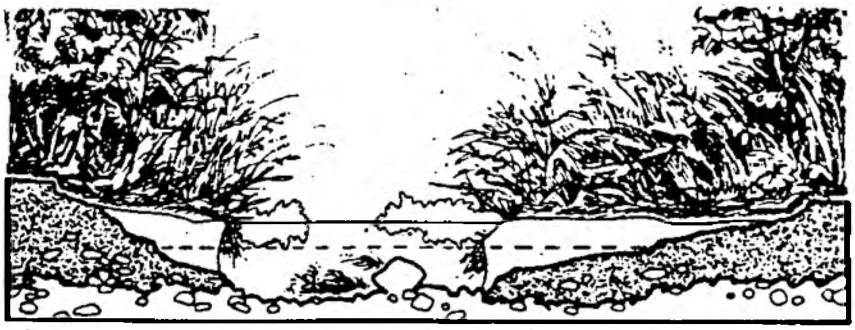


LATE IN THE NEXT WINTER:
Watercress has withered and drifted away. The silts it held slump into the channel, smothering many of the trout eggs buried in gravel and preventing fry from emerging into stream. Food is scarce. Broad surface of water exposed to cold. Shelter for trout almost as poor as at stage A and will not redevelop until May or June.

D

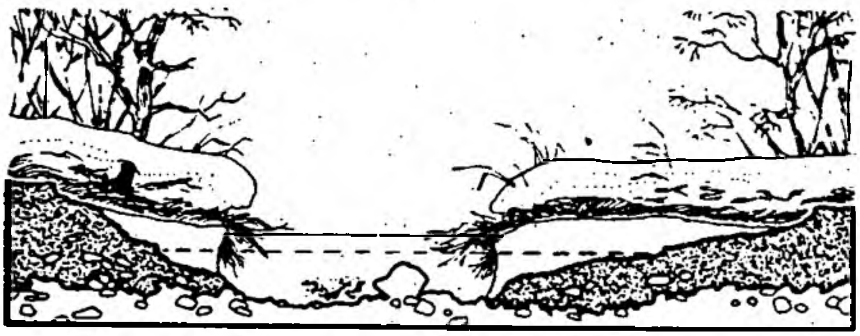


MIDSUMMER CONDITION IN ABOUT 3RD TO 5TH YEAR AFTER GRAZING HALTED:
Further scouring of fine sediments from stream bed. Silt bars at stream edges being tied down by reed canary grass with its tough system of roots and runners. Watercress flourishing, and submergents at peak of development. Only 4 feet of stream width exposed to sky, and this shaded much of day by high grasses. Greatest depth in cross-section about 2 feet (60 cm). For trout, shelter, food, and spawning gravels are ample.



E

MIDSUMMER A FEW YEARS LATER:
Silt bars further stabilized by turf. Channel narrowed by 40% to 50% since stage A. Only 2 feet of stream width exposed; therefore submergents less abundant. Also less volume of watercress due to shade of taller plants. Woody vegetation starting to dominate.

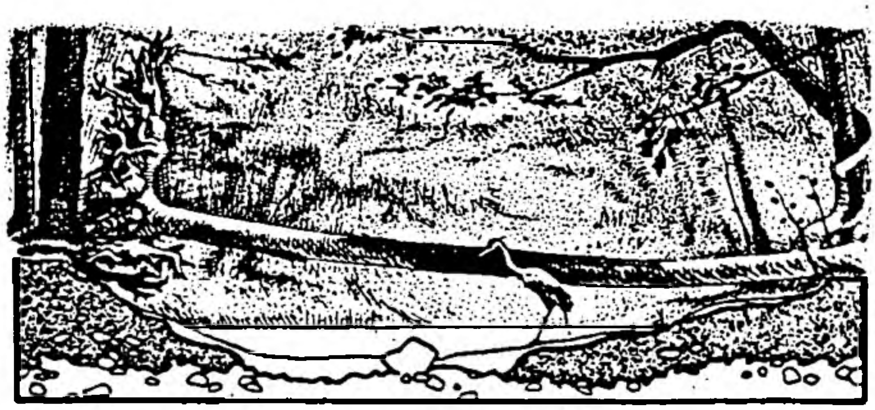


F

LATE WINTER DURING STAGES D AND E:
Turf still holds bank materials firmly. Overhanging fringes of matted grass provide shelter for trout. Gravels remain clean enough to allow normal hatching and emergence of fry.

G

MIDSUMMER 10 TO 20 YEARS LATER:
Alders or other high bushes predominate (saplings of ash, elm or maple at left). Turf completely shaded out. Water level high due to clogging by debris. For trout, food may be scarce, shelter is excellent beneath banks, among roots and fallen branches.
But:
Innermost rows of alders will soon tip into channel, further clogging flow and destroying overhanging bank. The largely vegetational processes of bank-building will not be repeated as long as shade persists.



H

MANY YEARS LATER:
Mature forest . . . Dense shade. Few plants on forest floor. Banks have eroded, channel has spread and silts again cover stream bed. Channel less than 1 foot deep. Little shelter for trout. Even trees undermined by current and toppled across the stream may provide poor hiding cover. Conditions almost as bad as in stage A.

LOG DAMS.

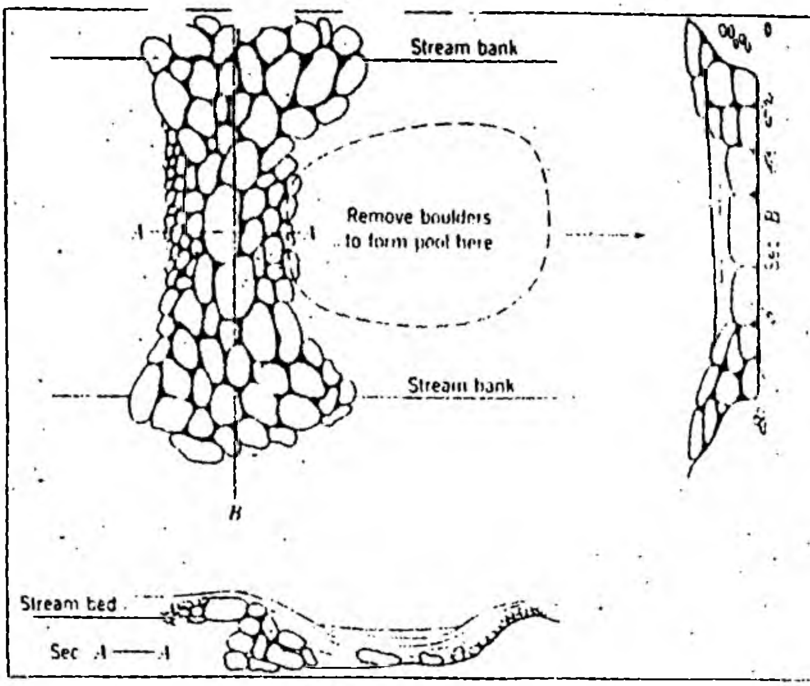


Figure 12-4. Rock and boulder dam. Courtesy of Lloyd L. Smith and John Moyle, Tech. Bull. 1, above

the dam can be built. Additional boulders are placed so that they interlock with the keystone and with each other. Care needs to be taken to protect the banks and insure against the water cutting around the ends of the dam.

The single-log *dam* is intended only for small streams not over 5 to 6 m in width; the construction makes it most adaptable for use on streams with soft bottoms. The backbone of this type of dam is the large log which extends across the stream and well into each bank, resting on log mud sills, the number of mud sills depending on the width of the stream. A channel is dug across the stream for the main log and channels upstream for each of the mud sills. The mud sills are notched to receive the main log. After the main log has been fastened securely to the sills, heavy wire is stapled to the main log and sills, after which the dam is covered with a layer of heavy rocks and then topped off with earth, sand, gravel, or more boulders. The dam should have a spillway to take care of overflow of low water. Care needs to be taken, as with all installations, to make certain the banks are protected so that the water will not cut around the device.

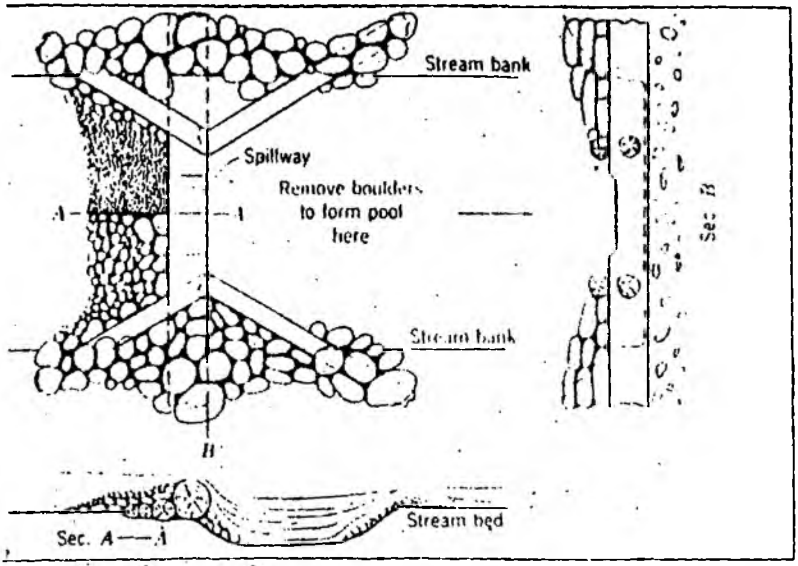


Figure 12-5. Single-log dam. Courtesy of Lloyd L. Smith and John Moyle. Tech. Bull above.

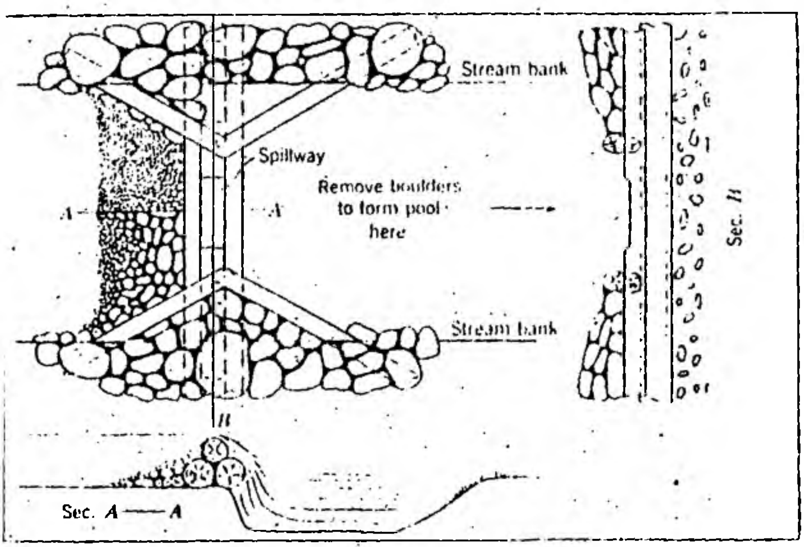


Figure 12-6. Pyramid-log dam. Courtesy of Lloyd L. Smith and John Moyle. Tech. Bull. above

basing these inferences upon observed weaknesses in the remaining structures.

At the time of the original Forest Service survey of the area, the river flow was about four to five cubic feet per second. Cassel (1935) found 44 pools in the one and one-quarter mile section where the improvement work was to be carried out. He defined a pool in this stream as ". . . any place where the three measurements taken at least two feet apart reveal minimum depths of 12 inches or over". Despite the

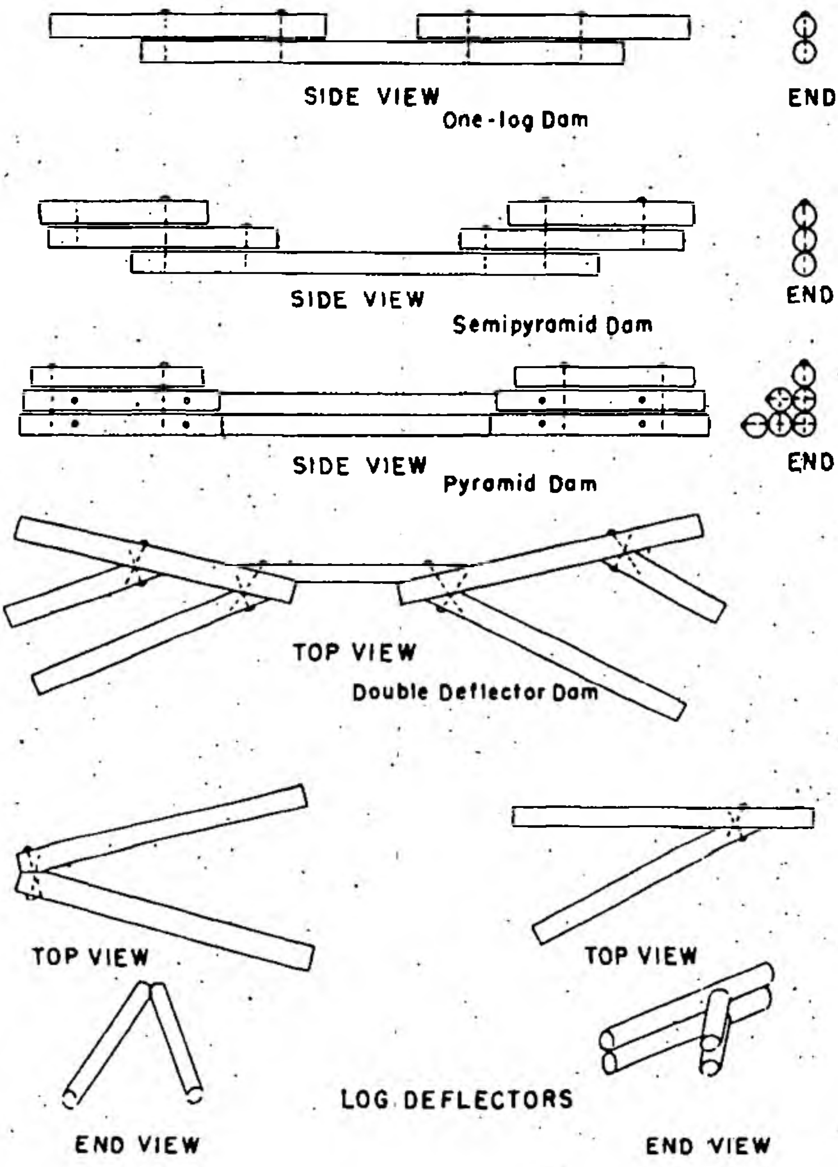


FIGURE 1. Types of log stream improvement structures employed.

large number of natural pools, he had instructions to install the check dams and, accordingly, 11 loose-rock dams (no masonry used), 15 log dams, 2 rock and log dams, 5 log deflectors, 2 earth dams, 1 wire crib dam, 1 masonry dam, 1 board dam, 1 double deflector, 1 underpass deflector, and 1 rock deflector were constructed under his supervision. The types of devices utilizing logs are shown in Figure 1.

Following the completion of the dams, Cassel observed, ". . . I have rated all 5 log deflectors as good, 10 of the dams as good, 17 structures as average, and 9 as poor. . . . . . It may be some of the structures will do more harm than good but only future surveys can reveal how and why they are harmful."

On October 26, 1936, and again on September 17, 1937, Mr. Bartholomew visited the improvement area to determine the condition of the devices and to make any needed repairs. Measurements of pool depths above and below the structures were made, and a discussion of maintenance needs and general success of the improvements was included in his reports to the United State Forest Service for the two years. Bartholomew and his crew spent about six days repairing the structures in 1936. In his 1937 report he stated, "The amount of maintenance work needed, due to the effects of high water, was approximately double the work done in October, 1936."

The number and types of devices functioning successfully during the check periods are shown in Table 1. The table reveals that the earth dams did not last even one year. Several of the rock dams were damaged severely during the winters of 1935 and 1936, but repairs were made which restored them to use. No repairs of any kind were made between 1938 and 1953.

TABLE 1

Summary of the Success of Improvement Devices

Type of structure	Number present and operating				Total present 1953†
	1935	1936	1937	1953*	
Rock dam	11	10	9	0	1
Crib dam	1	1	1	0	0
Log dam	15	15	15	6	9
Earth dam	2	0	0	0	0
Masonry dam	1	1	1	0	1
Board dam	1	1	1	0	1
Rock and log dam	2	2	2	0	0
Log deflector	5	5	5	2	5
Rock deflector	1	1	1	0	0
Double deflector	1	1	1	1	1
Underpass deflector	1	1	1	1	1
Totals	41	38	37	10	19

* Includes only those which are operating in their original locations.
† Includes nonfunctional structures also.

HISTORY OF TYPICAL STRUCTURES

Precipitation in the Sierra Nevada at the elevation of these structures occurs mainly in the form of snow. Peak flows result from occasional fall and summer thunderstorms and abnormal warm rains

Floo[illegible]ers since [illegible]ted [illegible]w channel around the structure, leaving the dam on a dry stream bed. However, even if the flow returns to this channel, it would go around the ends of the dam where fill materials have washed out.

Log Dams

Among the log dams remaining today, the following are typical examples of their relative success. The structures are numbered according to the numerical listing in Table 2, which presents data on the depth of pools formed by the dams and deflectors.

1. *Structure 14.* One-log dam with 2-foot port (Figure 6). Partially undercut in 1936; repairs were made in two hours. In 1937 a hole under the left side required additional repairs. The channel is now dry but the effectiveness of the dam was lost when the bank washed away.

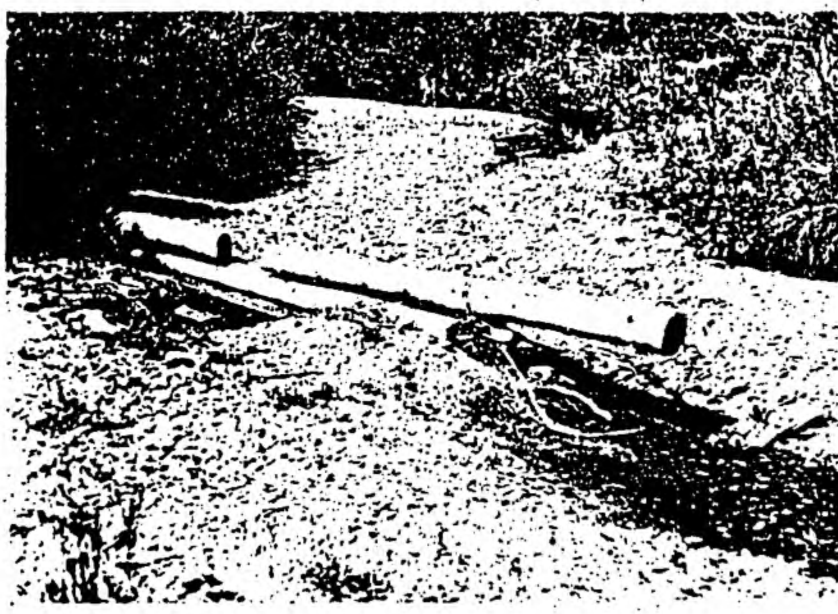


FIGURE 6. Structure 14 in 1953; a log dam, showing the results of bank erosion. This is typical one-log dam construction. *Photograph by the author.*

2. *Structure 32.* One-log dam with 6-foot port (Figure 7). Minor repairs were made in 1936 and 1937, although the dam was intact and operating very well. Good pools with good cover above and below the dam provide excellent trout habitat. This dam has proven successful, durable, and effective in creating trout pools.
3. *Structure 33.* Log underpass. Intact in 1936 but tended to catch debris. By 1937 the structure was almost filled in with gravel and repair crews converted it into a dam by adding sealing materials. Intact in 1953 but reverted to underpass type of structure. The stream seems to benefit little from this type of structure.

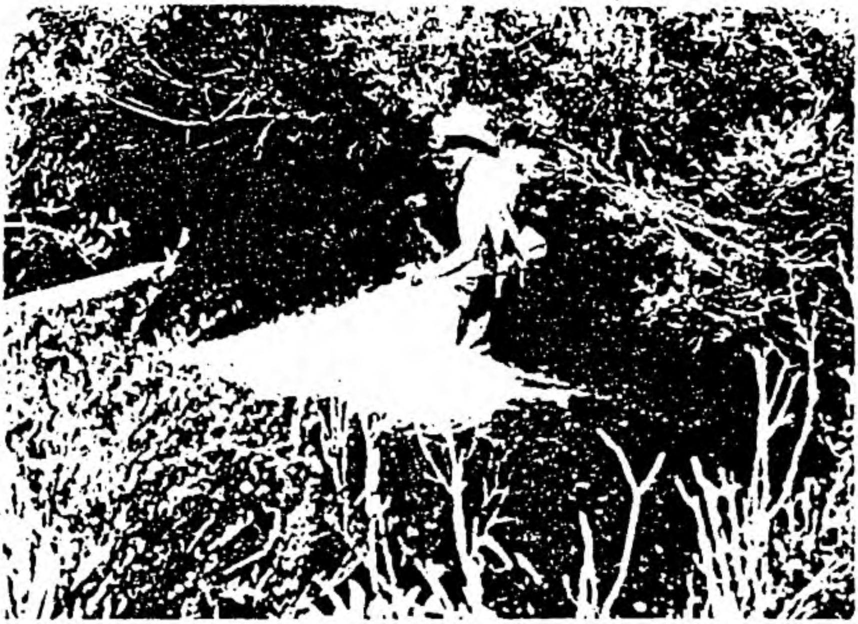


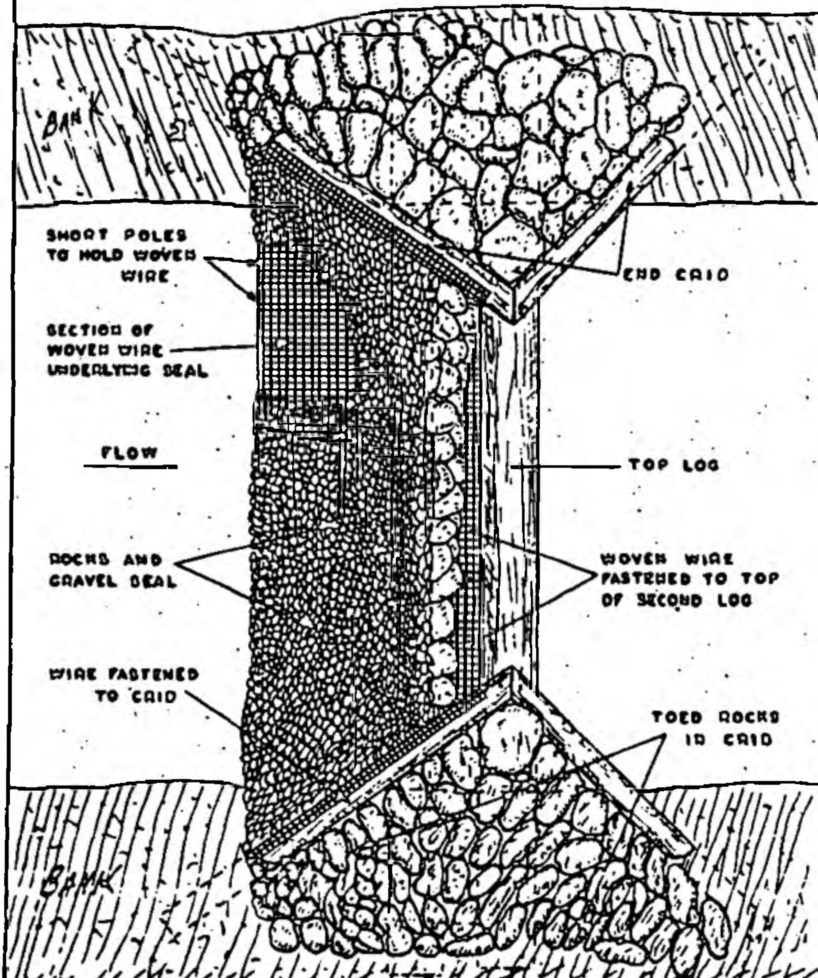
FIGURE 7. Taking depth measurements below structure 32, a log dam, still operating in August, 1953. *Photograph by the author.*

FIGURE 8. Structure 37, a log dam, on the downstream side in August, 1953. Another log dam that is still effective is visible in the background. *Photograph by the author.*

4. *Structure 37.* One-log dam with 15-foot port (Figure 8). Relatively free of damage during 1936 and 1937; this dam is now badly undercut on one end. The pool below is 18 feet long and

mountain streams of the West have a greater fall, their fluctuations of flow are usually greater and they present an entirely different improvement problem. The problems in Michigan generally consisted of the providing of pools and shelter, and the uncovering of the rubble gravel bottoms which are the chief food producing areas

SIMPLE LOG DAM WITH ROCK FILLED END CRIBS



PLAN VIEW

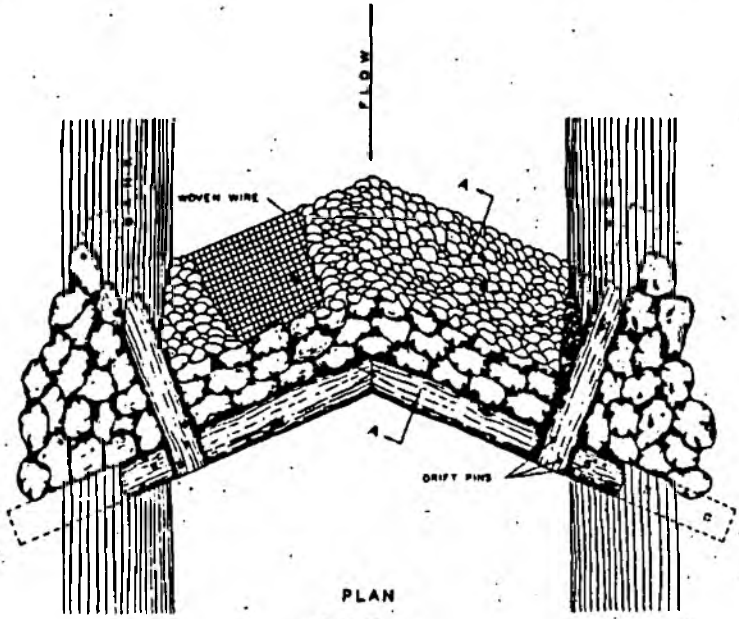
FIGURE I

(Tarzwell—1931). In the Southwest, however, the chief problems are the creation of pools and resting places and the slackening of the current so that it drops rather than sweeps away the debris and other organic materials so essential to food production in these streams. In view of these considerations it is clear why the dam is in general better suited for the improvement of southwestern streams than is the deflector. In these streams it is usually desirable to reduce the gradient and stabilize the bottom materials rather than to erode them. Dams accomplish this stabilization by stair-stepping the stream bottom through the formation of settling basins which collect and hold bottom materials moved by floods. This action usually destroys the pool created above the dam, thus the only permanent pool will be the one formed below the dam. If the dam is correctly built, that is, so built that the down stream edge projects some distance beyond the base, it will furnish cover as well as a permanent pool. Log dams built so that each log is slightly farther down stream than the one underneath it (Fig. 3) or board dams and dams having beneath their seal heavy woven wire or log sills covered with woven wire will provide cover for the pool they form on their downstream side.

It is essential to use some means for preventing the destruction of the seal of a dam due to the formation of a pool by the undercutting action of the water on the down stream side of the dam. Such destruction of the seal and the subsequent undermining of the dam can be prevented by the use of logs and heavy woven wire as shown in Fig. 3, or by the use of log sills covered with woven wire. This destruction of the seal has been the most common cause of the failure of dams in this Region.

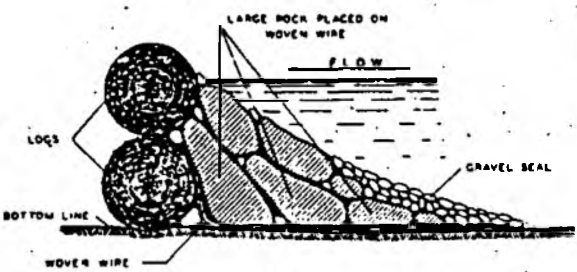
When correctly placed and built, dams have withstood severe floods and have created fine pools. It has been found necessary, however, to embed the dams deeply into the banks, to brace them on the down stream side with knee braces and to protect the banks and ends of the dams against high water by means of stone filled end cribs or stone riprapping which extends from the down stream side up and over the ends of the dam and for some distance up the banks.

Of the various types of dams used in this Region, four have been chosen as the best. The simple log dam with rock filled end cribs (Fig. 1) has proven to be permanent and quite effective, especially when the logs are placed as shown in Fig. 3. When so built this dam not only forms a pool but also furnishes cover. This cover can be made more effective by placing a small secondary dam twenty to thirty feet below the main dam so as to back the water up beneath



PLAN

FIGURE 4



SECTION-A A
(LARGER SCALE)

FIGURE 5

WEDGE DAM

cheap and effective way of providing cover and small pools. This method of improvement has the advantage of being relatively permanent and it adds to rather than detracts from the natural beauty of the stream.

Another practice which adds to the natural beauty of a stream as well as improves the habitat for fish is the fencing of stream bottoms to exclude domestic stock. This practice has greatly improved many southwestern streams as the vegetation which has become established on the stream banks has prevented bank erosion, kept the streams narrow, provided shade and cover, and increased the supply of terrestrial food.

EVALUATION OF THE RESULTS OF STREAM IMPROVEMENT

Although a good deal of stream improvement work has been done in many sections of the country during the past four years, investi-

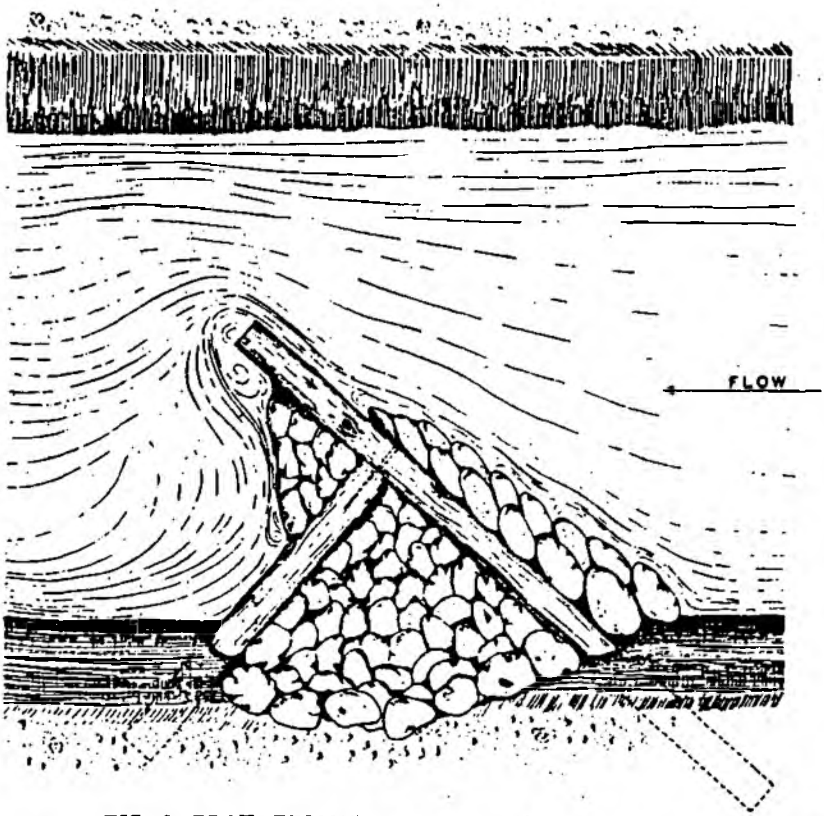


FIG. 6—PLAN, TRIANGULAR CRIB-WING DEFLECTOR

K DAM

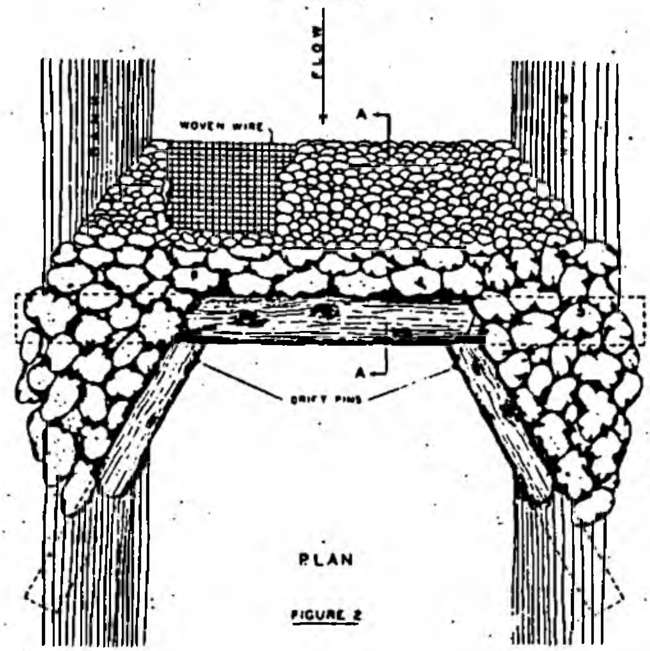


FIGURE 2

CROSS SECTION OF LOG DAM AT SPILLWAY

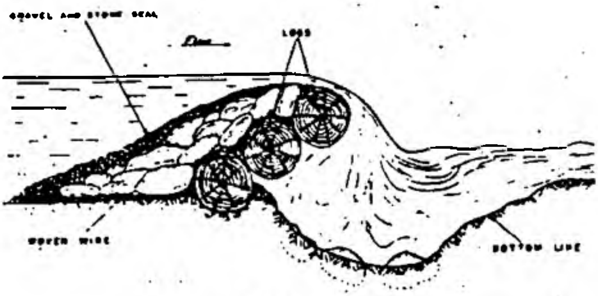


FIGURE 3

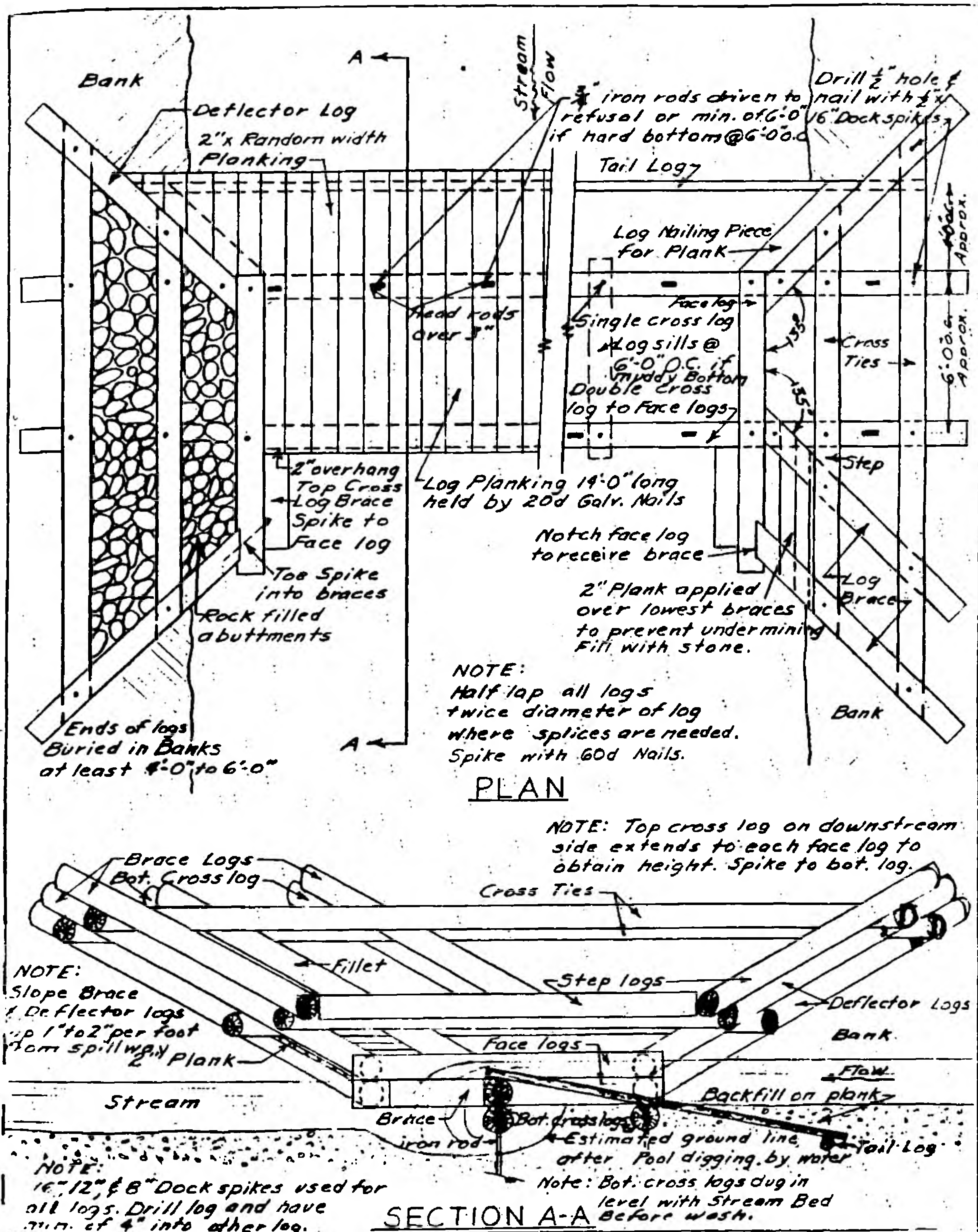
it. Where the banks are firm or floods are not severe, the end cribs can be omitted and a knee brace used as shown in Fig. 2. This type of dam is known as a K dam.

The wedge dam is quite effective and is especially suited to wide streams. While some feel that the wedge should point down stream in order to protect the banks, experience has shown that this is not necessary. If the banks are protected by a crib as shown in Fig. 4, very little erosion occurs. Also, when the wedge points up stream the dam functions better due to the action of the water and has less tendency to erode the banks than when it points down stream. When passing over an obstruction water tends to take a course perpendicular to the obstruction and thus in this instance is thrown to the center of the stream in passing over the dam and forms a better pool than when the wedge points down stream as in the latter type the flow is directed out toward the banks.

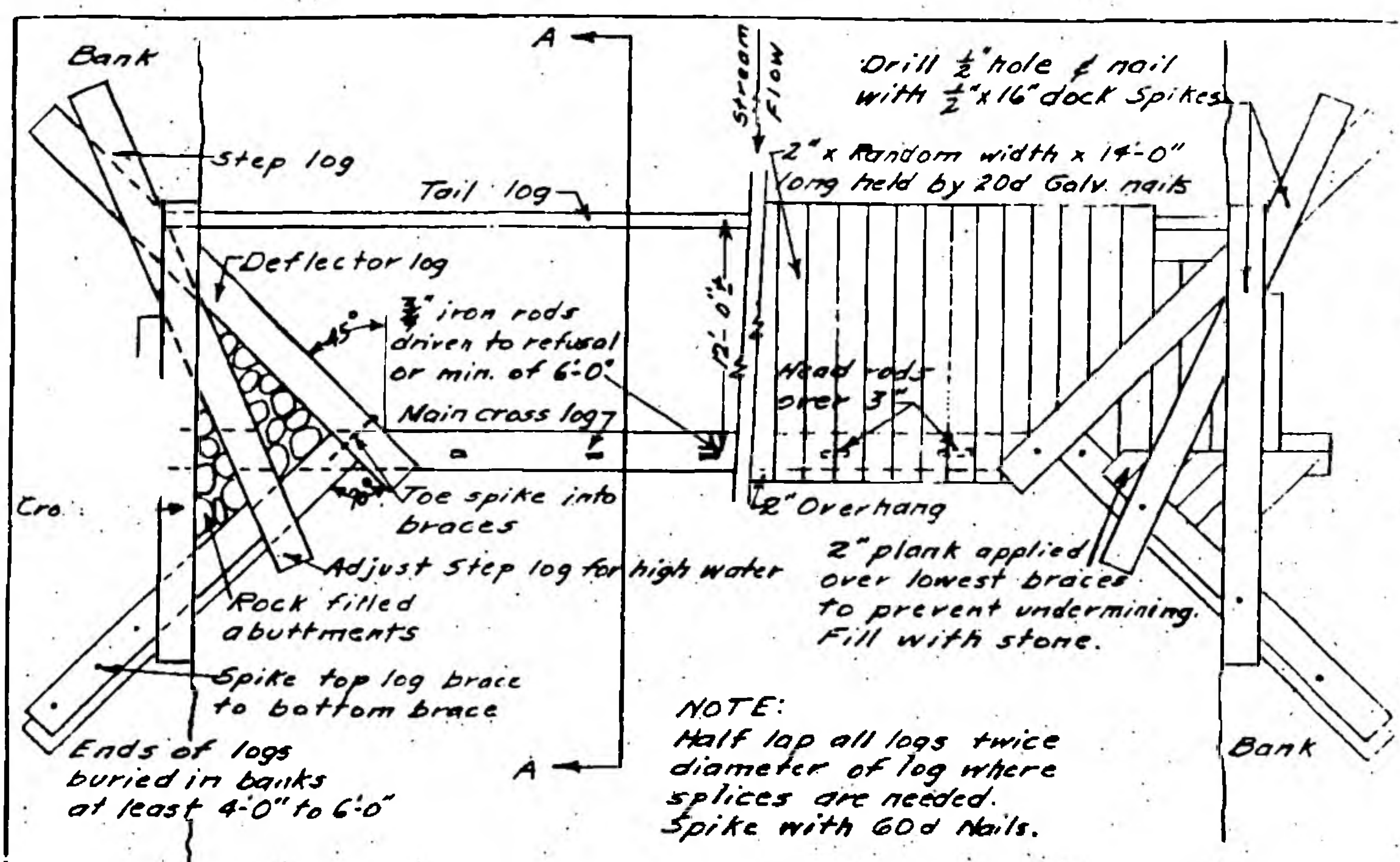
The plank or board dam has been found to be very effective and is constructed by placing a main log across the stream at the desired height and then laying planks of the desired length parallel to the flow with the up stream ends resting on the stream bottom and the down stream ends resting on the supporting log. This dam is a gravity type structure and since the planks rest on the bottom some distance up stream, undercutting and the formation of a pool on the down stream side does not destroy the seal but forms a pool under the planks which give excellent cover for trout. Knee braces on the down stream side of the supporting log and a sill under the up stream ends of the planks are desirable to give added strength to the dam. The seal is made by placing gravel and rocks on the planks.

While deflectors do not have a wide use there are certain situations in which they can be used to advantage, such as directing the current against a rocky cliff, narrowing the stream through confining the current and building up a bar below, or by forming pools in sections where there is no danger of bank erosion. Various types of deflectors have been used but the triangular crib deflector, Fig. 6, is considered the best.

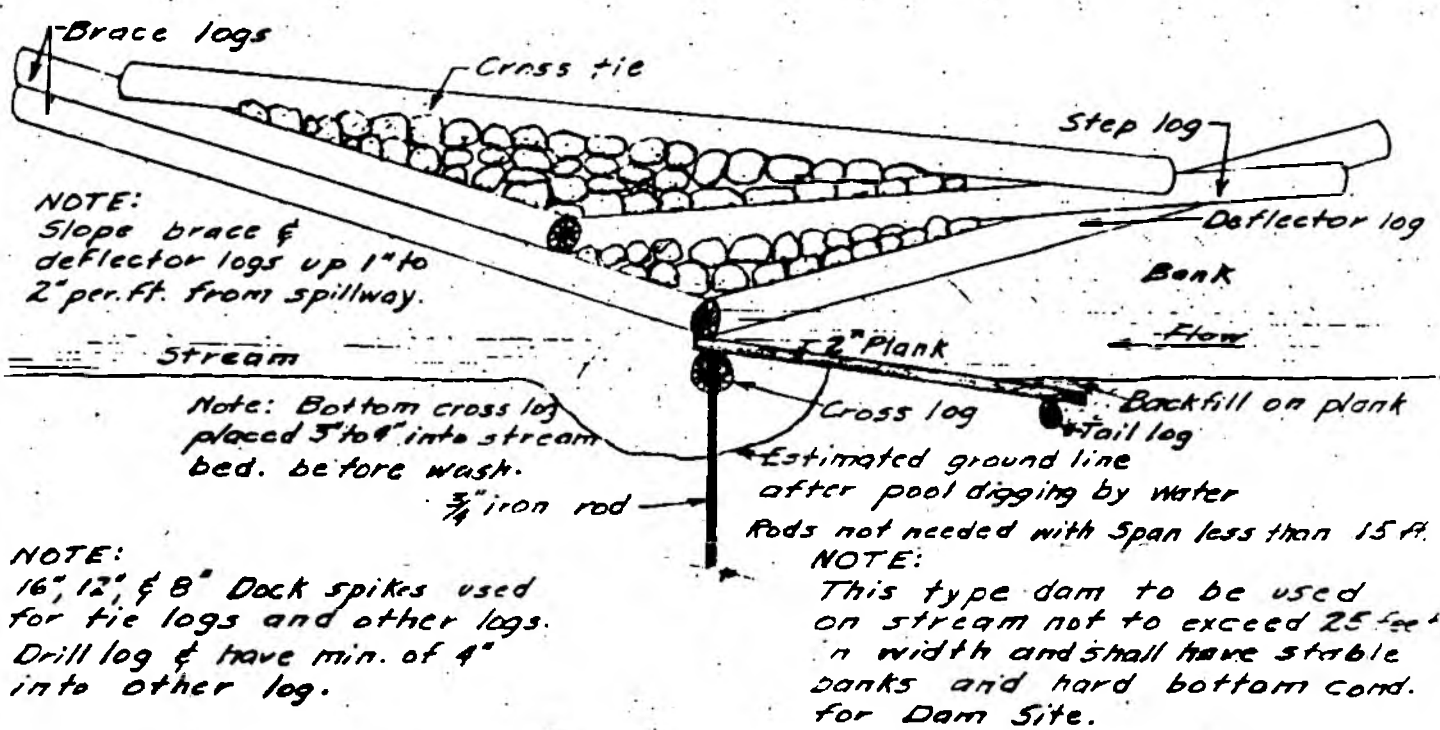
The creation of suitable cover has proven to be a difficult problem in many southwestern streams. It is difficult to hold most covers in the streams and if submerged covers are used they usually lose their effectiveness by collecting silt, sand and gravel and forming islands. One of the most effective covers is the projecting submerged bank cover shown in Fig. 7. This cover may be rectangular or triangular in shape. It has been found that the rolling of large boulders into a stream, where they are readily available, is a very



STRAIGHT LOG DAM TYPE A

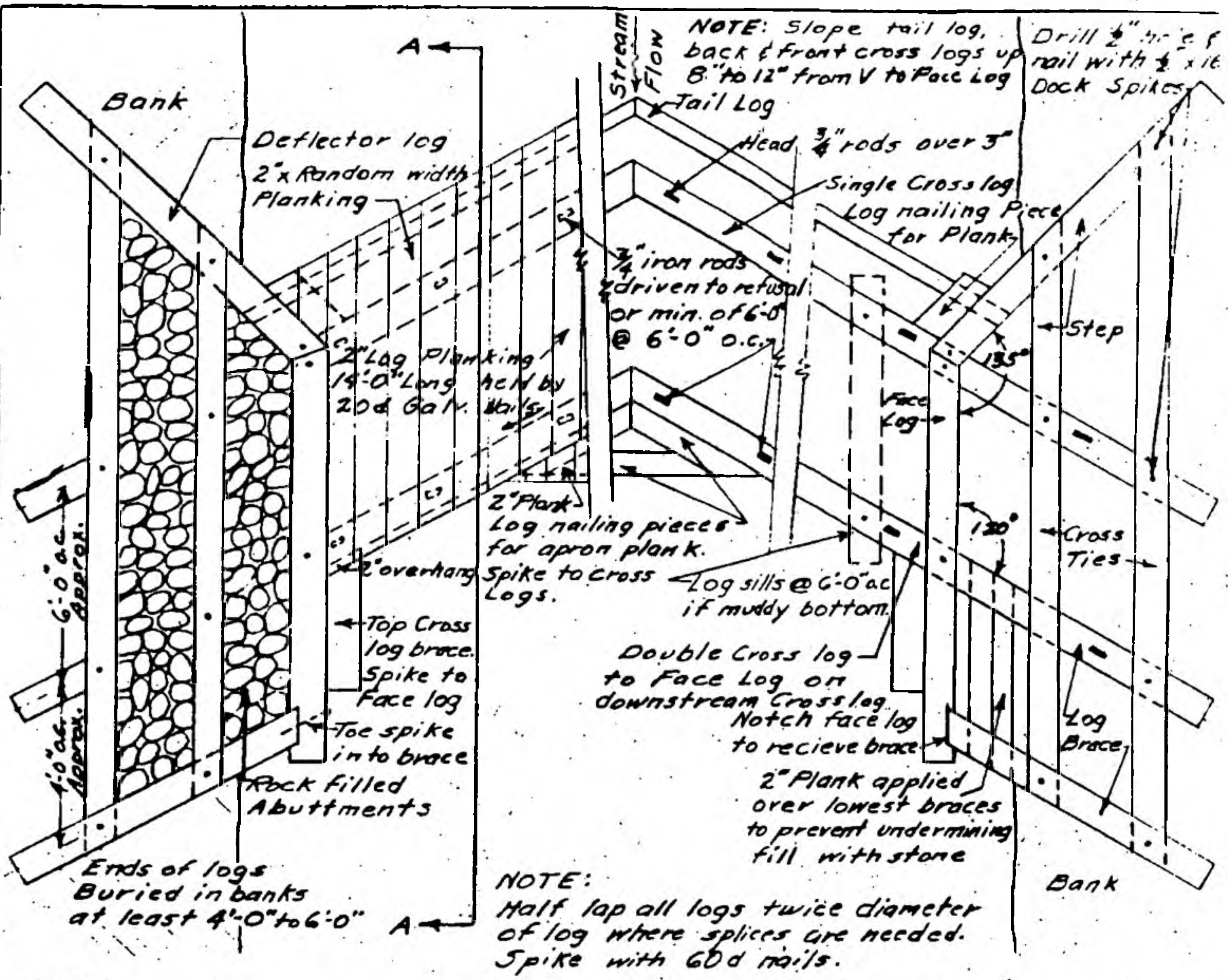


PLAN



SECTION A-A

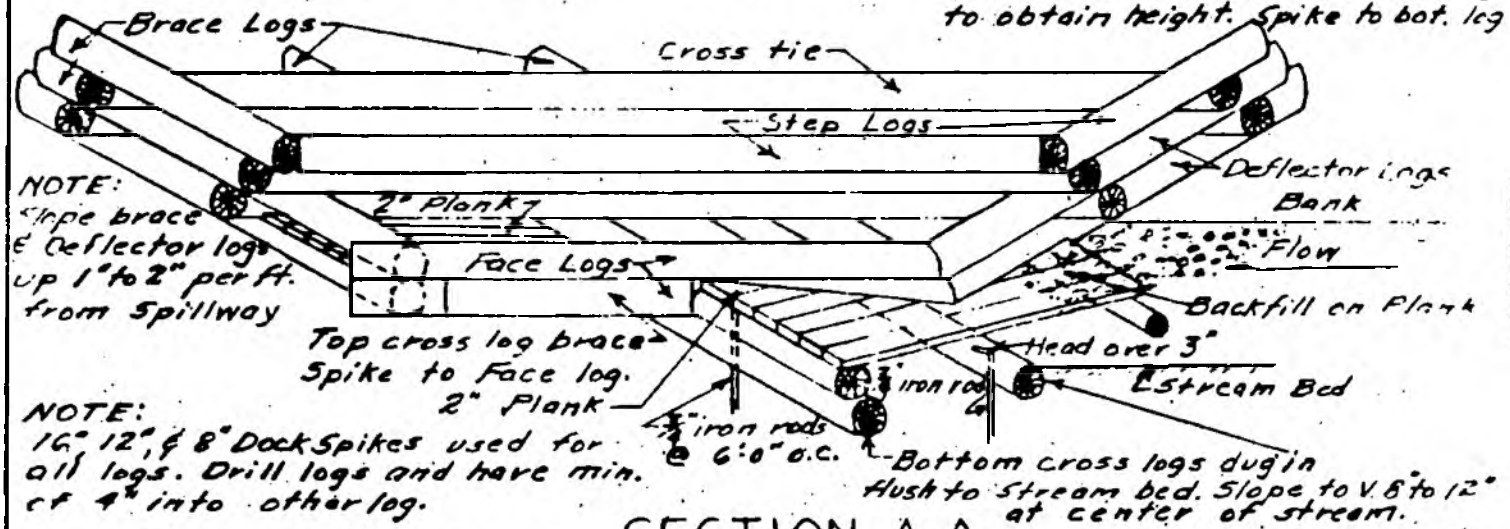
NEW YORK TYPE- STRAIGHT LOG DAM TYPE B



PLAN

NOTE:
This Type of Dam to be used on Stream not to exceed 35 ft. in width.

NOTE:
Top cross log on downstream side extends to each face log to obtain height. Spike to bot. log

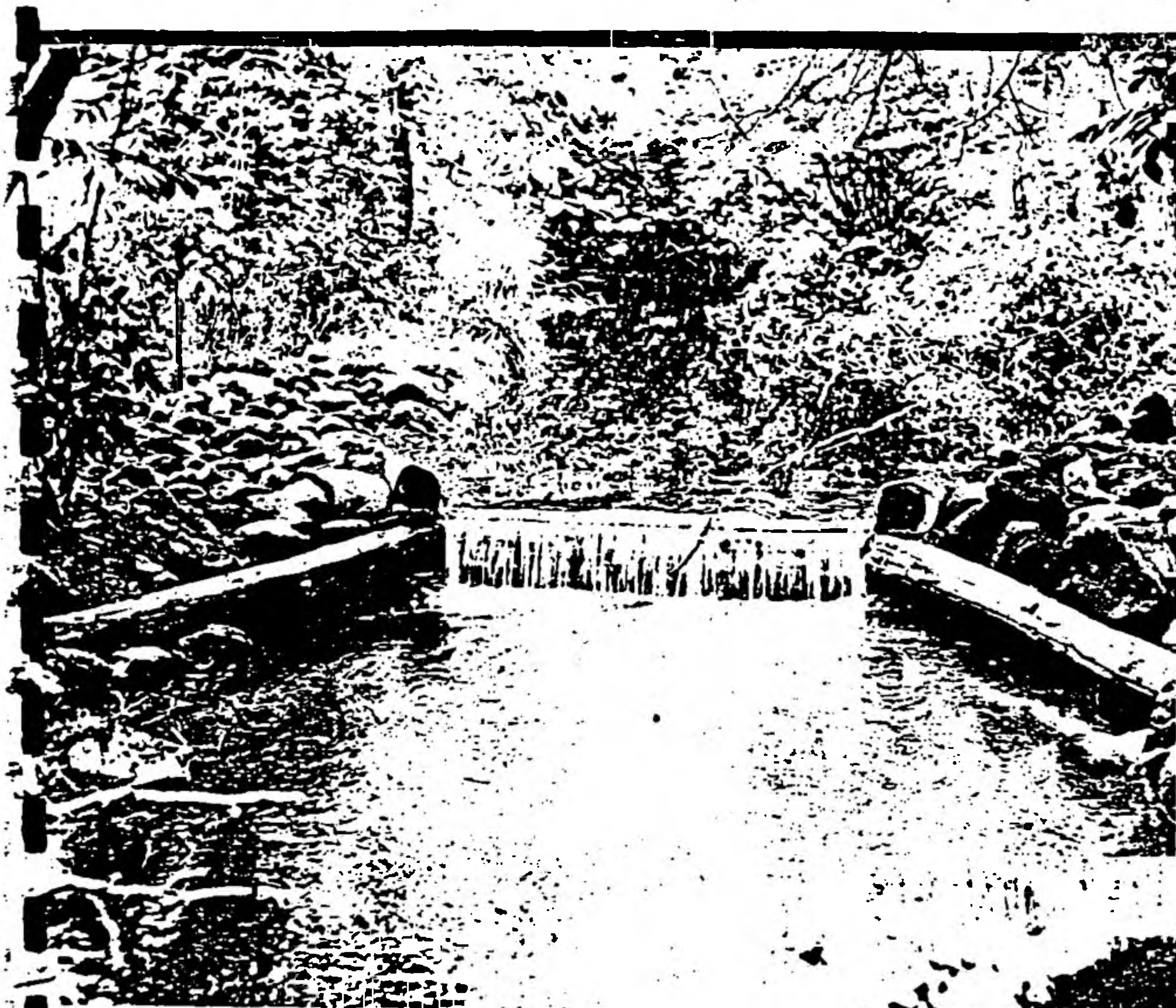


NOTE:
Slope brace & Deflector logs up 1" to 2" per ft. from Spillway

NOTE:
16", 12", & 8" Dock Spikes used for all logs. Drill logs and have min. of 4" into other log.

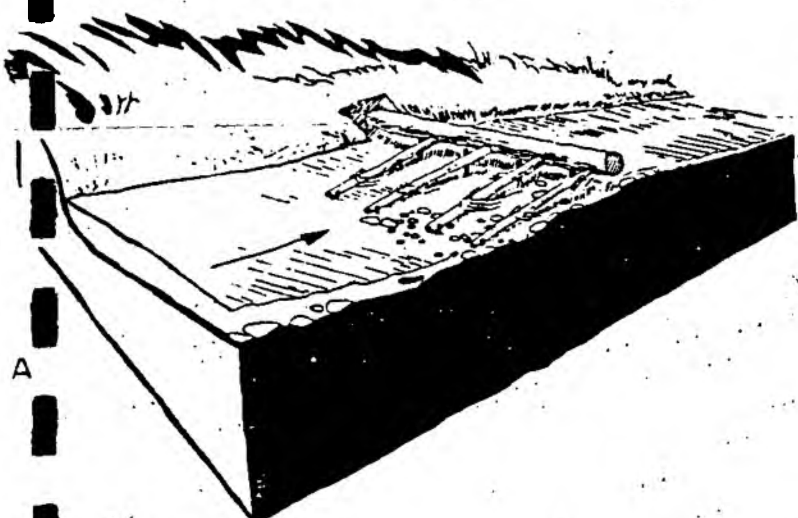
SECTION A-A

V LOG DAM

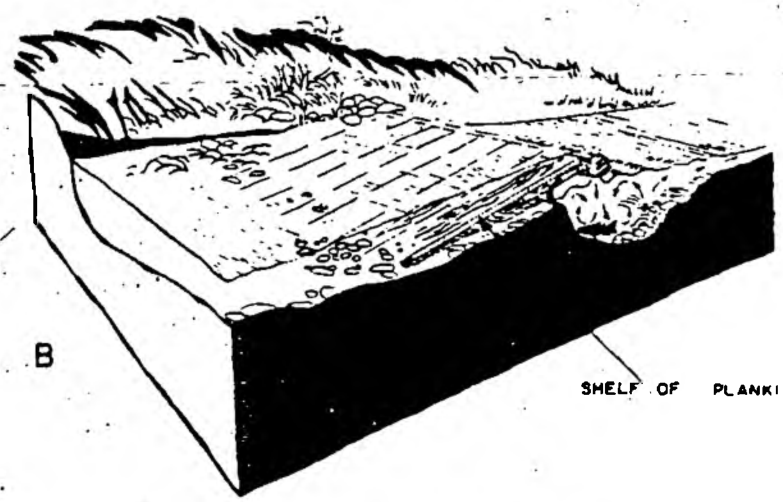


The sturdy basic construction of the Hewitt ramp is shown in the above figure. The log forming the ramp is well anchored in both stream banks by triangular footings. Excellent placement of ramp well downstream in the riffle avoids impounding the stream (right). Crest of riffle can be seen in the upper right (Photos from Minn. Dept. of Conservation).

Drawings below diagram construction of the Hewitt ramp.

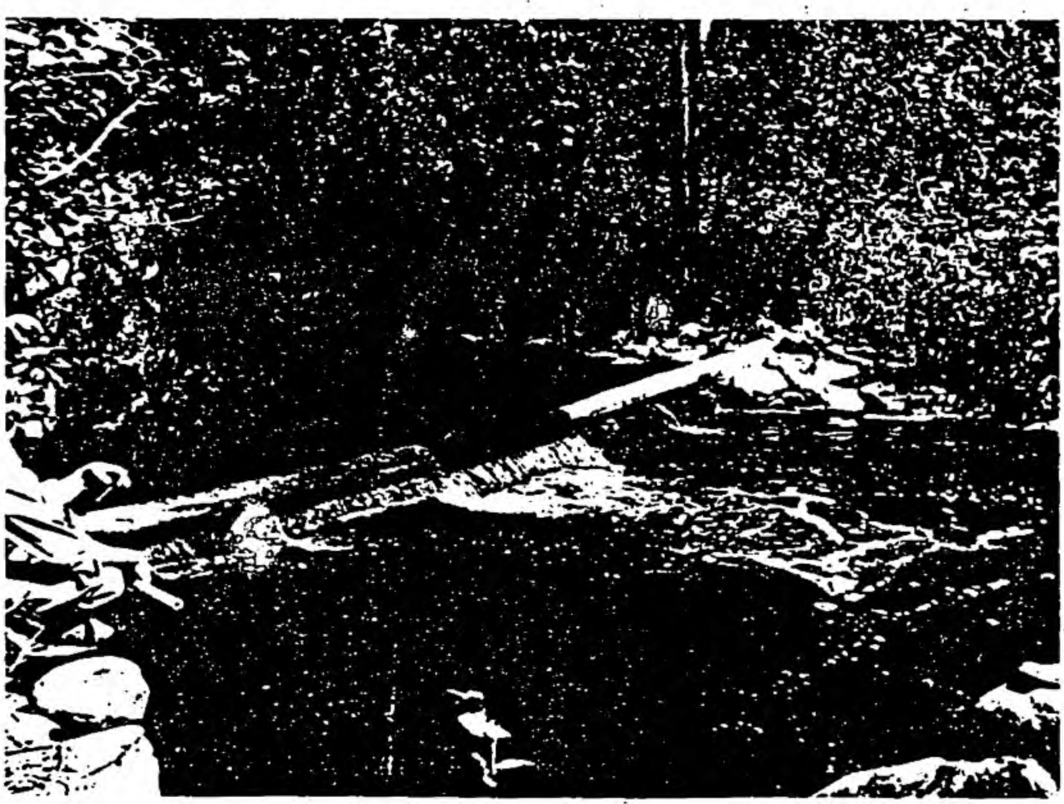


A



B

Another form of low dam which is desirable because of its natural appearance. It is made from rocks available at the stream site, and is an imitation of the natural stair-step pattern of very steep stream beds. (Minn. Dept. of Conservation)



A low, log dam — less desirable because of wooden construction.

BOARD DAMS.

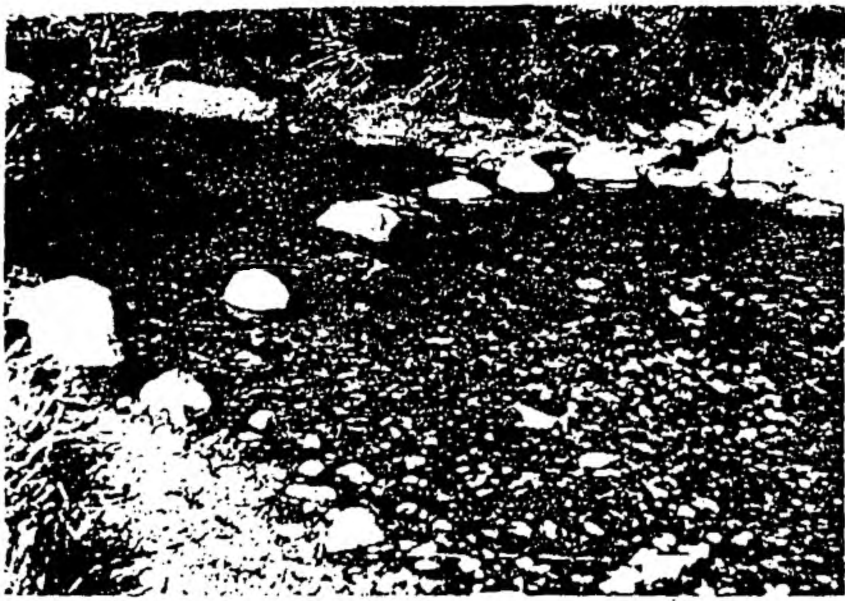


FIGURE 4. Only the key rocks of structure 30, an arched loose-rock dam, remain in position in 1953. This dam would have been effective if larger boulders had been available. *Photograph by the author.*

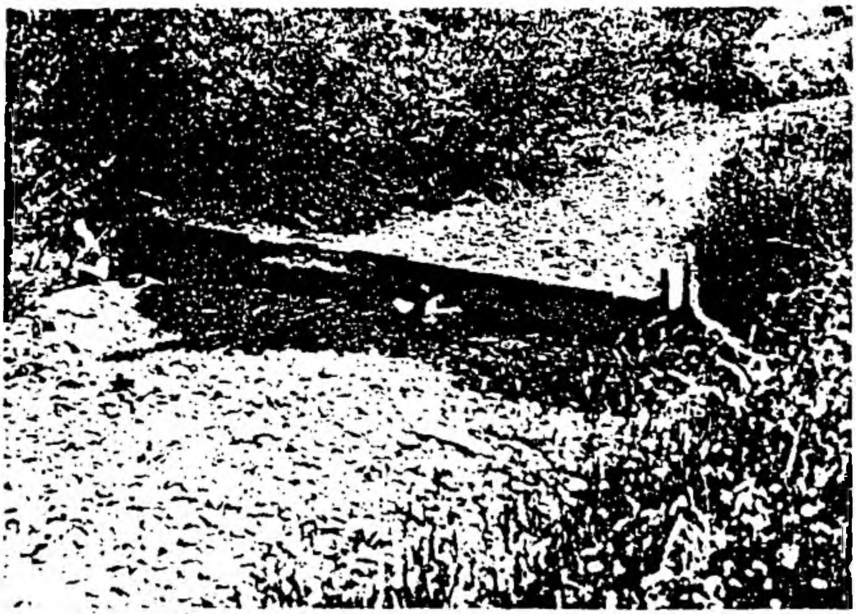


FIGURE 5. A board dam, structure 13, as it appeared in August, 1953. This channel is now dry. *Photograph by the author.*

The only board dam constructed in the area, although well built, was inoperative most of the time (Figure 5). Four and one-half crew hours were required to fill both ends in 1936 in order to prevent the dam from being left dry by endcutting. By 1937, 40 feet of one bank had washed out, requiring additional repairs. Further trouble was anticipated with the end fills.

TABLE 2

Maximum Depth of Pools Formed by Stream Improvement Devices *

Number and type of structure	Maximum depth of pool formed above the structure (inches)				Maximum depth of pool formed below the structure (inches)			
	1935	1936	1937	1953	1935	1936	1937	1953
1. Rock dam	20	17	30		15	25	27	20
2. One-log dam	25	20	33	WO	7	27	22	WO
3. Semipyramid	23	20	23	WO	8	27	28	WO
4. Masonry dam	32	21	22	20	8	31	33	38
5. Wire crib dam	32	22	27	WO	9	31	41	WO
6. Rock dam	16	18	15	WO	6	17	19	WO
7. Rock dam	27	18	WO	WO	9	21	WO	WO
8. Rock deflector	IN	IN	IN	WO	NM	NM	NM	WO
9. Rock dam	27	16	19	WO	15	22	29	WO
10. Rock dam	25	WO	WO	WO	14	24	24	WO
11. One-log dam	28	18	23	WO	18	35	40	WO
12. Semipyramid	34	34	31	FI	21	35	37	34
13. Board dam	35	32	36	Dry	17	42	41	Dry
14. One-log dam	38	38	40	Dry	20	27	30	Dry
15. Log deflector	21	NM	SP	Dry	12	NM	19	Dry
16. One-log dam	31	29	30	FI	17	22	26	26
17. Log deflector	23	NM	SP	SP	10	15	18	22
18. Log deflector	11	NM	NM	NF	7	NM	NM	NF†
19. Log deflector	9	NM	NM	NF	NM	NM	NM	NF†
20. Log pyramid	30	28	20	SP	24	29	34	34
21. Log pyramid	32	25	FI	WO	7	39	24	WO
22. One-log dam	17	15	15	NF	8	18	23	NF
23. Rock dam	18	15	15	WO	7	18	17	WO
24. None								
25. Earth dam	NM	WO			NM	WO		
26. Earth dam	NM	WO			NM	WO		
27. Rock dam	NM	WO			NM	WO		
28. Rock dam	21	13	18	WO	8	15	15	WO
29. Log pyramid	35	25	25	NF	18	31	29	NF
30. Rock dam	25	24	28	WO	7	21	25	WO
31. One-log dam	28	23	26	WO	19	21	25	WO
32. One-log dam	24	21	17	16	18	28	31	25
33. Underpass	13	NM	31		11	NM	32	13
34. One-log dam	33	37	34	WO	8	21	23	WO
35. Log deflector	31	NM	27	23	11	NM	NM	20
36. Double deflector	30	30	23	FI	15	28	34	32
37. One-log dam	29	33	35	FI	16	31	39	23
38. One-log dam	19	17	18	FI	10	26	26	23
39. Rock dam	23	22	23	WO	9	20	18	WO
40. Rock dam	20	24	21	WO	7	18	19	WO
41. Rock-log dam	NM	NM	29	WO	NM	NM	29	WO
42. Rock-log dam	NM	NM	32	WO	NM	NM	26	WO

WO = washed out.
NF = nonfunctional.
FI = filled in.
IN = intact.
NM = No measurement data available.
SP = Same pool as listed under "Maximum depth of pool formed below the structure (inches)."
* Data for 1935, 1936, and 1937 were taken from reports by Cassel (1935) and Bartholomew (1936 and 1937).
† May function during high water.

GABIONS.

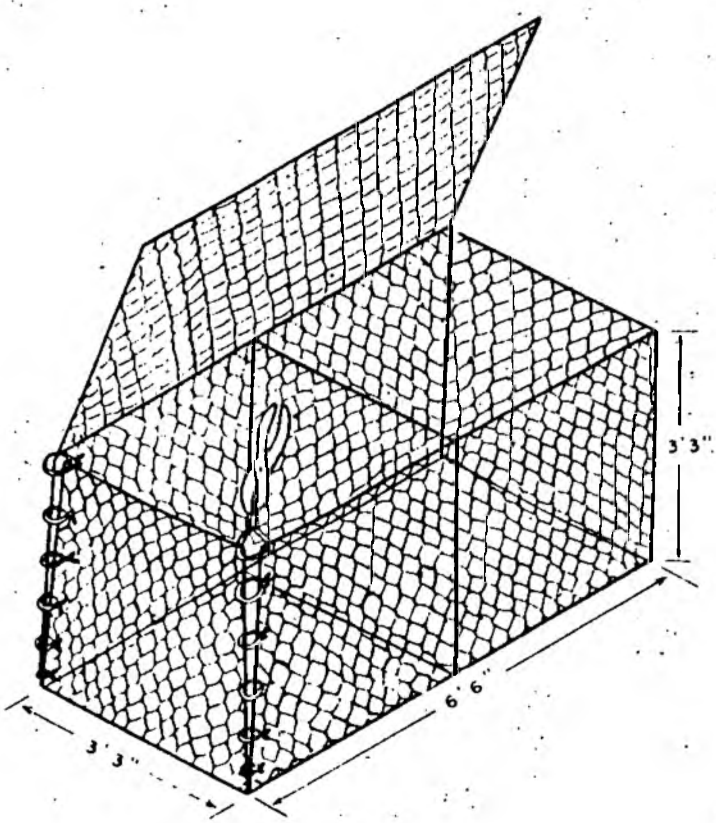


Figure 12-7 Gabion basket assembled and ready for placement and rock filling

current, they are apt to lodge in some area where they are harmful or aesthetically displeasing.

Log and boulder devices consist of a log crib inclined upstream for a meter or so, leaving a large area for shelter underneath. The boulders in the crib keep the device from floating or moving downstream with the current. Log shelters may extend from the bank to provide cover and, if covered properly with boulders, are inconspicuous. As with all habitat-improvement devices, a major concern should be the aesthetics of the area.

The idea of placing shelters in lakes has received a great deal of attention. Brush shelters may be constructed by tying bushes together and weighting them to sink. Some shelters have been more complicated, consisting of two frames with the inner frame less than 1 m square and the outer frame a little more than 1 m square. Bundles of brush are piled on the two frames, butt ends toward the center. Finished shelters are approximately 5½ m in diameter. Actually, what the shelter does in many cases is simply concentrate the fish for better availability by the angler.

The use of artificial reefs to improve sport fisheries in coastal marine waters has been developed, probably from the knowledge that fishing is good near sunken ships. The Sport Fishing Institute has provided excellent summaries on the building of reefs. The first recorded example of construction of a coastal fishing reef was in 1950 when broken-masonry building materials from New York City were deposited on the McAllister fishing grounds near Long Island, New York. Then again in 1953 a group of charter-boat captains dumped 14,000 concrete-weighted surplus wooden beer cases off Fire Island. No evaluation studies have been made of either of these reefs.

The first really substantial effort to construct artificial marine fishing reefs was in 1953 in the Gulf of Mexico by the Alabama Department of Conservation working with a charter boat club. Altogether, several thousand auto bodies were dumped in the Gulf floor off Alabama. Results were excellent. Snapper fishing became phenomenal, and there were snappers where there were none before. However, the auto bodies disintegrated in from three to five years. In Texas auto bodies were cabled together with concrete block weights in bundles of four and marked with lighted buoys. However, the bodies disintegrated in the same time as for Alabama.

California set up evaluation studies to measure relative effectiveness, durability, and costs for a reef of auto bodies, one of streetcars, and one of artificial rocks. California reports that auto body reefs were highly attractive to fish – streetcars somewhat less – but both disintegrated into a pile of rubble in only three or four years, and fish attraction was greatly reduced. The reports indicate that concrete shelters were more successful than quarry rockshelters, although quarry rock is considerably less expensive. The concrete units were modified pontoons, originally designed to support boat slips and docks. Each shelter was $1\frac{1}{2} \times 2\frac{1}{2} \times 0.8$ m with 8 to 10 38-cm-diameter holes. These 6-sided shelters cost $75 each. Including transportation, concrete shelters in units of 132, equal to 1,000 tons of quarry rock, cost between $8,000 and $8,700. Quarry rock in 2- to 3-ton chunks in 1,000-ton barge loads cost $4,800 dropped in three locations. An equivalent auto body reef would cost $3,000 but would have to be replaced in three to five years.

The Sandy Hook Laboratory of the National Marine Fisheries Service describes two tire units that can be carried offshore in any size

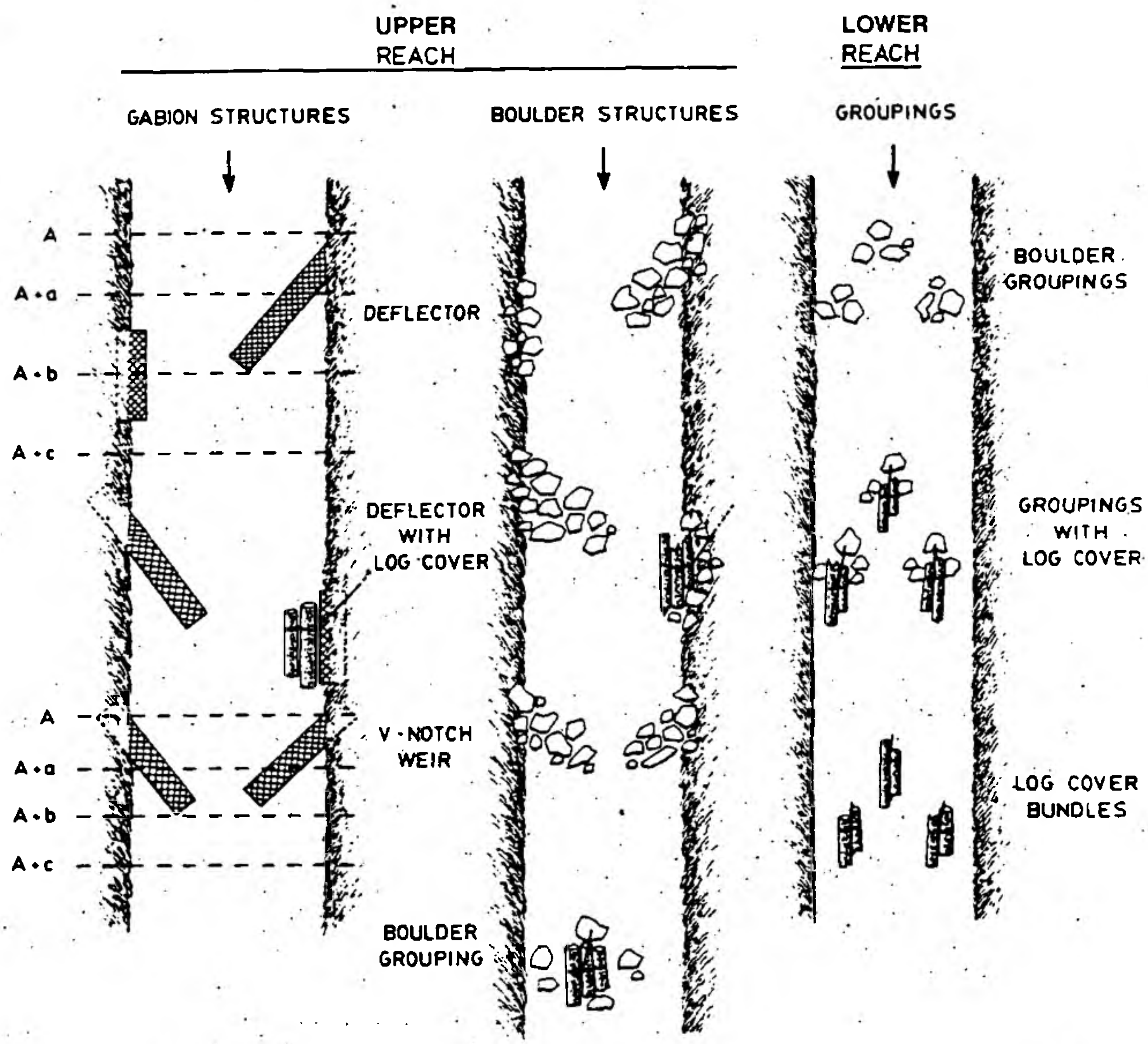


FIGURE 1. *Designs of boulder and gabion structures installed in the Keogh River (simplified).*

rearing areas for both coho and steelhead, were compared to detect natural fluctuations in salmonids before and after treatments.

Results

Hydraulic Effects in the Keogh River

Cross-sectional measurements in treatment sites in the upper reach indicated differing responses to floods. Small changes (10 cm) in depth occurred in boulder V-notch weirs and boulder groupings, but not in the other designs after the first year. Further changes in mean or maximum depth or 'wetted width' were insignificant or undetectable in the second year after placement of structures. Changes in

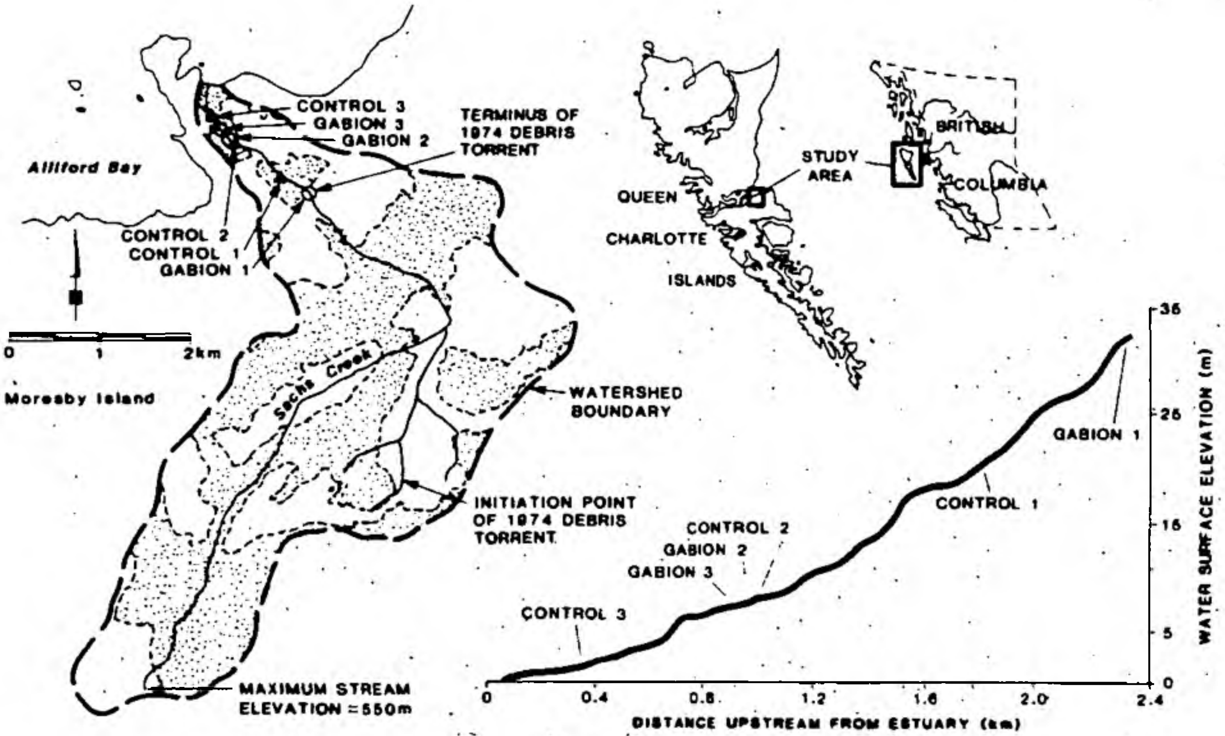


FIG. 1. Stream profile and location of study sites on Sachs Creek. ▨, unlogged areas.

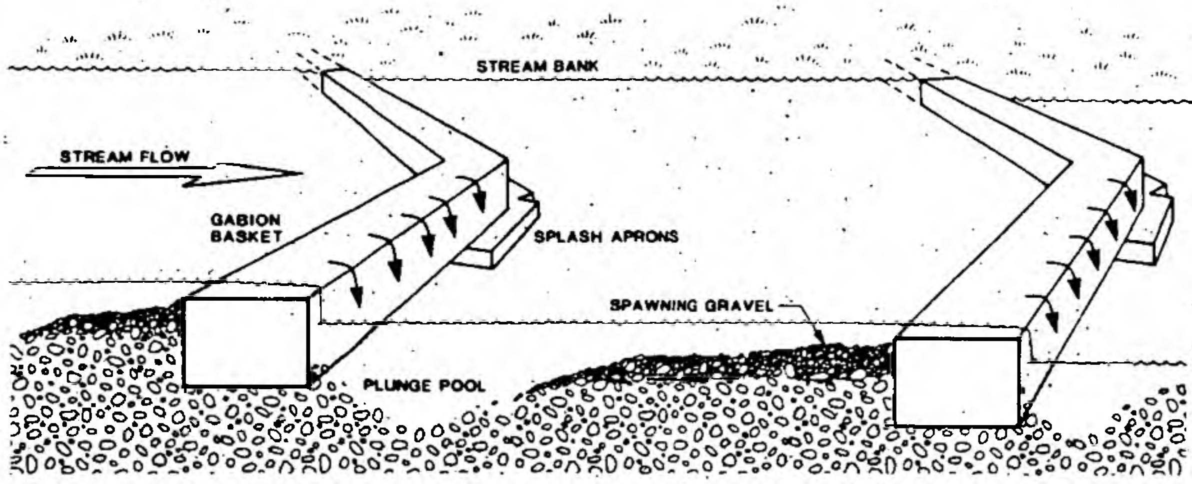


FIG. 2. Generalized view of gabion configuration.

with a mean particle size typical of salmonid spawning areas (Moreau 1981). Furthermore, the depth of gravel scour at gabions can be reduced by subsequent lowering of the peak flow shear stress at the surface of the impounded gravels (Lisle 1981). In addition to enhancing spawning habitat, gabions also have increased the pool habitat suitable for rearing juvenile coho salmon (House and Boehne 1984, 1985).

The objective of our study was to evaluate the use of gabion weirs for salmonid enhancement in a steep, rapid-runoff stream damaged by landslides in a heavily logged watershed. To meet this objective, summer rearing of juvenile salmonid populations and physical stream bed parameters influencing overwinter egg survival were examined. The study formed one component of the Fish/Forestry Interaction Program (FFIP), a multiagency-sponsored investigation into the extent, causes, and amelioration of landslide damage in forests and streams of the QCI (Poulin 1983).

Methods

Site selection

Three sites for gabion weir installation and three controls were selected in Sachs Creek on the northern end of Moresby Island, in the QCI, British Columbia (Fig. 1). Site selection was largely based on criteria recommended by Moreau (1981), with site 1 at a steeper slope (3%) than the lower sites (1%, Fig. 1). All sites were below the terminus of a severe debris torrent that occurred in 1974. Although summer low flow discharges were less than 0.1 m^3/s, Sachs Creek was "flashy," with rapid increases to greater than 65 m^3/s. About 40% of Sachs Creek's 19-km^2 watershed was logged, mainly from 1970 to 1984.

Site configuration

A gabion configuration shown to be successful in holding spawning gravels combined two tandem weirs, each V-shaped with the apices downstream (Fig. 2; Anderson and Cameron 1980; Moreau 1981). This design was installed at the three sites at Sachs Creek in August 198[illegible].

LOOSE ROCK. MASONRY AND EARTH DAMS

FIGURE 4. Only the key rocks of structure 30, an arched loose-rock dam, remain in position in 1953. This dam would have been effective if larger boulders had been available. *Photograph by the author.*

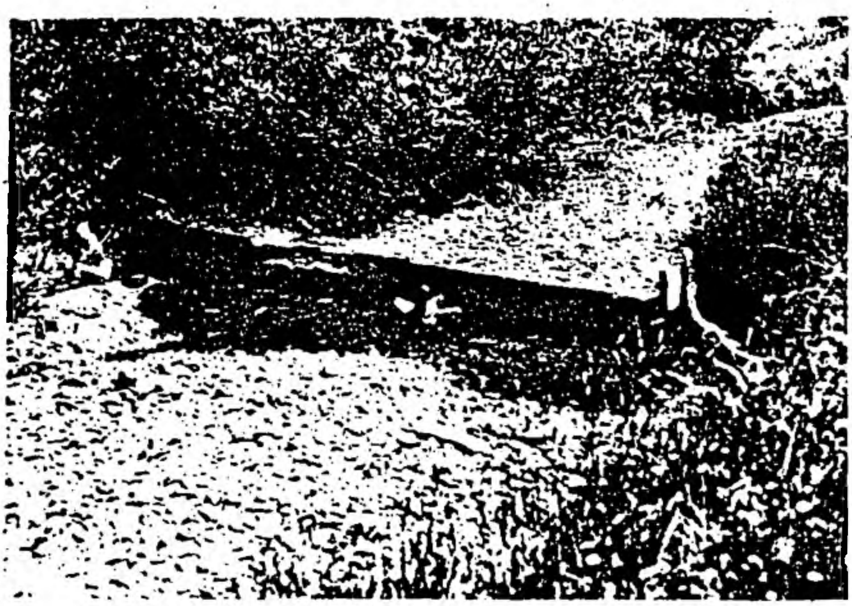


FIGURE 5. A board dam, structure 13, as it appeared in August, 1953. This channel is now dry. *Photograph by the author.*

Board Dams

The only board dam constructed in the area, although well built, was inoperative most of the time (Figure 5). Four and one-half crew hours were required to fill both ends in 1936 in order to prevent the dam from being left dry by endcutting. By 1937, 10 feet of one bank had washed out, requiring additional repairs. Further trouble was anticipated with the end fills.

TABLE 2

Maximum Depth of Pools Formed by Stream Improvement Devices *

Number and type of structure	Maximum depth of pool formed above the structure (inches)				Maximum depth of pool formed below the structure (inches)			
	1935	1936	1937	1953	1935	1936	1937	1953
1. Rock dam	20	17	30		15	25	27	20
2. One-log dam	25	20	33	WO	7	27	22	WO
3. Semipyramid	23	20	23	WO	8	27	28	WO
4. Masonry dam	32	21	22	20	8	31	33	38
5. Wire crib dam	32	22	27	WO	9	31	41	WO
6. Rock dam	16	18	15	WO	6	17	19	WO
7. Rock dam	27	18	WO	WO	9	21	WO	WO
8. Rock deflector	IN	IN	IN	WO	NM	NM	NM	WO
9. Rock dam	27	16	19	WO	15	22	29	WO
10. Rock dam	25	WO	WO	WO	14	24	24	WO
11. One-log dam	28	18	23	WO	18	35	40	WO
12. Semipyramid	34	34	31	FI	21	35	37	34
13. Board dam	35	32	36	Dry	17	42	41	Dry
14. One-log dam	38	38	40	Dry	20	27	30	Dry
15. Log deflector	21	NM	SP	Dry	12	NM	19	Dry
16. One-log dam	31	29	30	FI	17	22	26	26
17. Log deflector	23	NM	SP	SP	10	15	18	22
18. Log deflector	11	NM	NM	NF	7	NM	NM	NF†
19. Log deflector	9	NM	NM	NF	NM	NM	NM	NF†
20. Log pyramid	30	28	20	SP	24	29	34	34
21. Log pyramid	32	25	FI	WO	7	39	24	WO
22. One-log dam	17	15	15	NF	8	18	23	NF
23. Rock dam	18	15	15	WO	7	18	17	WO
24. None								
25. Earth dam	NM	WO			NM	WO		
26. Earth dam	NM	WO			NM	WO		
27. Rock dam	NM	WO			NM	WO		
28. Rock dam	21	13	18	WO	8	15	15	WO
29. Log pyramid	35	25	25	NF	18	31	29	NF
30. Rock dam	25	24	28	WO	7	21	25	WO
31. One-log dam	28	23	26	WO	18	21	25	WO
32. One-log dam	24	21	17	16	18	28	31	25
33. Underpass	13	NM	31		11	NM	32	13
34. One-log dam	33	37	34	WO	8	21	23	WO
35. Log deflector	31	NM	27	23	11	NM	NM	20
36. Double deflector	30	30	23	FI	15	28	34	32
37. One-log dam	29	33	35	FI	16	31	30	23
38. One-log dam	19	17	18	FI	10	26	26	23
39. Rock dam	23	22	23	WO	9	20	18	WO
40. Rock dam	20	24	21	WO	7	18	19	WO
41. Rock-log dam	NM	NM	29	WO	NM	NM	29	WO
42. Rock-log dam	NM	NM	32	WO	NM	NM	26	WO

WO = washed out.
NF = nonfunctional.
FI = filled in.
IN = intact.
NM = No measurement data available.
SP = Same pool as listed under "Maximum depth of pool formed below the structure (inches)."
* Data for 1935, 1936, and 1937 were taken from reports by Cassel (1935) and Bartholomew (1936 and 1937).
† May function during high water.

Fork of the Kaweah River at Mineral King reached at least 900 cubic feet per second in November, 1950. Peak flows of 2,500 c.f.s. or more probably occurred at other times during the period covered by this report.

Masonry Dams

Only one masonry dam was constructed in the section. It contained a center pass box with wings to the banks on either side.

In October, 1936, this dam was undercut for 13 feet, and the foundation masonry had cracked. Repairs were made but further damage was anticipated. By 1937, undercutting was so complete that the entire middle section had collapsed. Bartholomew (1937) stated, "While the dam is an eyesore, the pool below it is good, and may be expected to improve, since the materials at the bottom are movable. The dam will act as an underpass deflector."

As shown in Figure 2, the dam has now completely collapsed, wall sections are gone, and the pass box lies lodged upside down in midstream. The main flow drops down the left side over a few remnants of the concrete wall and into a pool 15 feet long by 38 inches deep. Willows line the shore, providing good shelter for numbers of 4- to 6-inch trout. Despite the fact that this is one of the best pools throughout the improvement area, the dam itself may be considered a failure in view of its condition, maintenance needs, and general durability. It was evident after the first year of operation that the dam would collapse without constant maintenance. For this reason, little can be said in favor of this type of structure for use in areas where movable bottom materials must be utilized as a base to support masonry.

FIGURE 2. All that now remains of the rock masonry dam (structure 4) in 1953 is the pass box and a few pieces of submerged concrete. *Photograph by the author.*

It was apparent early in 1936 that dams of this type would require constant maintenance and repair. Some 27 crew hours were spent replacing rocks, adding seal materials, and rebuilding banks for these rock dams during 1936 and 1937. Two dams were completely washed out by 1937. Another was badly damaged and, after repairing it in 1937, Bartholomew reported that it would not survive a flood. Eroding banks and loss of seal materials with resultant undercutting were the main difficulties encountered. In most instances, damage incurred in the first two years would have resulted in a complete loss if repairs had not been made.

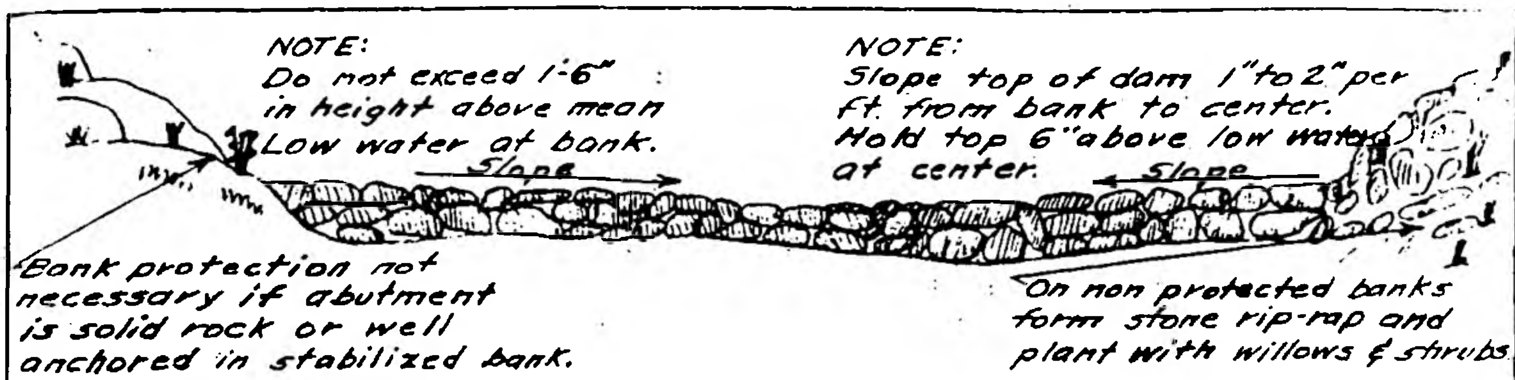
Figure 3 shows a rock dam in poor condition. Rock of this size will not withstand the peak runoffs that occur in the canyon. Where large rock is scarce, as in this area, construction of rock dams definitely should be discouraged. This type of dam is not only expensive to construct but requires costly annual maintenance.

FIGURE 3. In 1937 all that was left of structure 9 were a few medium-sized boulders. This is a good illustration of how inadequate the small rock available in the vicinity is for building loose-rock dams. *Photograph by U. S. Forest Service, 1937.*

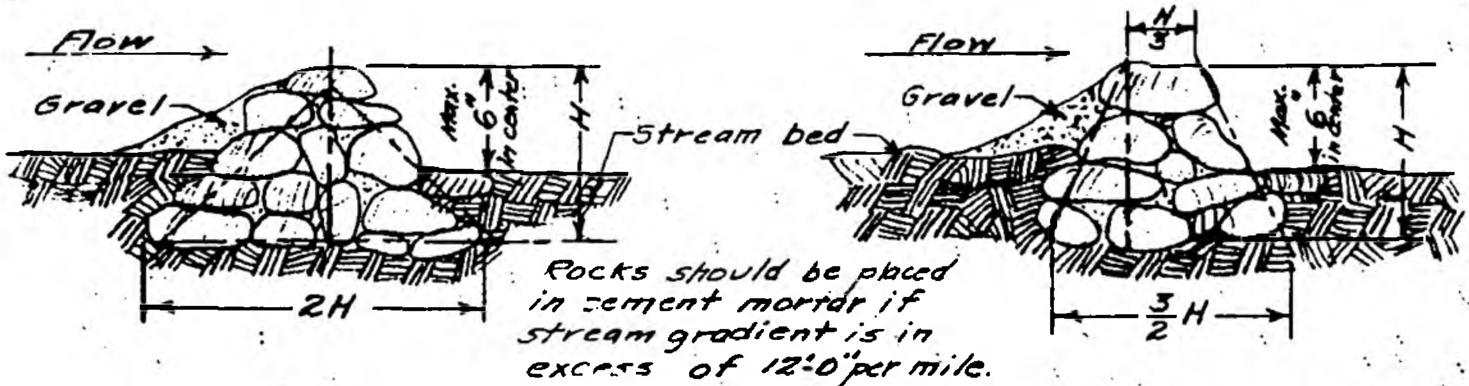
All of the rock structures (arched, straight, and deflector types) had washed out by 1953. In several cases, key rocks still remain in position (Figure 4), but for the most part no remnants remain at the original sites.

Earth Dams

Two were built in order to test their durability. Both were washed out the first year and never rebuilt.



LOOKING UPSTREAM



SECTION
For use on smooth and even stream bottom.

SECTION
For use on rough and irregular stream bottom.

VIEW

ROCK DAM AND BOULDER POOLS