STREAM CHANNEL MODIFICATIONS AND RECLAMATION STRUCTURES TO ENHANCE FISH HABITAT

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The process of channel modification has played a major, although not always beneficial, role in the development of this country. Land drainage has been necessary to convert swampland into fertile, productive farmland. Dredging of our stream bottoms has led to the discovery of precious metals and also to the creation of navigable waterways to transport our people and products. As our cities developed, it was often found that the river that provided a ready source for water supply and waste disposal was also likely to periodically carry damaging flood waters. Hence, the need arose to redesign and, in some cases, relocate these streams. Channel realignment has also been necessary in numerous instances to provide suitable bridge crossings and right-of-ways for our highway system. Overgrazing of the riparian communities bordering our rivers and streams has led to possibly more subtle but nonetheless damaging impacts. In total, Arthur D. Little (1973) estimated that by 1972, over 200,000 miles of stream channel had been modified in the United States.

Given the sheer magnitude of such river manipulations and an increasing awareness by the public of the environmental ramifications of such acts, it is little wonder that engineers and biologists find themselves continually debating the pros and cons of channel modification. Whether it is called channelization, improvement, alteration, realignment, or stabilization, there will be definite impacts to the specific stream reach involved as well as possible upstream and downstream effects. Such impacts can be positive or negative depending upon the nature of the modification and the nature of one's interest in the river reach undergoing change. Potentially, the following characteristics of a reach could be altered:

- channel morphology
- channel hydraulics
- sediment erosion and deposition processes
- water quality
- habitat for aquatic biota
- the aquatic biota itself
- aesthetics
- recreation opportunities
- riparian communities
- the biota of the riparian communities

Historically, of the characteristics listed above, consideration was typically given only to the first two, and possibly the third. This has changed dramatically however, in recent years, as the concept of river restoration has become more widespread.

Nunnally (1978) stated, regarding river restoration:

> Many of the detrimental effects of channelization can be avoided, with little compromise in channel efficiency, by employing channel design guidelines that do not destroy the hydraulic and morphologic equilibria that natural streams possess. These guidelines include minimal straightening; promoting bank stability by leaving trees, minimizing channel reshaping, and employing bank stabilization techniques; and, emulating the morphology of natural stream channels.

The underlying tenent of the river restoration approach is that by thorough planning done before modification activity begins, a design simulating that of nature as closely as possible can be developed that not only alleviates the problem causing the needed modification, but also preserves many of the other valued reach characteristics. Too often in the past, the preservation of fish habitat, for example, was given little or no consideration until after the modification was completed. Later, when population levels were found to be declining due to the loss of habitat, attempts were made to artificially increase the carrying capacity of the reach by the addition of a variety of improvement structures. This is not to say that there is no place for structures such as wing deflectors or bank covers in habitat management. Rather, the point is that if proper planning had occurred during the design process, the need for these structures may not have been so great.

From a fisheries standpoint, a most simplistic view of the channelization process and associated impacts could be illustrated by the following flow diagram:

$$\Delta \begin{matrix}\text{Land and/or}\\ \text{Stream Use}\end{matrix} \rightarrow \Delta \begin{matrix}\text{Channel}\\ \text{Morphology}\end{matrix} \rightarrow \Delta\ \text{Hydraulics} \rightarrow \Delta\ \text{Habitat} \rightarrow \Delta\ \text{Population}$$

where Δ = change in
$\rightarrow$ = leads to (5.1)

The key to the river restoration approach is for the habitat biologist to have input into the process prior to a change in channel morphology brought about by modification, rather than after the habitat and population changes have already occurred. Generally, the organization of this chapter will follow the progression shown in the above diagram. After a brief review of the basic in-stream components of fish habitat (for brevity, this will focus on the salmonid family), the impacts of various channel modification activities on habitat diversity will be discussed. The concluding section of the chapter will then concentrate on channel restoration procedures and structures to enhance fish habitat, from a planning aspect as well as from a design and installation approach.

HABITAT COMPONENTS

The four fundamental components of salmonid habitat are acceptable water quality, food-producing areas, spawning–egg incubation areas, and cover. The extent to which each of these components is present in a given stream is dependent upon the stream's physical, chemical, and hydraulic characteristics. To provide a complete habitat, no matter how large or small the stream, requires the proper range of flows *through a suitable channel configuration*, preferably one the stream itself has formed. It is in this regard that channelization activities have the potential to devastate a stream habitat, unless adequate planning and reclamation are carried out.

Following are descriptions of these fundamental habitat components. As water quality considerations are discussed in other portions of the book, these will not be included. Rather, the emphasis is placed on providing general physical/hydraulic descriptions which may be used as design criteria for reclamation structures and practices.

Food-Producing Areas

There are generally two types of habitat exhibited in streams: riffles and pools (Odum 1959). Riffles are characterized by having a greater than average velocity, a less than average depth, and substrates composed of gravel-rubble. Pools are characterized by having a less than average velocity, a greater than average depth, and substrates composed of silt–fine gravel. Of the two, riffles are the primary food-producing areas. Careful examination of the parameters velocity, substrate, and depth will explain the reasons for this.

Velocity

According to Scott (1958) and Allen (1959), velocity is the most important parameter in determining distributional patterns of aquatic invertebrates. These invertebrates (benthos) live in a vertically constricted boundary layer (Pradtl's layer) between the water mass and the stream substrate (Giger 1973). At this level, water velocities would be at or near zero since velocity varies approximately as a parabola from zero at the bottom to a maximum at or near the surface (Linsley et al. 1975). Ambuhl (1959) stated that current velocity becomes important to the benthic invertebrate by governing the rate of oxygen renewal to the boundary layer. Logically, the faster the water current, the faster and more efficient the renewal rate. In fact, Ericksen (1966) felt that water velocity was perhaps of greater significance to respiration than the actual dissolved oxygen content of the water. Ambuhl (1959) showed the importance of velocity by showing that some species of invertebrate die quickly in oxygen-rich still water while living in oxygen-poor running water. Apparently, many of the swift-water invertebrates lack the morphological features and mechanisms which are present on many still-water forms for creating their own currents for respiration. Organisms in rapids communities do exhibit adaptation for maintaining position in swift water. Odum (1959) lists some of the more important adaptations: (1) permanent attachment to the substrate; (2) hooks and suckers; (3) sticky undersurfaces; (4) streamlined bodies; (5) flattened bodies; (6) positive rheotaxis (orient upstream); and (7) positive thigmotaxis (response to touch).

According to Ruttner (1953), the influence of water current is manifested in the quantity of organisms produced per unit area. Increased water velocities increase the exchange rate between the organism and its water supply, thereby promoting respiration and food acquisition (Giger 1973). Eriksen (1966) felt the importance of water current lies in its ability to renew the respiratory environment of forms that do not have the capability to do so for themselves.

Studies have been conducted that relate water velocity to numbers of organisms. Kennedy (1967) found the greatest numbers of organisms associated with velocities of 0.3–0.4 mps, with few invertebrates present in lower velocities. Needham and Usinger (1956) found the highest numbers of Ephemeroptera (mayflies) associated with velocities of 0.4–0.8 mps and Trichoptera (caddisflies) and Diptera (flies) with velocities of about 0.9 mps. Kimble and Wesche (1975), working on a small stream in southeastern Wyoming, determined that mayflies, caddisflies, and Plecoptera (stoneflies) exhibit preferences for mean water velocities greater than 0.15 mps. Based on limited studies in California, Hooper (1973) considered velocities of 0.5–1.1 mps as optimum for food production. Delisle and Eliason (1961) designated food-producing areas as those where current velocities near the bottom ranged from 0.15–0.9 mps. Giger (1973) felt that 0.15 mps was too marginal for food production and defined an ideal range of 0.3–0.6 mps. Regardless of the specific range of velocities, each of these studies points to the fact that food production is greater in riffles than in pools.

Substrate

Substrate size is directly related to water velocity, with larger materials (rubble, boulder) associated with faster currents, and smaller materials (silt, sand) associated with slower currents. The size of the material has been related by numerous investigators to the standing crops of benthic invertebrates. According to Pennak and Van Gerpen (1947) benthic invertebrates decrease in number in the series rubble, bedrock, gravel, sand. Kimble and Wesche (1975) reported a similar decrease in the series rubble, coarse gravel, sand and fine gravel, silt. Sprules (1947) noted that insect emergence decreased over substrates composed of rubble, gravel, muck, and sand. Sprules reported that in general, the diversity of available cover for bottom fauna appears to decrease as the size of inert substrate particles decreases. The majority of research conducted on substrate types has singled out rubble as the most productive. This larger substrate provides the insects with a firm surface to cling to and also provides some protection from the force of the current. These concepts of protection and attachment have been investigated by Ambuhl (1959), Sprules (1947), and Egglishaw (1964).

Depth

According to Kamler and Riedel (1960), water depth influences which habitat benthic organisms prefer. However, the exact influence of depth on food production remains largely unknown. Needham (1934) stated that depth influences the photosynthetic production of invertebrate food by regulating the light intensity. The deeper the water, the less the light penetration, the less the photosynthetic production of food, resulting in a decrease in invertebrate numbers. In their study of Prosser Creek in California, Needham and Usinger (1956) found the majority of organisms in relatively shallow, flat areas, with mayflies and caddisflies in depths of less than one foot. Kennedy (1967) reported the greatest numbers of organisms in depths of 0.08–0.15 m, with decreasing numbers at greater depths. The study by Kimble and Wesche (1975) indicated depth preferences of less than 0.3 m for mayflies, stoneflies, and caddisflies. In general, areas of highest productivity usually occur in trout streams at depths between 0.15 and 0.9 m, provided substrates and velocities are suitable (Hooper 1973).

Other factors thought to influence food production include stream size, light intensity, and stream gradient. However, the governing influence on a stream's invertebrate production is found in the parameters of velocity, substrate size, and depth. These parameters combine in the riffle sections of streams to provide optimal conditions for the majority of invertebrate species. Riffles are thus much more productive than pool areas.

Drift

Velocity and aquatic insects are also closely related in another way, that being in the delivery of food to the fish by the mechanism called *drift,* the movement of the organism downstream by the current. There has been much speculation as to the reasons for drift, some individuals feeling that it is a passive phenomenon while others feel it is an active, voluntary process.

Many investigators (Chapman 1966; Elliot 1967; Mundie 1969; Waters 1969; Everest and Chapman 1972; Good 1974) have shown a positive correlation between water velocity and the quantity of drift. Good (1974), in his studies of runoff on Nash Fork Creek in Wyoming, reported that drift rates increased with discharge through June 22–24, whereafter they decreased to lower levels. According to Waters (1969), water velocity is the major factor influencing the amount of drift, with increasing velocities increasing the drift up to the point of catastrophic conditions.

Other studies have shown increased drift at night (Chapman 1966; Elliott 1967; Chapman and Bjornn 1969; Dill 1969; Everest and Chapman 1972; Good 1974). This is largely explained by the fact that most benthic invertebrates are negatively phototactic, hiding during the daylight and becoming more active during the night. The invertebrates are thus more likely to enter the drift during this period of greater activity, for it is at this time that they become exposed to the current.

Reimers (1957) and Dimond (1967) both found evidence that drift was density related. Dimond found a definite relationship between the number of organisms in the drift and the increased bottom standing crop. This indicated that as the bottom became more crowded, the rate of drift increased. Bovee (1974) offered several interactions which may be involved in this phenomenon: (1) competition for food in dense populations could lead to more searching behavior by the animals, which makes them more susceptible to dislodgement; (2) territorial behavior might be practiced and individuals without territories comprise the drift; (3) high population densities might cause animals to spread into marginal habitats which are prematurely vacated. This last interaction suggests that invertebrates may voluntarily enter the drift to remove themselves from a crowded area. Elliott (1967) and Waters (1969) reported increased drift by certain species of mayfly during very low levels of water velocity. It is thought that this apparent voluntary entrance into the drift is made by the organism to create currents for respiration and is associated with drought conditions. Waters (1969) suggests that this type of drift may also redistribute the organisms to sites of more rapid current.

Regardless of whether the phenomenon of drift is voluntary or catastrophic in nature, the supply of drift available to salmonids has been found to be greater in areas of faster current velocity. Thus, if more food is available, it can be theorized that a fish will require less time and space to obtain his food, his territory size can be reduced, and population densities in a given area can be increased.

Spawning–Egg Incubation Areas

Spawning

Spawning habitat has been defined by numerous individuals (Thompson 1972; Hooper 1973; Hunter 1973; Smith 1973; Sams and Pearson 1963; Reiser and Wesche 1977) who have measured the hydraulic and physical parameters existing in the stream sections utilized by actively spawning fish. Parameters considered include water velocity, water depth, and substrate size. Generally, acceptable spawning areas exhibit water velocities between 0.15–0.9 mps, water depths of 0.15 m or greater, and substrate sizes between 0.6–7.6 cm. To a large degree, fish size will determine if an area is acceptable for spawning, with larger fish being able to dislodge larger substrate and endure swifter currents than smaller fish. According to Hunter (1973), interspecies spawning preferences for salmonids of the same size will be closer than intraspecies requirements for fish of varying size.

Incubation

The successful development of the incubating eggs is dependent upon certain chemical, hydraulic, and physical parameters.

Chemical. The most important chemical parameter relative to incubation is dissolved oxygen. The development of salmonid eggs is directly related to dissolved oxygen, with ever-increasing demands for it as the eggs develop, and a maximum requirement just prior to hatching (Hayes et al. 1951; McNeil, 1964). Recommended incubation flows for the Snake River in Hells Canyon were based on having at least 5.0 mg/l intragravel dissolved oxygen for the spawning salmonids (Thompson 1974). Hatchery operations are best carried out in water having a dissolved oxygen concentration of 7.0 mg/l (Bardach et al. 1972).

Hydraulic. Hydraulic parameters important in comprising a good incubation environment include the percolation rate of water through the spawning gravels, a pool-riffle sequence, and to a large degree, ground water seepage.

Because the percolation of water brings the necessary oxygen to the incubating eggs and removes the metabolic waste materials, the percolation rate influences the length of the incubation period and the relative sizes of new fry (Shumway et al. 1964). This, of course, is dependent on the dissolved oxygen concentration. In two redds with different percolation rates but with the same concentration of dissolved oxygen, conditions for embryonic development may be better in the area with the higher exchange rate of water (Coble, 1961).

A pool-riffle sequence in streams is important in providing cover, resting, and food-producing areas. The interchange area between a pool and riffle provides an excellent spawning environment, with velocities great enough to carry away silt and debris that may clog the redd substrate. In addition, the stream bottom at the lower end of a pool gradually assumes a convex appearance as the riffle area approaches, causing a downwelling of the current into the substrate. The convex nature of the tailspill also causes downwelling of water into the egg nest. Vaux (1962) has shown that both increased permeability and a convex streambed induce downwelling while a concave streambed causes upwelling. This movement of water into the gravel provides a constant supply of oxygen to the eggs and effectively removes metabolic waste materials. In addition, Stuart (1953) has suggested that this downward current may assist the female on the spawning grounds in maintaining her position against the force of the current.

Numerous investigators (Kendall 1929; White 1930; Greeley 1932; Hazzard 1932; Webster and Eiriksdotter 1976; and others) have shown that brown (*Salmo trutta*) and particularly brook trout (*Salvelinus fontinalis*) select spawning sites in areas with ground water seepage. This may also be true of other salmonids. Benson (1953) found a direct relationship between the amount of ground water, size of trout populations, and number of redds. It was thought that ground water would provide a constant flow over the eggs ensuring sufficient dissolved oxygen for development. Also, as ground water temperatures are often warmer than surface waters in the winter, the eggs are protected from freezing conditions and hatching time is reduced. Latta (1969) felt that in years of high ground water levels there is a greater survival of eggs and fry than in years with low levels. Hansen (1975) has shown that brown trout spawn in areas with and without ground water inflow in about equal numbers. Where ground water inflow was present, the brown trout preferred areas of intermediate surface-ground-water mix and avoided areas where strictly ground water flowed. The warmer ground water is able to hold less dissolved oxygen than the surface water and at the same time may cause an increased demand for oxygen by the developing embryo. Hansen (1975) suggested that the major benefit of ground water may be the wide range of hatching dates which ensures the survival and recruitment of new fish.

Physical. Primary physical parameters important in incubation include water temperature and permeability of the substrate.

To a large degree, the rate of egg development is dependent upon water temperatures, with the higher the temperature (to a point), the faster the egg development. For example, brown trout eggs will take 156 days to hatch at a temperature of 1.6°C but only 41 days at 10°C (Leitritz 1969).

The permeability of the substrate surrounding the eggs determines to an extent the percolation rate of water through the redd. This is important in two respects: (1) dissolved oxygen is brought to the developing eggs via the percolating water; and (2) metabolic wastes are removed from the developing eggs via the percolating water. According to McNeil and Ahnell (1964), the permeability of the material is dependent on: (a) density and viscosity of water; (b) porosity of stream bed; and (c) size, shape, and arrangement of solids. Permeability is considered high by McNeil and Ahnell (1964) when the bottom materials contain less than 5% by volume of sands and silts passing through a 0.833 mm sieve, and is low when the materials contain greater than 15%. The nest construction activity of the female, in effect, cleans the substrate of the very fine materials and results in gravel with a high permeability. However, certain land use practices such as timbering, road construction, and overgrazing can result in increased sediment loads being deposited in the interstices of the spawning gravels, reducing the permeability of the substrate and percolation of water to the developing eggs. This, of course, may result in an increase in egg mortality.

Thus, successful reproduction of salmonids depends on the presence in a stream of sufficient areas suitable for spawning that possess environments conducive to egg incubation.

Cover

Cover can be defined as those in-stream areas providing the fish protection from the effects of high current velocities and predation. Cover for fish in streams can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects (stumps, logs, roots, rocks), floating debris, and water turbulence (Giger 1973). The extent to which each of these forms is used is dependent upon species preference, and of course upon its availability in the stream. As was noted by Giger (1973), the cover requirements of mixed populations of salmonids are not easily determined. Shelter needs may vary diurnally (Kalleberg 1958; Allen 1969; Chapman and Bjornn 1969); by fish species (Hartman 1965; Ruggles 1966; Allen 1969; Chapman and Bjornn 1969; Lewis 1969; Pearson et al. 1970; Wesche 1973); and by fish size (Butler and Hawthorne 1968; Allen 1969; Chapman and Bjornn 1969; Wesche 1973, 1974, and 1980).

Overhead cover may consist of overhanging vegetation (trees, grasses, etc.), logs, or undercut banks. Many investigators (Newman 1956; Wickham 1967; Butler and Hawthorne 1968; Baldes and Vincent 1969; Chapman and Bjornn 1969; Lewis 1969) have shown that overhead cover is used by many species of salmonids, brown trout, brook trout, and rainbow trout (*Salmo gairdneri*) which exhibit photonegative behavior. Overhead cover is also utilized by species showing thigmotaxis (desire to be in close contact with an object). Giger (1973) cites another use of overhead cover, that of providing shadow areas along stream margins where water currents are frequently optimal for resting small fish.

Butler and Hawthorne (1968) and Lewis (1969) reported that brown trout utilize overhead cover to a greater degree than rainbow trout. Wesche (1973) determined that brown trout utilize overhead bank cover more so than in-stream rubble-boulder areas and devised a cover rating system whereby cover comparisons can be made on a stream section at different flows or on different stream sections at the same flow. Wesche (1974) began subsequent investigations into the relationship of cover to standing crop.

Submerged cover (e.g., stream substrate, aquatic vegetation, etc.) has been shown to be important in all stages of salmonids, from the newly hatched larva to the adult. Even salmonid eggs rely on submerged cover (substrate) for protection. Hoar et al. (1957) and Hartman (1965) reported that small salmonids recently emerged from the spawning gravel frequently hid under stones. Wesche (1973) noted that brown trout less than 15 cm used in-stream rubble-boulder areas to a greater degree than overhead cover. This suggests, as was noted earlier, that cover selection is in part based on fish size.

Generally, fish will establish a territory around the selected cover type. This tends to spread the fish population throughout the stream system, leading to a more efficient utilization of the food supply (Hunter 1973). It is within this microhabitat that the fish will spend the majority of its time, feeding and resting. According to Hunter, a fish that has succeeded in obtaining a station with favorable feeding conditions usually retains the territory partly by aggressive actions and partly because it grows faster than its neighbors which have less desirable stations. Hooper (1973) states that abundance of suitable cover determines the number of territories, and thus, the fish population.

That cover is indeed important is shown by the effects of its removal from different streams. Elser (1968) found 78% more trout in an unaltered stream section than in an altered section having 80% less cover. Boussu (1954) showed that losses in brush and undercuts from a stream section resulted in subsequent losses in the number and weight of resident trout. Peters and Alvord (1964) noted similar reductions in twelve Montana streams.

IMPACTS OF CHANNEL MODIFICATION ON HABITAT DIVERSITY

From the preceding discussion of habitat components, it becomes obvious that a key characteristic of any productive in-stream habitat is *diversity.* Considering the physical and hydraulic aspects, it is imperative that the proper blend of water depths, water velocities, and substrate types be present, together, to form the necessary food production, spawning-incubation, and cover areas that combine to form the complete habitat. In the case of cover, the composition and vigor of the riparian community is also critical. Having suitable depths and velocities available as spawning habitat for a given species is well and good, but if these depths and velocities are not present over the proper substrate size, the habitat value is diminished. Likewise, a stream reach consisting entirely of riffles and runs may have more than adequate food production and spawning capacity, but may not be capable of holding mature fish due to the absence of pools and the often associated cover. Thus, on a more microscopic level, the diversity of depths, velocities, and substrates must be present to adequately provide for each habitat component; while on a more macroscopic level, the diversity of habitat components must be available to form a complete habitat if the needs of all life stages of a given species or combination of species are to be met.

In recent years, the capability of biologists to obtain some measure of diversity has been greatly enhanced by the development of several methods for habitat assessment. Among these would be the Habitat Quality Index (HQI) of the Wyoming Game and Fish Department (Binns 1976, 1978, and 1979), the Habitat Suitability Index (HSI) models under development by the U.S. Fish and Wildlife Service's Western Energy and Land Use Team (Raleigh 1978 and 1982), the Physical Habitat Simulation (PHABSIM) System models developed by the USFWS Instream Flow Group (Bovee 1978; Bovee and Milhous 1978; and Milhous et al. 1981), and the Cover Rating Method developed by the Wyoming Water Resources Research Institute (Wesche 1980). Models or indices such as these allow for measurement and evaluation of the various habitat components before a river reach is modified and can provide valuable input into the planning process for the modification. Also, the application of such procedures can be used to identify critical habitat features that should be preserved and can facilitate habitat protection, mitigation, and/or postmodification improvement. The PHABSIM models are especially well suited for predicting impacts and also allowing cost-efficiency analysis for habitat improvement.

Following this brief discussion of the components of fish habitat, the need for preserving habitat diversity, and some methods for evaluation, a review of the general impacts of various types of channel modifications on in-stream habitat is appropriate before proceeding to habitat restoration planning, procedures, and structures.

There are numerous types and variations of development activities that can fall under the general heading of channel modification or channelization. For our purposes, mention of four major types of activities which can have major impacts on fish habitat should suffice. These are: channel enlargement, channel realignment, clearing and snagging, and bank stabilization. York (1978) presented the following definitions of these activities:

Channel enlargement. The overall enlargement of channel cross section to increase its capacity to convey water and/or provide drainage.

Channel realignment. Includes construction of a new channel and widening and/or deepening of the existing channel where the new alignment coincides with the existing channel. It usually includes straightening the channel to increase its capacity to convey water.

Clearing and snagging. The removal of obstructions from the channel and river bank including the removal of vegetation and accumulations of bed material.

Bank stabilization. A protective lining of concrete, timber, or large rock over all or part of the river bank to prevent erosion and/or increase the capacity of the channel to convey water.

Typically, the overall goal of most types of channel modification is to increase the discharge the channel can carry within its banks by altering the stage-discharge relationship, thereby facilitating the drainage of runoff water and protecting property located adjacent to the active channel. Inspection of the basic discharge equation reveals the hydraulic parameters that can be modified to realize this increase in discharge capacity:

$$Q = A \times V = (W \times D) \times V \tag{5.2}$$

where Q is discharge, A is cross-sectional area of the channel, W is width, D is depth, and V is velocity. Obviously, the channel cross section is increased by widening and deepening, while an increase in velocity is proportional to an increase in energy gradient (S) and hydraulic radius (R), and inversely proportional to channel roughness (n), as described by Manning's equation:

$$V = \frac{1.49\, S^{1/2}\, R^{2/3}}{n} \tag{5.3}$$

At first glance, this may not appear disastrous from the habitat aspect. Potentially, width, depth, and velocity, hydraulic parameters upon which habitat quality depends, are all increased. However, the reality of the situation can be quite different. While the capacity of the modified channel has been increased to handle peak flood flows, and if we assume for the sake of example that no flow augmentation is occurring, the net result may be that during low flow periods, which for western streams may be 75% or more of the time, water depths and velocities are reduced while only the water width or wetted perimeter is increased. Should depths and velocities be reduced below the minimum levels needed to meet the hydraulic requirements for fish spawning, incubation, resting, passage, and feeding, the habitat losses become obvious.

Numerous case studies have been conducted in recent years to specifically examine the impacts of channelization to aquatic habitats, the populations supported therein, and the bordering riparian zone. A sampling of these include the work of Wydoski and Helm (1980) on low gradient Utah streams; Chapman and Knudsen (1980) on small western Washington streams; Griswold et al. (1978) on warm-water streams in Ohio and Indiana; Schmal and Sanders (1978) on a Wisconsin marsh; Peters and Alvord (1964) and Elser (1968) on Montana trout streams; Barstow (1971) on wetland habitat in Tennessee; Marsh and Waters (1980) on the downstream effects of channelization in southwestern Minnesota; Stern and Stern (1980) on the effects of bank stabilization on smaller streams and rivers; Marzolf (1978) on potential effects of clearing and snagging on stream ecosystems; Maki et al. (1980) on effects on bottomland and swamp ecosystems in North Carolina; Barclay (1980) on impacts to riparian communities in Oklahoma; and Bulkley et al. (1976) on warm-water streams in Iowa.

Possibly even more critical to a fish population than reductions in water depths and velocities can be the reduction in channel roughness inherent in most channel modification projects. Numerous physical and biological factors contribute to roughness. Among these, those that have a direct relationship to habitat diversity include:

- channel configuration
- substrate type
- bank composition
- bank type
- bank configuration
- aquatic vegetation
- riparian vegetation
- snags

Typically, a straight channel reach offers less impedence to flow than does a meandering section. From a habitat perspective, however, the pool and associated undercut banks that may have been formed along the outside of a meander may be critical resting and cover areas for game fish. Likewise, a mixed substrate of cobble and boulders may contribute roughness to a channel, but in doing so provides additional rearing habitat as resting and feeding microhabitat for fish and key habitat for benthic macroinvertebrate production. As previously discussed, the value of undercut banks lined with snags and overhanging riparian vegetation is unquestioned as prime fish cover. However, such a bankside situation increases the overall channel roughness and is often replaced by smooth, clean banks in the modified channel. Aquatic vegetation can also have a good deal of influence on the stage-discharge relationship of a channel reach by increasing roughness while at the same time providing food and shelter for macroinvertebrates and fish life.

In summary then, it should be kept in mind that a major objective of many of the aquatic habitat reclamation treatments described in the next section of this chapter is to add some degree of roughness back into a modified channel. The key to doing this successfully is the combined skills of the habitat biologist, who will assess the habitat needs, and the project engineer, who will be able to assess the degree of reclamation that can be accommodated within the hydraulic constraints of the channel reach in question. Together, a feasible habitat improvement or rehabilitation plan can be designed that has as high a possibility of success as is economically possible.

HABITAT RECLAMATION TREATMENTS

The enhancement of in-stream aquatic habitat for fish life can be accomplished through a variety of approaches. Among these would be included:

- stream flow regulation (e.g., minimum flows, flushing flows, fluctuation control)
- watershed improvement and regulation of land use activities
- riparian management and enhancement
- overall channel design and alignment, including such treatments as installation of in-channel sediment basins, substrate manipulation, and development of artificial meanders
- stream bank stabilization and improvement
- obstruction removal
- biological enhancement, such as the planting of beaver in suitable areas
- water quality enhancement
- construction of spawning facilities
- installation of in-channel structures

The employment of any one or combination of these general approaches depends upon the particular problem at hand and the philosophy of the management agency involved.

As previous chapters in this book have dealt with such topics as riparian revegetation, water quality protection and restoration, applications of geomorphology to river reclamation, the use and design of meander patterns, and substrate manipulation to enhance benthic macroinvertebrate colonization, the primary focus here will be on in-channel reclamation structures and practices, the combination of which we will term *treatments*, to enhance fish habitat. The intent is not to downplay the importance of proper watershed management and avoid the debate which has been ongoing for several years regarding the merits of in-stream structures (Wydoski and Duff 1982; Haugen 1982; Platts and Rinne 1982). Rather, the objective is to provide the reader with information regarding the options available once the overall planning process has been completed and the decision has been made to utilize in-channel treatments. To this end, the discussion will be directed toward descriptions of the various types of structures which have been designed and tested, their intended purpose, an evaluation of their effectiveness in a variety of stream situations and over time, the selection of proper construction materials, and where possible, estimates of cost. To begin, it is first necessary to discuss the proper approach to planning a river reclamation project utilizing in-stream enhancement structures.

Planning

Patrick (1973) states: "Man must remember that the streams and the flood plains have evolved over long periods of time, and have developed a system that is best for the natural conditions at hand. He should study it carefully and make sure that modification follows the dictums of nature."

Such a philosophy should be adopted by anyone planning a channel modification project, whether it be the placement of a single-log dam in a small mountain stream or a lengthy channel relocation project on a major river. The question, of course, becomes, How does one go about determining what the "dictums of nature" are on the particular reach of stream in question, especially in light of the dynamic characteristics of unaltered streams, let alone one that has or is undergoing artificial changes in its watershed as a result of such activities as logging, grazing, road construction, urban development, mining and the like? Assuming an answer is found to the first question, the second question posed must be, How can we best reclaim or enhance this habitat in accordance with these "dictums of nature?" Once the answer is found to our second question, all that remains is the conduct of the appropriate treatments and hopefully, monitoring of these treatments over time to gauge their success or failure.

A good first step in the planning process would be to form an interdisciplinary team to help in addressing the two major questions posed above. Wydoski and Duff (1982) suggest that members of this team represent a variety of disciplines including not only fisheries biology, but also hydrology, hydraulic engineering, and soil science. Other specialists to possibly be included, depending upon the scope of the project, would be a vegetation specialist, someone trained in aesthetic evaluations and considerations, and a water quality specialist.

Once the team has been selected and coordination established, a sound second step would be for each specialist to develop a list of questions which need to be answered regarding their specific discipline and its relationship to the project at hand. Questions raised by the habitat biologists may follow along these lines, as modified from Claire (1980):

1. What fish species are now present?
2. What fish species are being managed for?
3. What are the habitat needs and preferences of these species?
4. What habitat conditions do we have at present?
5. What would be the preferred condition of the habitat?
6. What types of natural habitat do we have in presently unaltered stream sections?
7. How can the characteristics of the desired natural habitat best be restored or duplicated?
8. What habitat treatments are reasonable and practical given the constraints of the project and the limitations of the habitat?
9. What habitat treatments will enhance the habitat?

Generally, the answers to questions 1–6 can be found by the biologist, working independently of the rest of the team, through review of fish and wildlife agency records, field sampling of fish populations, and employment of one or several of the habitat evaluation techniques previously discussed. If the reclamation project is to be successful, questions 7–9 must be answered through close coordination with other team members.

The type of questions raised by other team members, primarily the hydrologist and the engineer, may include some of the following:

1. What are the shape and dimensions of the channel?
2. What are the shape and dimensions of the normal hydrograph through the stream reach to be reclaimed?
3. What are the extremes of flow over the period of record?
4. What are the probabilities of occurrence of various magnitudes of flood and low flows?
5. What is the natural pool-riffle ratio?
6. What is the spacing between successive pools and successive riffles?
7. What is the natural meander pattern and slope of the reach?
8. What is the composition of the stream bed sediments and the stream banks?
9. Is the stream reach, in which the reclaimed section is located, stable?
10. What natural or presently existing hazards to habitat quality (e.g., gully erosion, bank erosion, channel aggradation, channel degradation, pattern migration and change) need to be taken into consideration in the project design?
11. What is the mobility of the stream bed sediments?
12. Is the stream bed capable of enough scour to form pools or must structures be designed and installed to accomplish this?
13. What effect will various types of reclamation structures have on channel roughness and therefore the conveyance capacity of the channel?
14. Based upon the flood frequency analysis, what forces should the structures be designed to withstand for various anticipated flood frequencies?

15. Will the reclamation project affect the soil-water relationship between the stream and the riparian zone?
16. Will revegetation be required?
17. Given the type and condition of the stream bank soils and plant species, what will be the best revegetation plan?
18. To achieve revegetation, will artificial methods such as irrigation, fertilization, and fencing be required?
19. What effects will various treatment options have on the aesthetics of the reach?
20. What effects will various treatment options have on recreational use of the reach?

Certainly, the list of questions that need to be answered is potentially endless. The examples given above are offered as "food for thought" to anyone planning a habitat reclamation project. The specific questions that should be asked for given types of projects will, of course, vary, dependent upon the type of stream to be reclaimed, the extent of the reclamation, and the environmental, sociologic, and economic constraints of the project. The important point to be made, however, is that questions must be asked and answered as best as possible before arriving at the stream armed with shovels, chainsaws, tractors, and the like.

While it would be physically impossible, given the confines of this single chapter, to thoroughly discuss methods available to answer all of the questions raised above, there are several either new or relatively obscure references which should be mentioned that can aid the planning process. Skinner and Stone (1982) discussed the potential of using color infrared aerial photography for identifying ten instream hazards to trout habitat quality. Key indicators are given to assist in the identification process and possible techniques for mitigating each type of hazard are provided. Brooks (1974) and Lu (1975) had some degree of success in predicting the effects of various habitat reclamation treatments on a high mountain stream based upon the physical modeling of the stream reach in a laboratory flume. Cooper and Wesche (1976) designed and field-tested temporary reclamation structures to obtain some measure of the degree of habitat enhancement to be achieved before permanent structures were installed.

Heede (1979) demonstrated how theory and practical experience can be blended to assist hydrologists in predicting impacts of stream restoration projects when field time and on-site data are limited. Also, Heede (1980) discusses stream dynamics and their importance to the nonhydrologist. Such information can be critical to the biologist in the planning process for habitat reclamation projects.

Knowledge of the relative stability of a stream reach can be crucial to the success or failure of a reclamation project. Pfankuch (1975) has developed a quite simple procedure, entitled "Stream Reach Inventory and Channel Stability Evaluation," that allows the investigator to systematically evaluate the resistive capacity of low-order mountain streams to the detachment of bank and bed materials and gain knowledge of the capacity of streams to adjust and recover from potential flow or sediment production alterations. While not specifically designed for use in the siting of habitat reclamation structures, an understanding of the key features included in this index will provide valuable information needed throughout the planning process. Eifert and Wesche (1982) field-tested Pfankuch's procedure and found it to be a reliable indicator of trout habitat quality as well as channel stability. Also closely related to Pfankuch's work, Robinson (1982) has developed and tested the Wyoming Range Stream Inventory method for evaluating stream morphology in the context of user impacts to the riparian zone.

Goodwin (1979) presented a discussion of several empirical and theoretical approaches to determining the stability of artificial channels, while Lane and Foster (1980) developed procedures to predict channel morphology for small streams given changing land use and related this to sediment yield. Again, papers such as these can provide valuable input to the planning process.

An excellent example of the team approach to the successful conduct of a habitat reclamation and enhancement project is described by Brouha and Barnhart (1982). Working in the Upper Browns Creek watershed of northern California, the biologists involved identified the habitat deficiencies and needs, while the hydrologists analyzed the stream flow regimes to determine the needed flood and low-flow frequency information. Based upon these data, expertise in hydraulic engineering was utilized to determine the stream flow forces which reclamation structures would need to withstand. With this as input, the design engineer was able to determine the necessary specifications.

Based upon the results of the questions asked and the answers obtained under step two, the third step of the planning process would be finalization of the habitat reclamation plan. Participation is required here from all team members. Also, it is at this point in the process that care must be taken to ensure that all of the more practical aspects of the proposed project have been considered. Examples of the types of questions that must (or should) be answered include:

1. What is the cost-benefit ratio of what we are proposing to do?
2. What materials and equipment will be needed at the site?
3. What materials are naturally available at the site?
4. What are the personnel requirements for the installation?
5. Given local climatic and hydrologic conditions, when is the best time for installation?
6. Will private landowners need to be consulted regarding trespass rights and other possible matters of concern?

Once these three steps on the planning process have been completed, the next phase is the implementation of the plan. The following section describes the types of in-channel reclamation treatments which have been designed and tested over the years to reclaim and/or enhance fish habitat.

The final phase of the process, one which is often overlooked, is the careful monitoring and evaluation of the project following implementation. As stated by Wydoski and Duff (1982): "One of the most unfortunate and surprising features of stream habitat improvement has been the almost complete lack of quantitative evidence to base conclusions on the ultimate results."

Little guidance is given by the literature in regard to the proper timing of evaluations. Common sense dictates that the logical time for initial analysis of the hydraulic changes brought about by and the physical stability of the structures themselves would be immediately following the first ice-out and high water condition. Also critical could be an evaluation of conditions following a long period of uninterrupted low flow. Valuable information could be gathered regarding sediment deposition patterns and their possible short-term impacts on the habitat. Subsequent hydraulic and structural evaluations could be conducted following hydrologic events of unusual magnitude, both from the high-flow and low-flow aspects.

Regarding the evaluation of biologic response to channel reclamation, Gore and Johnson (1980) found that maximum densities of benthic macroinvertebrates were achieved in a completely reclaimed reach of the Tongue River in northern Wyoming within 70 to 100 days, while a stable macroinvertebrate community was attained within 300 days of water being turned into the new channel. By the end of the study (approximately one year after reclamation was completed), there was no indication that fish populations had reached maximum densities nor that a stable community had been attained. The authors suggested that if fish having a small home range, such as rock bass, are members of the local community, their presence in reclaimed habitat be used as an indicator of a stable community. Working with brook trout populations in Lawrence Creek, Wisconsin, Hunt (1976) found that the biomass of fish over 15 cm and production increased significantly during the first three years following habitat improvement. However, the greatest population responses were recorded during the second three-year period. Hence, we can tentatively conclude from these studies that while the evaluation of macroinvertebrate response can probably be done within one year of reclamation, to obtain a clear picture of the effect on fish populations, it may be best to wait at least four years.

While it is not always possible given the time, staffing, and budgetary restraints of resource management agencies, it is strongly recommended that whenever and wherever possible, the postmodification evaluation be conducted. Only through such research will we be able to learn from our past mistakes and make progress in the future.

Applications, Construction, Installation

A review of the published literature and in-house agency reports indicates that the most commonly used in-channel treatments are current deflectors, overpour structures such as dams and weirs, bank covers, and boulder placements. Other less commonly applied reclamation treatments that have been used successfully (and unsuccessfully) include digger logs, trash catchers, simple gabions, substrate manipulation, pool excavation, channel blocks/barriers, and beaver management. As one proceeds through this section, it should be kept in mind that history has clearly shown us that there is no need for a great variety of structures for stream habitat reclamation (Duff 1982). As there are really only several things that can be done to a stream or river to make it more accommodating for fish, an experienced person who pays heed to the "dictums of nature" and has an understanding of fish habitat can accomplish a great deal with only a relatively few simple types of deflectors, dams, and shelters.

Deflectors

Current deflectors have historically been one of the most commonly used in-channel treatments to improve fish habitat. In general, they are relatively easy to construct, inexpensive, easily modified to suit on-site conditions, built from a variety of materials, applicable to a wide range of stream sizes, adaptable for use with other treatments, multifunctional, and when properly planned, designed, and constructed, successful in improving habitat. Deflectors have and can be built with a variety of purposes in mind, including:

- directing current to key locations such as bank covers
- assisting in the development of meander patterns within the confining banks of channelized reaches
- deepening and narrowing channels
- scouring pools
- increasing water velocities
- removing silt from spawning gravels and critical areas for benthic invertebrate production
- protecting stream banks from erosion
- serving as barriers to keep flow out of side channels, thereby consolidating low flows
- encouraging development of riparian vegetation by means of silt bar formation
- helping to keep water temperatures cool
- enhancing pool-riffle ratios

As with any in-channel treatment we will discuss, there have been both successful and unsuccessful applications of current deflectors. White and Brynildson (1967) state that deflectors may be the best all-around devices for modifying stream channels, while Nelson et al. (1978) echo this view. Saunders and Smith (1962) reported that one year after the installation of deflectors and dams on Hayes Brook, the number of age I and older brook trout had doubled in the modified reach. Shetter et al. (1946) found that five years after twenty-four current deflectors were installed on Hunt Creek (Michigan), the number of good quality pools had increased from nine to twenty-nine, average pool depth had increased by 0.5 feet, and additional spawning gravel had been exposed. The authors concluded that the brook trout fishing had improved as a result of the in-channel devices. Hale (1969) altered over two miles of the West Branch of Split Rock Creek in Minnesota with a combination of deflectors, shelters, and dams. After three years of postinstallation evaluation, he concluded that: (1) the artificial alteration had improved the carrying and reproductive capacity of the reach for trout; (2) the alteration was cost effective when compared with stocking; and (3) the deflectors had their greatest effect on the substrate, increasing the percent of exposed gravels in the reach from 14 to 24%. Evaluation of rock jetties (deflectors) sixteen years after installation five channel widths apart on a channelized reach of Little Prickley Pear Creek (Montana) indicated that pool frequency, size, and depth were comparable to that found in unaltered sections, and that rainbow trout populations had been enhanced (Lere 1982). Tarzwell (1932 and 1936) found benthic invertebrate production in a Michigan stream to have increased 4- to 9-fold following deflector installation. Cause for the increase was attributed to silt bar formation below the structures and the subsequent development of beds of aquatic vegetation. Cooper and Wesche (1976) had success increasing brown trout habitat on a mountain stream impacted by dredging activity in southeast Wyoming through the installation of a 50-meter-long gabion deflector and flow consolidator. This structure functioned as an extension of a point bar which had developed in the widened channel and directed low flow to the opposite stable bank where artificial overhangs had been installed to provide cover. The massive structure functioned well during the first low-flow season and survived the subsequent ice-out and spring runoff. Unfortunately, beaver activity in the reach inundated the structure during its second summer and long-term evaluation could not be carried out.

While there have been numerous successful installations of current deflectors, there also have been failures. Rollefson and Erickson (1970) reported that following installation of a double-wing deflector on Cranney Creek (Wyoming), some silt was displaced and the channel was slightly deepened between the wings. However, the deposition which occurred immediately downstream from the structure negated any habitat gains. Lewis (1974) and Maughan et al. (1978) found that on West Virginia streams gabion deflectors were quite susceptible to damage and needed frequent repair. Knox (1982) found that of twenty-three log deflectors built in a channelized reach of Ten Mile Creek in Colorado, only five produced even marginal habitat while eighteen were of no value. Rock deflectors were also installed and one-half survived the flood flows of up to 31 m^3/sec, providing fair habitat. On portions of channelized reaches on the St. Regis River (Montana), Lere (1982) found the stream to be too steep and confined for rock jetties. Flood flows had reduced the ability of certain structures to concentrate the flow, while the pools formed provided little trout cover. Probable cause for the lack of success was attributed to the structures being spaced only two channel widths apart. Ehlers (1956) evaluated five log deflectors eighteen years after they were installed in a California stream. Three were still in excellent shape, while two had failed due to end- and undercutting.

A most critical step in the installation process is the selection of the proper in-channel location for placement of the structure. While the final siting decision will rely on the knowledge and good judgment of the project participants, much can be learned from the past experiences of others working in the field. The following list of current deflector siting criteria have been drawn from such examples:

Deflectors can be successful on streams of various size and are not limited to only smaller streams (Seehorn 1982).

Typical placement is in wider, shallow, lower gradient stream sections lacking pools and cover (Seehorn 1982).

Locations where the gradient exceeds 3% should be avoided (U.S. Forest Service 1969).

Either avoid reaches having vast flow fluctuations or design low-profile structures geared for the low-flow channel (U.S. Forest Service 1969; Cooper and Wesche 1976).

Don't build at the head of riffles as this may cause damming of the stream (White and Brynildson 1967; Nelson et al. 1978).

Avoid reaches that carry a great deal of debris as this may result in clogging or damming (Claire 1980).

The bank opposite the deflector must be stable (Claire 1980).

Avoid areas having a soft and/or unstable substrate (Barton and Winger 1973).

In straight reaches, alternating deflectors spaced 5–7 channel widths apart can produce a natural sinuous pattern of flow (Nelson et al. 1978; Lere 1982).

Avoid steep, high, eroded banks unless the plan calls for stabilizing the entire height of the bank (Seehorn 1982).

Be certain that bank conditions are such that it will be possible to anchor the ends of the structure 1.2–1.8 m into the bank (Seehorn 1982).

Point bars can provide an opportunity for constructing low-profile gabion or rock deflectors that consolidate and direct flow to the opposite stable bank (Cooper and Wesche 1976).

Greater cost efficiency can be achieved if natural materials (logs, rocks) are available at the site (Seehorn 1982).

If the outside bank is stable, a deflector placed on the inside of a bend can enhance a marginal pool (Wisconsin Dept. Natural Resources 1980; Seehorn 1982).

Avoid constricted channels having a high transport capability (Bailey 1982).

Current deflectors are generally quite easy to construct and are typically built of various combinations of logs, rocks, boulders, gabions, and wire mesh. Figure 5.1 illustrates the design of three simple types, the log-boulder deflector, the gabion deflector, and the *V*-type deflector. Construction details are provided. Figure 5.2 shows a simple rock-boulder deflector. The combination of the two deflectors at the upstream end, in Figure 5.1, forms a double-wing deflector, a modification which will be discussed later. Figure 5.3 provides a view of the habitat

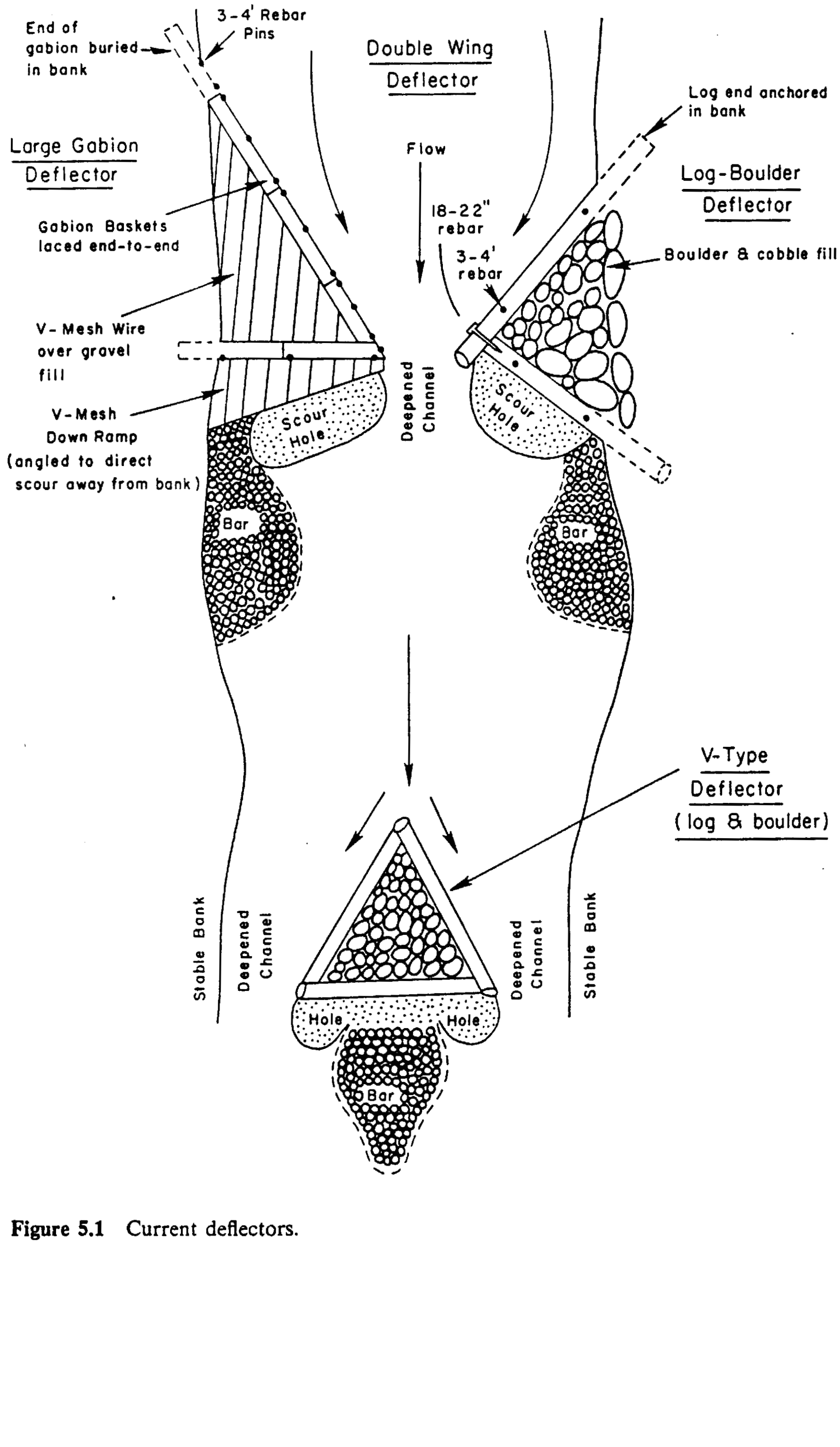


Figure 5.1 Current deflectors.

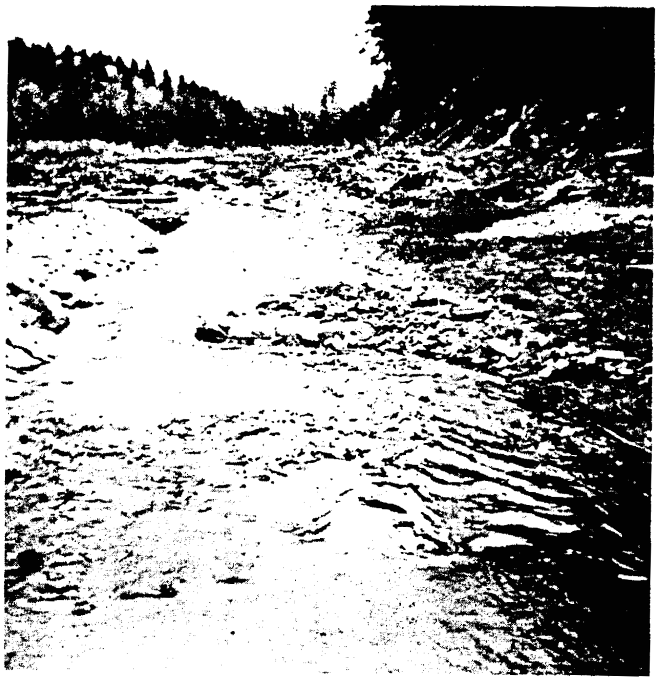


Figure 5.2 Log and boulder deflector with riprap stabilization on opposing bank.

that can be created by construction of a low profile gabion deflector on the streamward side of a long (50 m) point bar.

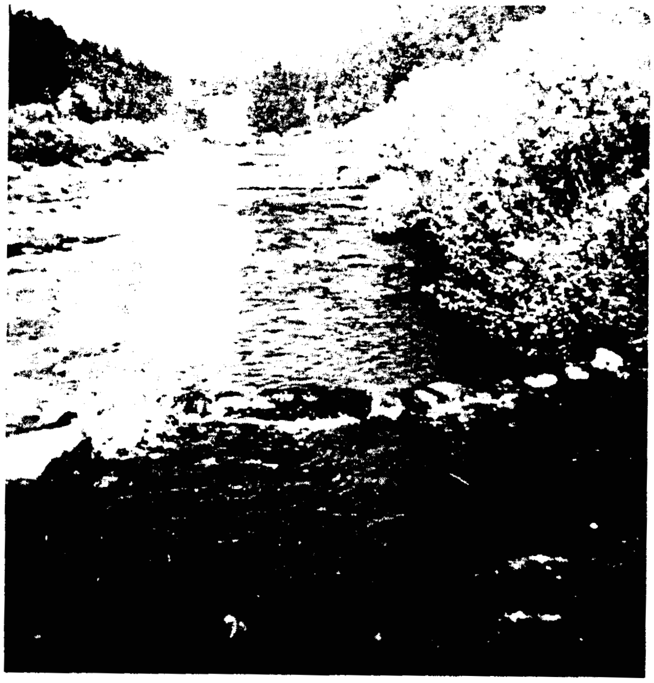
Several important characteristics of any current deflector that must be given consideration before the actual construction begins are the shape of the structure, its height, the angle of the deflector, the length it will extend into the channel, and the materials to be used. Regarding *shape*, several forms have been considered over the years, the most common being the peninsular wing (jetty) and the triangular wing (Figure 5.2). White and Brynildson (1967) recommend the use of this latter form because it reduces the tendency for erosion of the bank and bed behind the structure during high flow. Structure *height* is generally dictated by the elevation of the water surface at low flow. To avoid excessive damage to the structure itself and the opposite bank during high flow, the structure should not extend more than 0.15–0.3 m above the low-flow elevation (Seehorn 1982; Cooper and Wesche 1976; White and Brynildson 1967).

Typically, deflectors are *angled* downstream at approximately 45° from the current, while the back brace log is set at approximately 90° to the deflector log (Seehorn 1982; Swales 1982). Of course, these angles can vary depending upon the specific requirements of the project at hand. For setting the proper angle, Cooper and Wesche (1976) found temporary deflectors, made of hinged planks

(a)

(b)

Figure 5.3 (a) Low flow habitat before deflector-barrier construction. **(b)** Gabion cells in place, ready to be filled. (c) Completed gabion deflector-barrier.



(c)

Figure 5.3 (*concluded*)

and sand bags, to be quite helpful before the permanent structures were installed. Regarding the angle of the brace (downstream edge of deflector), the important consideration is that water overtopping the structure must be directed toward the stream, not the bank.

As with deflector angle, the *distance* that the deflector extends into the channel will vary from site to site, depending upon the specific results desired. In southeastern streams, Seehorn (1982) found that in most cases, the stream width had to be narrowed 70 to 80% to achieve good results. It should be noted, however, that the opposite banks were stabilized with a cover log that controlled the amount of erosion. Swales (1982) was successful on a small lowland river in England extending his deflectors one-third to one-half the distance across the channel. For general planning purposes then, a figure in the 50% range would probably be appropriate. On-site knowledge of relative bank stability, substrate size and compaction, and design flow and associated hydraulic characteristics would be necessary to determine more exact lengths.

Rock-Boulder Deflector. Probably the easiest type of current deflector to construct is the rock or boulder deflector. All that needs to be done is to shovel out a trench in the stream bed in the desired shape and set large interlocking angular boulders in place. The inside of the structure is then filled with smaller material (U.S. Bureau of Fisheries 1935). Claire (1980) recommends that dense, angular, nonerodible rock from 4- to 30-inch diameter be used, with at least 50% ranging from 6- to 24-inch diameter. For constructing rock jetties in Montana streams, Lere (1982) found that Type A riprap (at least 80% by weight has volume of at least 0.03 m^3) did poorly, while Type B riprap (at least 40% of total volume of rock of at least 0.11 m^3) was still performing successfully after sixteen years.

One of the most stable types of deflectors is the log-boulder structure illustrated in Figure 5.2. Installation instructions are as follows (modified from Wyoming Game and Fish Dept. 1982a; and Seehorn 1982):

1. Notch the ends of the posts and drill all holes on the bank for reasons of safety. If preferred instead of notching, a 0.4–0.6-m-long piece of rebar can be driven through the logs to connect them at the point.
2. Structures can be built one or two logs high, depending on specific needs. Seehorn recommends logs at least 0.3 m in diameter be used.
3. Dig the lower posts into stream bed about halfway.
4. Anchor logs 1.2–1.8 m into the bank, if possible.
5. Drive two 0.9–1.2-m-long pieces of rebar in each post. To provide added strength and prevent undercutting, the Wyoming Game and Fish Department recommends 2 or 3 additional lengths of rebar be driven through the point.
6. Nail with ring-shank nails.
7. Fill with rock and, if desired, cover with sod.

Gabions. The use of gabions for construction of in-channel structures has been debated for quite some time. The major objections to their use have been for reasons of aesthetics (U.S. Forest Service 1952) as well as their susceptibility to damage and frequent need for repair (Lewis 1974). Maughan et al. (1978) found that on Jennings Creek in the Southeast, repairs were needed every four to six years to replace broken wire sections and refill rock that had been lost. On the positive side, Johnson (1967) found that on Straight Creek in Montana the habitat provided by gabion deflectors was at least as good as natural habitat and that the undercuts formed under gabions as they twisted or settled provided good cover. Cooper and Wesche (1976) found that low-profile gabion structures were effective, easy to install, strong enough to withstand high discharge and fairly inexpensive. Also, when used on relatively wide, cobble-bottomed streams with well-developed point bars, the gabions tended to blend in quite well after they had been in place long enough to trap small debris particles.

Cooper and Wesche (1976) describe the step-by-step procedures for constructing the gabion deflector shown in Figure 5.3 as follows:

1. Using shovels, the stream bed was levelled where the deflectors would be.
2. Six 2.0 m x 0.8 m x 0.15 m gabion cells were cut from the larger factory gabions and placed end-to-end, in place, and laced to each other.
3. Where the ends of the structure abutted the banks of the high-flow channel,

a trench was dug back into the bank 0.3 m in order to anchor the structure and protect against erosion. Additional anchoring would be preferred, if possible.

4. The gabion cells were then filled with relatively clean cobble (0.1 m diameter). It is best to remove any sand or fine gravels before filling, as these smaller materials will wash out during high flow and cause sag.
5. Cells were filled level full, packed, then filled again until they were moderately rounded on top.
6. Lids were then laced on tightly. It was found that lacing lids to one edge of the basket before filling reduced overall lacing time because lacing through the packed cells was quite tedious.
7. After the cells were filled and closed, the area enclosed by the gabions was filled with cobble and covered with *V*-mesh fencing wire. This wire was secured on two sides to the gabion cells and on the bank side with rebar pins.
8. To resist unwanted scour, a downramp of *V*-mesh wire and cobble was then added to the downstream edge of the gabion.
9. To stabilize the streamside edge of the cells, rebar pins were driven through the filled gabions into the stream bed.

It is recommended that plastic-coated gabions be used, as galvanized material was found to oxidize readily. Expected life of the plastic-coated gabions was expected to be in excess of fifteen years.

Double-wing Deflector. While the three basic types of deflectors described above are the "standards of the industry," so to speak, several variations have been developed and tested which on certain occasions have proven successful. The most common of these would be the double-wing deflector, as illustrated in Figure 5.1. Very simply, this type consists of two current deflectors opposite each other in the stream channel. Construction of each is the same as that described above. Seehorn (1982) stated that the double-wing deflector is suitable for use in larger streams (greater than 30 ft wide), should narrow the stream by approximately 80% at the apex to be effective, is well suited to shallow sections where the gradient may be too steep for single deflectors and where the banks are too low to build a check dam, and costs less to build and maintain than a check dam. The U.S. Bureau of Land Management (1968) is somewhat more conservative and recommends the stream should not be narrowed more than 50%. The Wyoming Game and Fish Dept. (1982a) reports that results have been mixed with double-wing deflectors in scouring holes and that in smaller streams, formation of unwanted debris jams could be a problem.

Underpass Deflector. A second variation is the underpass deflector, or digger log, a very simple structure suitable for use on small streams. The purpose is to "blow out" silt and soft bottom materials, thereby scouring a pool (Everhart et al. 1975). Construction consists of setting the main log across the channel several centimeters up off the bottom. The ends are anchored well into the bank and braces on the downstream side can be added for additional stability. An extra benefit is that overhead cover is provided as well. As with double-wing deflectors, a major problem is formation of debris jams. Also, bank erosion and formation of unwanted silt bars downstream can reduce the effectiveness of underpass deflectors.

Current deflectors are often used in combination with other in-channel treatments. Cooper and Wesche (1976) and Seehorn (1982) report using deflectors to guide the flow to artificial covers placed on the opposite bank, while numerous authors report using them in combination with check dams on smaller streams to increase circulation in pools and enhance pool quality. Also, brush or artificial overhangs can be added to the downstream edge of deflectors to enhance their habitat value. Once the main structure is in place, a bit of imagination can go a long way toward improving even more the fisheries benefits of the project in a very cost-effective manner.

While it is difficult to estimate the costs and personnel requirements involved in constructing current deflectors, the literature does provide some guidance. Seehorn (1982) found that a four to six person crew could install 2 or 3 log and boulder deflectors and associated cover logs per day, while 1.5 to 2 double-wing deflectors could be built per day, depending on stream size. Knox (1982) reported that construction of twenty-two log and rock deflectors on the White River in Colorado averaged about $1500 per structure (1979 dollars), while Shaw (1982) indicated that installation of three *K*-dams and three double log deflectors cost $700 (1963 dollars). The total cost of construction materials for the modification work described by Cooper and Wesche (1976) was $1500 (1974 dollars). This included three gabion check dams, five deflectors of varying size (up to 50 m long), and numerous artificial overhangs. For a crew of three to four, actual construction time varied from less than one day for a small deflector up to five days for the 50 m structure.

Dams

Another often-used reclamation structure is the low-profile dam. Known by a variety of names, including check dam, weir, plunge, and overpour, this type of structure is generally used to create or enhance habitat on small, steep-gradient headwater streams. While possibly not as adaptable as the current deflector nor as easy to construct, dams can be multifunctional, relatively inexpensive, built from a variety of materials, and successful in improving habitat. Low-profile dams have and can be built with a variety of purposes in mind, including:

- deepening existing pools
- creating new pools above and/or below the structure
- collecting and holding spawning gravels upstream
- encouraging gravel bar formation for spawning below the structure
- raising water levels up to culverts to allow fish passage
- improving flow patterns and aiding flow recovery on intermittent streams

- trapping fine sediments on tributaries to prevent their movement into the mainstream
- aerating water
- slowing the current, thereby allowing organic debris to settle out and promote invertebrate production

Parallel to our discussion regarding current deflectors, the literature is dotted with examples of both the success and failure of dams for improving instream habitat. Duff (1982) reviewed the history of stream improvement in the United States and, based upon the trial and error efforts of such groups as the Civilian Conservation Corps, U.S. Bureau of Fisheries, U.S. Forest Service, and U.S. Bureau of Agricultural Engineering during the 1930s, concluded that probably no form of stream improvement has greater possibilities than the use of check dams. Rinne and Stefferud (1982) reported that the artificial pools created by dams in McKnight Creek (New Mexico) were 50 to 70% greater by volume than were natural pools, were 38 to 50% deeper, provided seven times more cover, and held half again as many Gila Trout by numbers and twice the biomass. Gard (1961), in a study comparing three types of dams on the headwaters of Sagehen Creek (California), considered the project successful as brook trout could be held after dam construction in previously barren waters. Rockett and Mueller (1968) reported that the construction of rock check dams was instrumental in creating additional habitat on Bear Trap Creek (Wyoming) which allowed the survival and maintenance of stocked rainbow trout. Spawning activity was found to increase from 1 or 2 spawning pairs per year to 35–40 pairs per year on Patrick Creek (California) following installation of rock and gabion weirs to collect and hold spawning gravels (Bailey 1982). Claire (1978) reported the successful use of log dams to raise water levels up to culverts to allow fish passage. The pools created were found to hold up to five times as many fish as adjacent natural pools. Otis (1974) described low dams as one of the most effective pool forming devices, while Boreman (1974), working on a New York stream, found that juvenile rainbow trout occupied pools formed by log overpours in equal numbers to natural pools. Maughan et al. (1978) evaluated log dams built in two Virginia streams thirty-five years prior and found them to be in excellent condition. The pool area in the improved sections was three to four times greater than in the natural channel, although no statistical difference was found between fish populations. A possible cause for this was higher fishing pressure in the improved reaches.

Certainly not all dam installations have met with the degree of success described above. Leusink (1965) found that the construction of low-elevation gabion dams on a Colorado stream did not impair or improve invertebrate production. Rockett (1979) reported that the installation of nine check dams on a small Wyoming stream did not increase the number of catchable-size fish. While the number of yearlings was increased, their growth rates and condition were reduced. It was felt that the food supply was not adequate for the increased number of yearlings being held. Richard (1963), evaluating seven log dams built on a California stream in 1955, concluded that the structures caused erosion, didn't help the fish population, and should be used only on streams having low to moderate flows where escape cover is needed. Log step-downs were also found to be unsuccessful on Benchmark Creek in Montana because they formed small pools and blocked fish passage (Johnson 1967), while on Ten Mile Creek (Colorado), only nine of thirty-nine log dams were still in fair to excellent condition four years after installation. The remainder were washed out, buried, or nonfunctioning. Of five rock dams built, only one survived (Knox 1982). Hutchinson (1978) reports poor results with gabions installed across the Siuslaw River in Oregon to create pools and collect gravel. The structures were installed over bedrock and were held down with steel pins and cable. A large percentage either washed out or rolled over, while those that remained tended to collect silt and debris rather than gravel.

There are two primary factors which govern the fate of any in-channel structure such as low dams: proper siting and proper construction. Drawing upon the experience gained from past successes and failures such as those described above, the following list of siting criteria has been developed:

- Generally, low dams are successful on smaller (1–9 m wide), high-gradient (0.5–20% slope) headwater streams not susceptible to excessive flood flows (peaks from approximately 2.8 to 5.7 m^3/sec) (Raleigh and Duff 1980; White and Brynildson 1967; U.S. Forest Service 1969; Wyoming Game and Fish Dept. 1982a; Seehorn 1982).
- A good location for placement is in a straight, narrow reach at the lower end of a steep break in the gradient (Seehorn 1982).
- The stream bed substrate should be stable.
- The banks should be stable and well defined.
- It should be possible to anchor both ends of the dam well into the banks (1–2 m).
- Successive structures should be placed no closer than 5–7 channel widths apart (White and Brynildson 1967).
- The reach selected should be pool-deficient.
- Water temperature regime should be such that if current is slowed, no harmful effects will result.
- A site should be selected which allows low dam height (0.3 m) to be maintained to allow fish passage but still enhance pools (Alvarado 1978).
- If passage is blocked, spawning gravels should be present between structures (Claire 1980).
- The availability of natural construction materials can make a project much more economically feasible.
- If heavy equipment is needed, access must be available.

There are three general types of low-profile dams that have been built and tested over the years, including rock-boulder dams, log dams, and gabion dams. The selection of the proper type for given situations will depend upon the specific objectives of the project at hand, the size and flow characteristics of the stream in question, available manpower and equipment, natural materials present at the site, economic constraints, and the desired lifespan of the structure.

Rock-boulder Dams. A typical design for a rock-boulder dam is presented in Figure 5.4. A structure such as this is ideal for very small streams, assuming that some large flat boulders are available as well as a good backhoe operator to set them securely in place (Wyoming Game and Fish Dept. 1982a). A seal is formed by packing finer gravels in front of and between the boulders. If a good seal can be obtained, habitat can be enhanced upstream from the structure in addition to the plunge pool created below. Aesthetically, the structure is natural looking and quite appealing.

Rock-boulder dams are generally quite easy to build and require less construction time than do log or gabion dams. Rockett and Mueller (1968) report building thirty-seven rock dams in only two days, while Gard (1961) averaged only 3.6 hours per structure on a stream ranging from 1.5 to 4.6 m wide.

Problems that have been encountered with rock-boulder dams include:

- difficulty in sealing (Warner and Porter 1960; Gard 1961)
- a lack of stability and durability in high runoff streams (Bender 1978; Gard 1961; Ehlers 1956)
- collapsing back into the plunge pool (Wyoming Game and Fish Dept. 1982a)

Log Dams. As shown in Figure 5.5, log dams can be designed in a variety of configurations, depending primarily upon the desired height and stability, as well as stream size. Over the past fifty years, numerous designs have been tested. The U.S. Bureau of Fisheries (1935) presents construction plans for ten different types of log dams. However, experience has shown that generally one of four types can be applied to most situations. These four are the single log dam, the *K*-dam, the wedge dam, and the plank or board dam (Duff 1982).

Regardless of the specific type of log dam to be built, adherence to the siting criteria given above, as well as to certain general construction criteria, will pay future dividends regarding structure utility and longevity. Following are some construction criteria which may prove beneficial:

- Secure anchoring of the structure is critical to its success. Log ends should be sunk 1 to 2 m into the banks if possible or at least ⅓ of channel width into the bank on both sides (Nelson et al. 1968; Alvarado 1978; Claire 1978).
- Undercutting is a main cause of failure. To reduce this risk, imbed the base log at least 0.15 m into the substrate. If the stream bed is soft and erodible, add a mudsill to the upstream face of the log for added stability, as shown in Figures 5.6 and 5.7 (Duff 1982). The placement of cobbles and boulders along the upper edge is also very beneficial.
- Endcutting is another major cause of failure. In addition to anchoring the

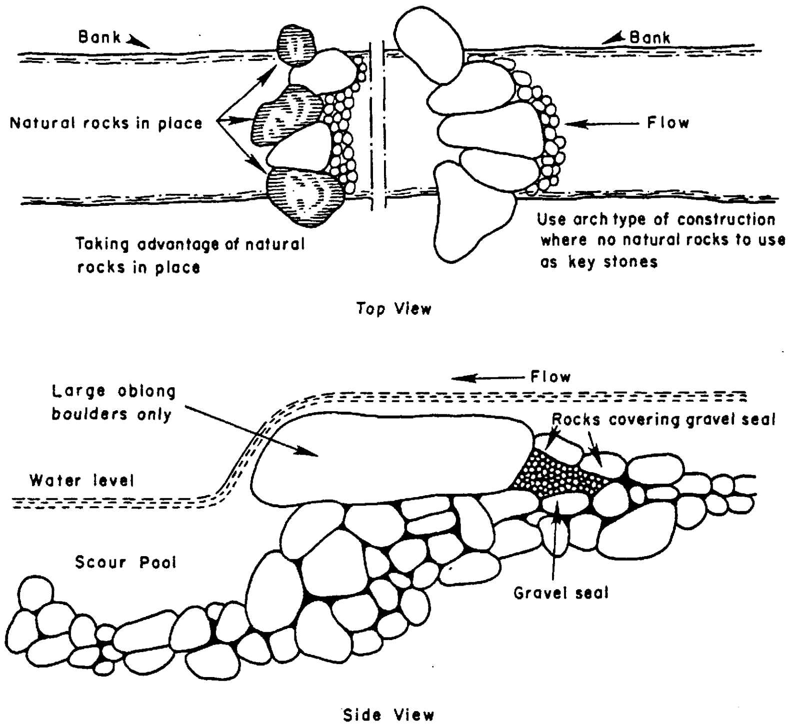


Figure 5.4 Boulder dams.

log ends into the banks, riprap should also be placed over each end. If additional stability is required, log and rock cribs (similar in design to current deflectors) can be constructed on each log end.

- The size of logs used will depend on stream size, availability at the site, desired height of structure, and availability of heavy equipment. The minimum size used should be no smaller than approximately 0.30 m in diameter. For a single log structure, this would allow 0.15 m to be imbedded and still leave a waterfall height of 0.15 m for scouring purposes.
- The type of log to be used will more than likely depend upon what is available at the site. Claire (1978) found western larch to be very durable, while Alvarado (1978) also recommends aspen or cottonwood. Ehlers (1956) reported success with white fir logs while the Wyoming Game and Fish Dept. (1982a) found railroad ties to be an excellent construction material.
- The key to longevity is to attempt to keep as much of the logs wet at all times as possible. Alvarado (1978) recommends keeping a small amount of overflow along the entire log to prevent rot and decay. This will of course require some experimentation in placing the log and also in designing the spillway, if one is desired to facilitate fish passage and centralize scour pool

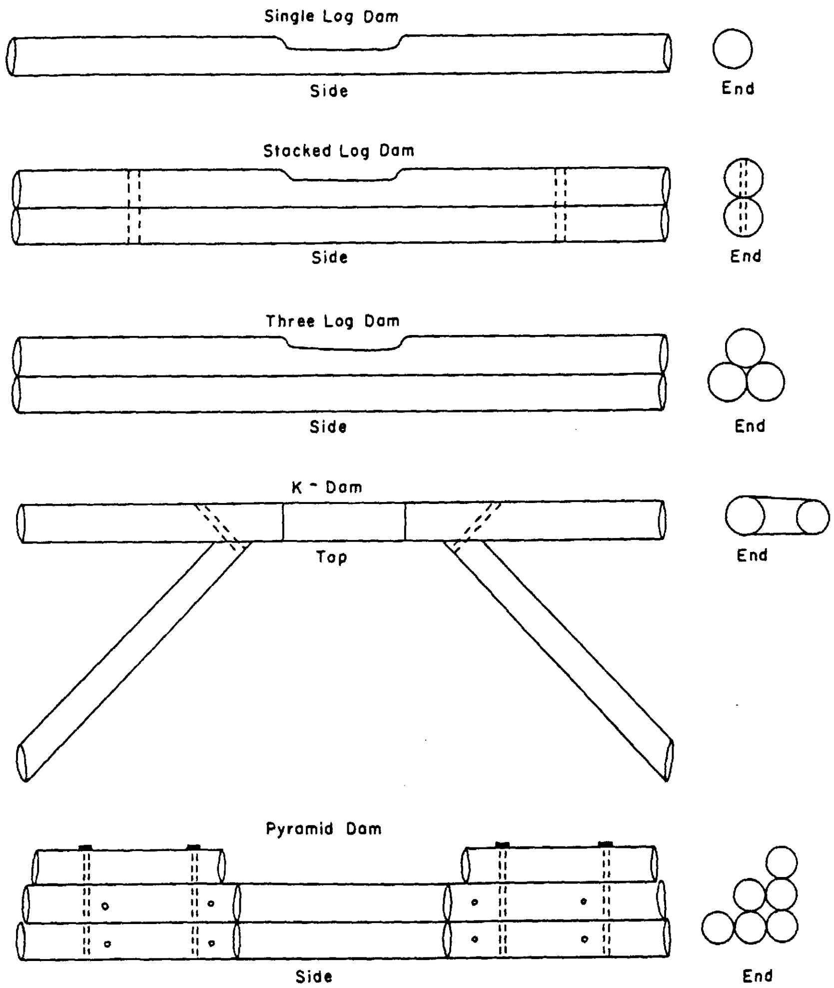


Figure 5.5 Various types of log dams.

development. Based upon the literature, life expectancies in the range of 20 to 40 years are not out of the question.

If the primary purpose of a dam is to raise the upstream water level, obtaining a good seal on the upstream face is the key to success. If the dam is several logs high, the logs should be hewn smooth so that they lie flat against each other, thus minimizing leakage. To lessen seepage under the structure, a wire and gravel mudsill should be added to the upstream face as shown in Figures 5.6 and 5.7. Bender (in Oregon Dept. of Fish and Wildlife, 1978) reports success by sloping gravel up the upper face of the logs, overlaying this with fence post-type stringers attached to the log parallel to the flow,

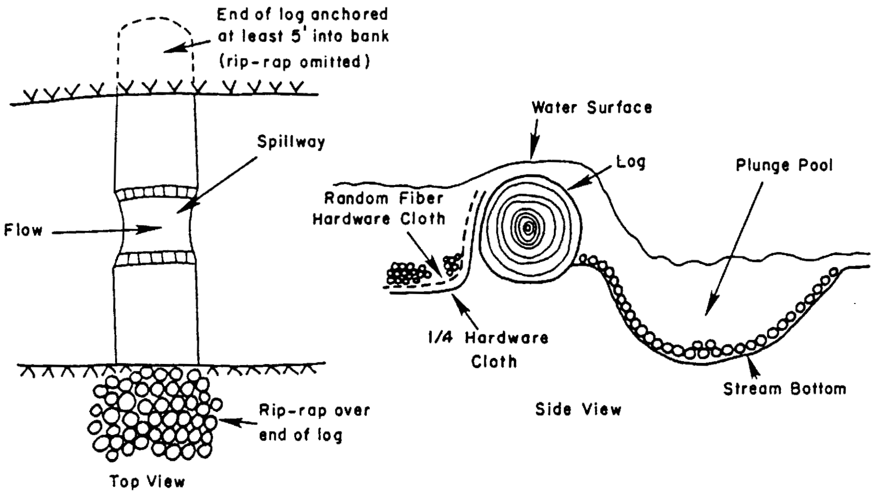


Figure 5.6 Single log dam.

covering the stringers with cyclone fencing, and then applying a final covering of gravel. Alvarado (1978) recommends that the height of the seal shouldn't exceed ⅔ the height of the logs. Maughan et al. (1978) found a plank fronting similar to that described by Bender to be more effective than using just wire mesh.

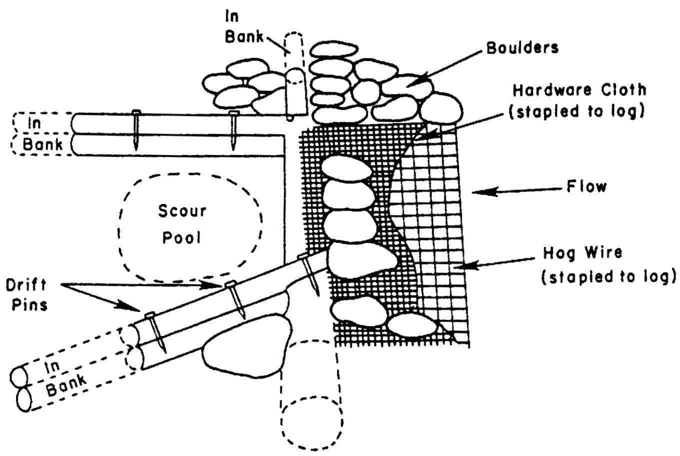


Figure 5.7 K-dam.

Probably the simplest, easiest to construct, most effective, and most commonly used log dam is the *single log dam.* Construction details are provided in Figure 5.6, while Figure 5.8 illustrates the installed structure. Generally, it is used in smaller streams up to 5 or 6 m wide when deepening of pools in the range of 0.15–0.3 m or formation of small scour pools is desired. Richard (1963) reported construction time as being 16 hours per structure when using logs approximately one meter in diameter, while Gard (1961) found that 4.5 hours per structure was required. Cost of the structures will of course vary with location, labor, stream width, and site characteristics, among other factors. Bailey (1982) reported that single log weirs averaged about $850 each, while Coffin (1982) found that single log dams cost $210 per structure, with $180 of this total being for labor, the remainder for materials.

A somewhat more stable variation of the single log dam is the *K-dam,* which derives its name from the configuration of the structure once the two downstream braces have been added (Figure 5.5). Figure 5.7 shows construction details with a wire and gravel mudsill in place. The Wyoming Game and Fish Department (1982a) reports the *K*-dam to be a "good solid structure with good results" when installed on a stream 7 to 9 m wide using a log 0.4 m in diameter. Richard (1963) also found the *K*-dam to be more sturdy than single log structures, although

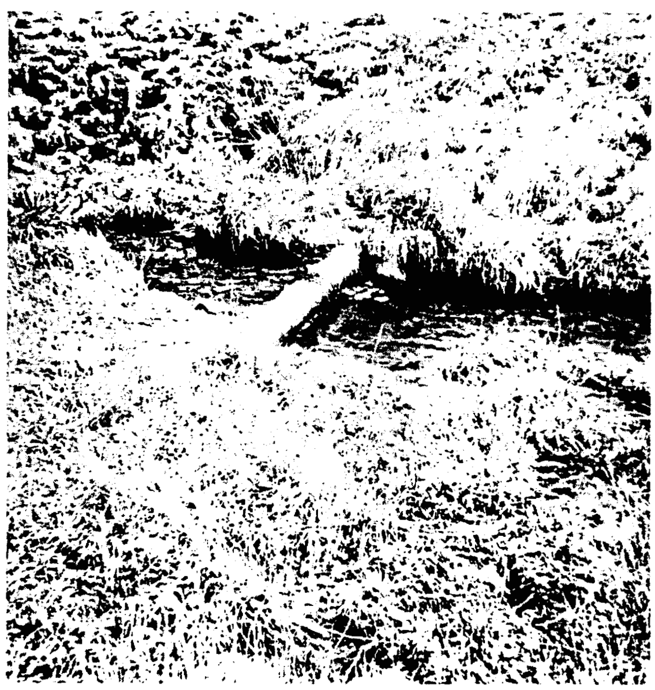


Figure 5.8 Single log dam in place.

it required more construction time (41 hours compared to 16 hours). Seehorn (1982) reports that a crew of four to six people could construct 1 to 1.5 structures per day on streams 3 to 4 m wide.

The *plank or board dam* is another variation of the single log dam which has met with some success (Duff 1982). Also known as the Hewitt Ramp (White and Brynildson 1967), the principal advantage of the structure is that undercutting action is shifted from the base of the main log upstream to the point where the planks, which extend upstream from the top of the main log, intersect the streambed. This also protects the gravel seal on the upstream face of the main log. White and Brynildson caution that the structure should only be used on steep gradient reaches where water will not be impounded upstream for a distance greater than 5 channel widths. The important pool formed is the one scoured out below the structure. Disadvantages of the structure, as reported by the Wyoming Game & Fish Dept. (1982a), are that it is difficult and time consuming to install and seal, the result being an extremely costly structure.

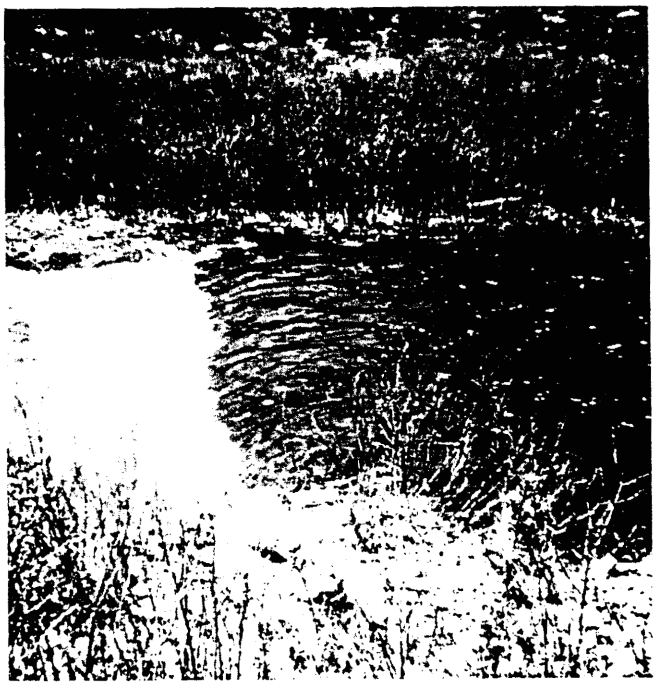
The fourth general type of log dam is the *wedge or V-dam.* Generally, there are two advantages of this type over the *K*-dam. First, the wedge dam can be used on slightly larger streams because there are two shorter logs which form the wedge or *V,* and together span the entire width of the stream. With the *K*-dam, a single log must traverse the entire stream, making it more difficult to maneuver. Secondly, the wedge dam is less prone to undercutting (Seehorn 1982).

The design of the wedge dam is such that the wedge or *V* points upstream. The two main logs face upstream at 45° to the streamflow and are pinned together with rebar at midchannel. The ends of the main logs are, of course, well anchored into the banks. The two brace logs, very similar to the braces used on *K*-dams, are pinned to the main logs at approximately 90°, with the other ends well anchored into the banks. If necessary, a mudsill can be added to the upper faces of the main logs to prevent undercutting. All banks in the immediate vicinity of the structure must be well riprapped, especially on the upstream end where the wedge will tend to force the current toward the banks. Seehorn (1982) estimates that a crew of four to six can construct 1 to 1.5 wedge dams per day, depending upon stream size.

Gabion Check Dams. Gabion check dams have probably not been used as extensively as log dams primarily because they are quite expensive, time-consuming, and at times aesthetically unpleasing. Cooper and Wesche (1976) and the Wyoming Game & Fish Dept. (1982a), have, however, found that excellent habitat can be created. Possibly the best application of gabion dams would be in wide, shallow streams and rivers lacking pools and having an abundance of coarse gravels. As gabions can be laced together to form any width or configuration of structure desired, a low dam could be built without the aid of heavy equipment. By comparison, such equipment would definitely be needed to set a 10 m long by 0.4 m wide log in place.

A gabion check dam is illustrated at both low and high flow in Figure 5.9, while Figure 5.10 presents construction details. The following description of the

(a)



(b)

Figure 5.9 (a) Gabion check dam immediately after construction. (b) Gabion check dam at high flow.

step-by-step procedure for building an 8 m wide gabion dam is summarized from Cooper and Wesche (1976).

First the stream bed where the structure would lie was leveled. While this was being done by two crew members, others were preconstructing the gabion structure on the bank. This consisted of first cutting eight 2.0 m x 0.75 m x 0.15 m cells from the factory gabions. Four of these were laced end-to-end making the base of the dam 8 m long and 0.75 m wide. The other four baskets were also laced end-to-end and one of the lower edges was laced to the corresponding upper edge of the first row of baskets. This made a structure 0.3 m high, 0.75 m wide, and 8 m long.

The stream bed, where the upstream edge of the dam would be, was then dug down 0.3 m (the height of the structure) and sloped as shown in Figure 5.10. This allowed the two rows of baskets to be laid into the excavation in a sloping manner, thus creating the ramp and dam. The upper row of baskets was then folded back so that the lower row could be filled with rock from the dredge piles. When this was complete, the top row of baskets was once again folded over the bottom row and laced down so that it became the lid for the bottom row. The top row was then filled full with 0.1–0.15 m diameter rock. At this point, a layer of rubber mat was draped over the rock in the top row of baskets and tucked in around the edges of the gravel. This was done to completely seal the structures so no leakage could occur through the spaces between the fill rocks, and to facilitate the movement of high flows over the dam and resist scour. Another layer of rock was then placed over the mat to conceal it, and the lid was laced on to complete the structure. Wherever the ends of the structures abutted the stream banks, they were dug back into the banks to prevent erosion around the ends, covered with bank material, and then reinforced with boulders.

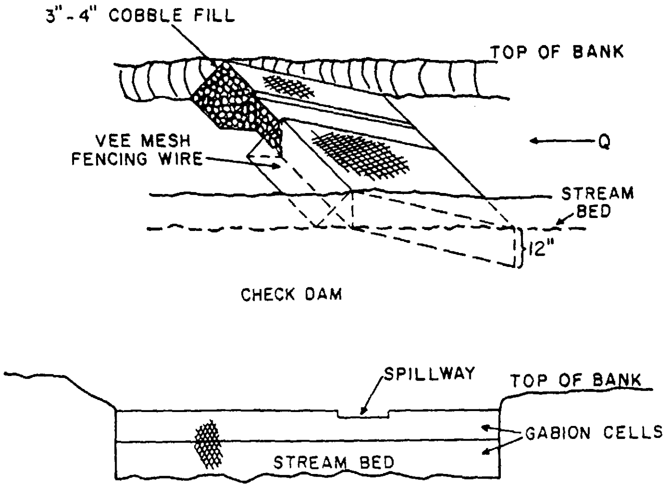


Figure 5.10 Design of gabion check dam.

Next, using the basic continuity equation $Q = VA$, the desired cross-sectional area of the spillway could be determined by knowing the minimum desired velocity through the spillway, and the discharge. Location of the spillway in the structure was determined by location of the thalweg through the structure area, while height of the spillway was determined by the height of the bank cover upstream from the dam. It was found that the spillway should be located as near the thalweg line as possible, but not right against the bank. This maintained the natural pattern of flow through the pool and still avoided scour at the channel banks, while maximizing the depths at the bank cover immediately upstream. Construction of the spillway was accomplished by first choosing the location based on the above criteria. The depths desired in the upstream pool, as well as the desired length of the pool, were then noted. When the width and depth of the spillway were thus decided, the upper basket of the dam was cut open at the desired place, and fill rocks were removed or hand placed until the correct spillway was formed. The rubber mat within the upper baskets was formed to fit the spillway, and the gabion was then molded to fit the depression and laced shut.

The final step in construction was the addition of the *V*-mesh downramp on the downstream edge to prevent undercutting of the check dam at high flow by not allowing an abrupt plunge to occur, except in the area of the spillway. The plunge pool formed below the spillway thus created a standing wave sufficient to aid trout in passage over the check dam even at low flow.

Beaver Introduction. A final type of treatment that can produce results similar to low-profile dams without any of the artificiality associated with such construction would be beaver introduction (reintroduction) and management. The influence of beaver on wildlife has long been recognized. In regard to salmonid habitat, beaver dams can play a key role in creating pools and escape cover as well as regulating flow, temperature, and sediment transport regimes. Especially in low-order, headwater streams, where low-profile dams are typically constructed, beaver activity can have a strong influence on the numbers and biomass of trout supported. Gard (1961) found that in some cases streams with beaver ponds had up to six times the total weight of salmonids than did adjacent habitat lacking ponds. In western mountain streams where the availability of riffles and spawning areas is typically not severely limiting, beaver ponds can provide critical rearing and overwintering habitat (Munther 1982). Also, by raising water tables, beaver dams can have a positive effect on the development or rehabilitation of riparian communities (Smith 1980), which in turn can provide additional bank cover and organic matter for the aquatic system.

Other In-Channel Treatments

Boulder Placement. The placement of individual boulders or boulder clusters is one of the simplest and most commonly applied in-channel treatments that can improve habitat on streams of any size. Generally, boulder placements are made with one or more of the following management objectives in mind (Claire 1980):

- provide additional rearing habitat;
- provide fish cover;
- improve pool-riffle ratios;
- restore meanders and pools in channelized reaches;
- protect eroded banks by deflecting flow.

While the literature detailing the results of boulder placements is not abundant, most applications appear to have been successful. Barton and Winger (1973) reported good results in forming holes on the Weber River in Utah, while on the St. Regis River in Montana, Lere (1982) found that after eight years a majority of the boulders were still functioning properly and that trout numbers were greatest in a river reach mitigated with random boulders. Knox (1982) found that random boulders placed in the Eagle River (Colorado) were successful in creating pool habitat in a channelized reach. In British Columbia, Haugen (1978) noted a twenty-fold increase in coho salmon numbers one year after rock clusters were installed on the Keough River, while in Wyoming, the Wyo. Game & Fish Dept. (1982b) reported boulder placements were successful in creating in-stream habitat in "rubbly glide" reaches of the Green River below Fontenelle Reservoir. Also, Kanaly (1971) found that the trout population in a channelized section of Rock Creek mitigated with large boulders quickly recovered to levels comparable with unaltered reaches.

Boulders can be placed either randomly or selectively, in clusters or individually. This will depend primarily upon the best judgment of the project biologist, the size of the stream, and the pattern of natural boulders in the river reach. Figure 5.11 illustrates several of the placement options available. While siting and construction considerations may not be as critical for boulder placement as for other in-channel treatments previously discussed, the following observations may be of help in the conduct of a successful project:

- Placement should be done during low flow to assure proper location and facilitate movement of heavy equipment in the channel.
- Boulder size will depend on stream size, flow characteristics, and bed stability, as well as the size of heavy equipment available for the project. Claire (1980) recommends rock in the 0.6 to 1.5 m diameter range, while Kanaly (1971) reported success using 1.5 m wide boulders. The U.S. Bureau of Land Management (1968) recommends that material in the 1 to 2 cubic meter size range be used.
- The harder the rock used, the better. Granite is much preferred over sandstone.
- Embedding the boulders a short distance into the streambed will result in a much more stable situation.
- Placement near streambanks should be done with caution to avoid erosion.
- The U.S. Forest Service (1969) has found that boulder placements will have their greatest effect on fish populations when employed in stream reaches having less than 20% of the area in pools.

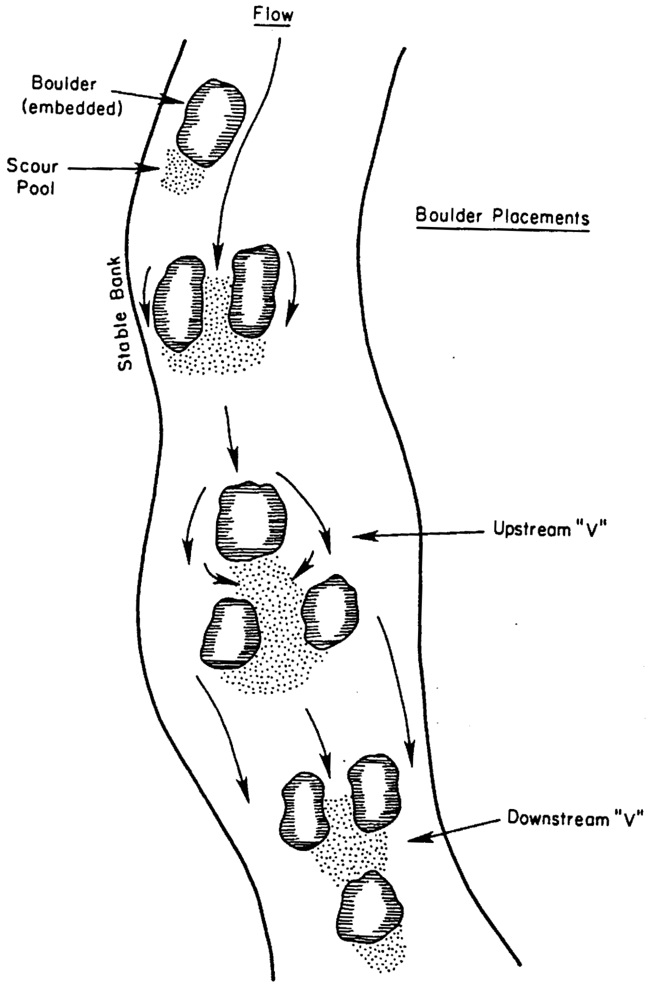


Figure 5.11 Boulder placements.

- The economics of any project will be greatly enhanced if natural material is available at the site.
- If the project stream is used for rafting and boating, this should be taken into consideration when locating the boulders.
- To avoid damage to the channel, the heavy equipment used should have rubber tires.

For locations on larger streams inaccessible to heavy equipment, Cooper and Wesche (1976) designed and tested a gabion structure, termed an *artificial boulder*, for creating additional holding water and cover for trout. Figures 5.12

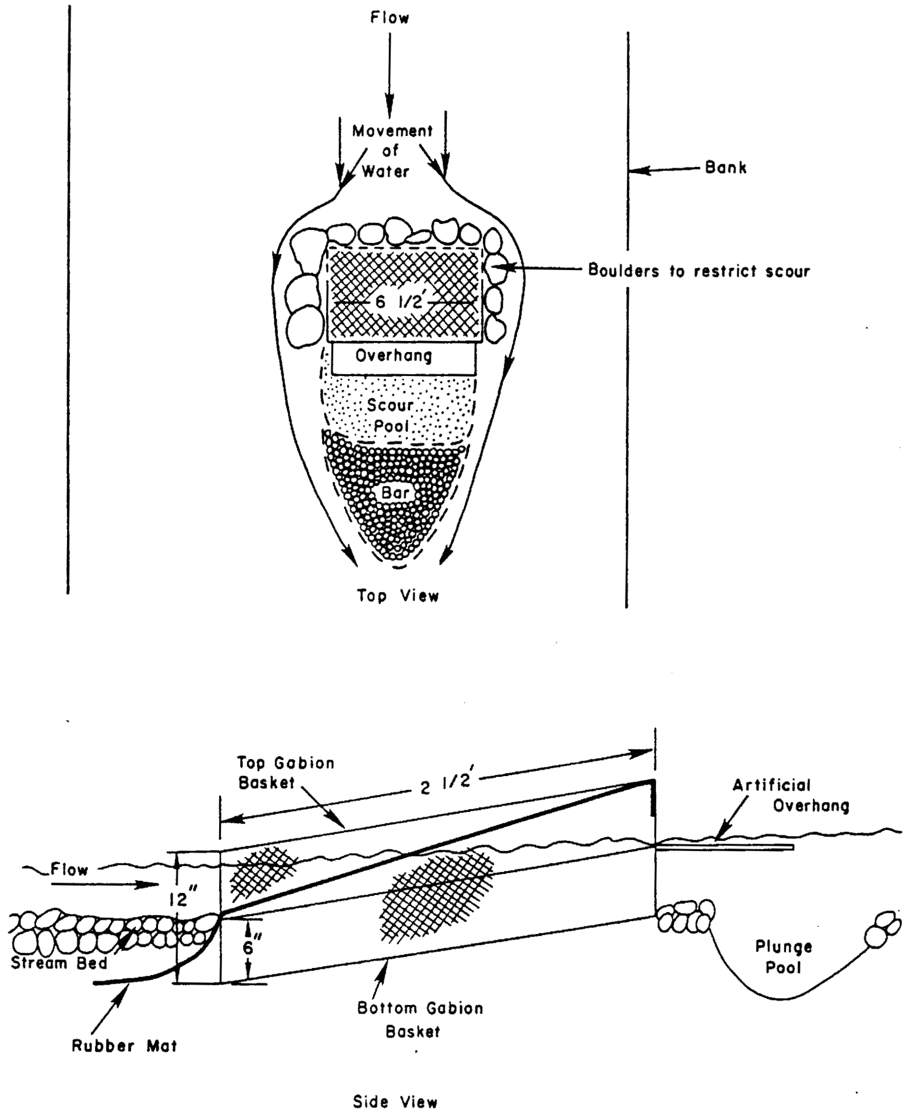


Figure 5.12 Design of artificial boulders.

and 5.13 present construction details of the structure, while Figure 5.14 shows a completed structure installed on the Blacks Fork River of southwest Wyoming. Testing of the structure on Douglas Creek and the Blacks Fork indicated that discharges in excess of 28 m³/sec could be withstood (two out of eight did wash out). Also, the design of the structure does allow for attachment of an artificial overhang to provide overhead cover and formation of a gravel bar (spawning-sized gravel) on the downstream side (Wesche 1976). However, the structures

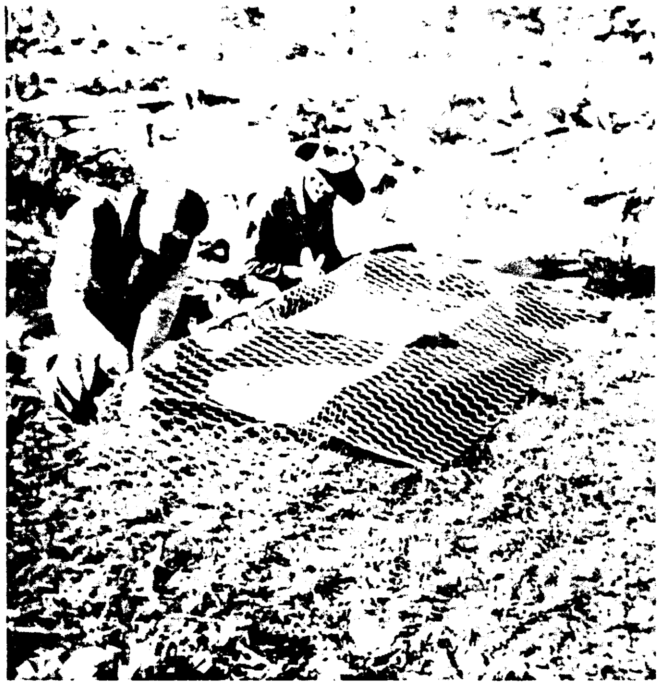


Figure 5.13 Lacing gabion cells together to form artificial boulder (rubber mat in place).

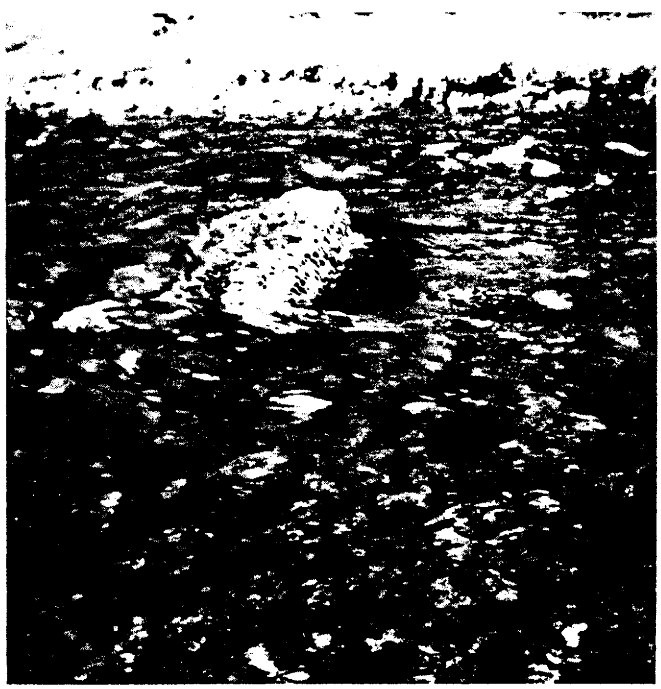


Figure 5.14 Completed artificial boulder.

are quite expensive to build, time consuming (at least eight hours per structure), and need to be extremely well anchored by 1–2-m-long rebar pins on both the upstream and downstream faces. For these reasons, application of artificial boulders is considered to be quite limited.

Trash Catchers. Trash catchers or barriers are easily constructed habitat reclamation devices that can be used to create pools, increase stream surface area, provide cover, slow velocities, and hold spawning gravel in place. While generally they are used in small, headwater streams to function much like low-profile dams, they can also be used in large streams to provide isolated pockets of cover. The primary use of trash catchers has been in the higher gradient mountain streams of the western United States (Wyoming Game and Fish Dept. 1982a; Navarre 1962; Knox 1982; Oregon Dept. of Fish and Wildlife 1978; Rinne and Stefferud 1982; Coffin 1982).

Navarre (1962) presents the following construction details for building a simple trash catcher across the entire width of a small stream:

1. The materials needed include steel fence posts (2 m long), 0.8 m hog wire (.08–.15 m mesh), and #12 galvanized tie wire.
2. The structure is sited using the criteria discussed above for low-profile dams.
3. The fence posts are cut in half and the 1 m sections are driven into the streambanks and bottom at 0.6 m intervals with approximately 0.2 meters left protruding above the low water level. The last post on each bank is placed just above the high water line.
4. The top of the hog wire is attached to the steel posts by a double strand of tie wire.
5. The hog wire is also attached to each post at two other locations.
6. The remaining hog wire is bent upstream and rocks are piled on the upstream edge to hold it in place.

Once constructed, the theory of operation is that the wire mesh will fill with silt, debris and gravel, thus forming a low dam. Navarre estimated that construction costs of trash catchers were only one-third to one-sixth of that required for log dams. While they are time and cost efficient as well as adequate producers of habitat, trash catchers can be aesthetically unpleasing if careful attention is not paid to detail (Figure 5.15). Also, their longevity can be hampered by the wire rusting out.

In larger streams (greater than 7 to 10 m wide), small, isolated trash catchers which do not traverse the entire channel width can be installed to create instream pockets of cover. For aesthetic purposes and to avoid collecting large pieces of drifting debris which could wash out the structure, the top should be located slightly below the low water line, as shown in Figure 5.16.

Half-logs. Another very simple but effective device for adding in-stream cover to almost any channel is the half-log. Johnson (1982) reports that electrofishing

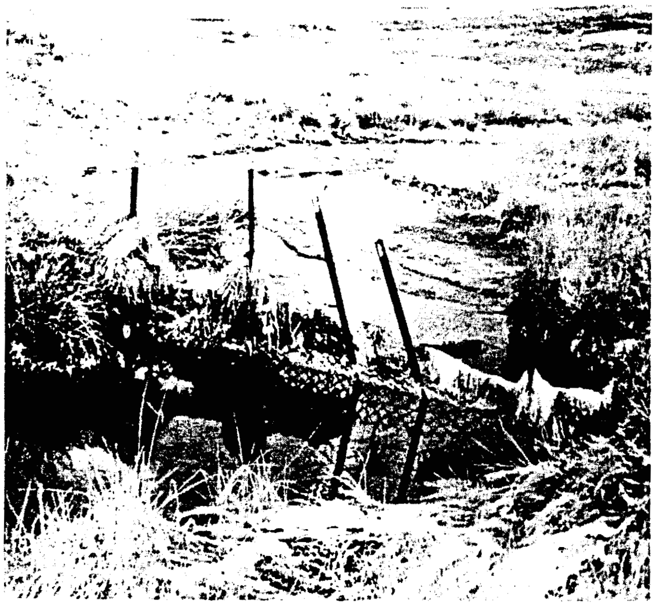


Figure 5.15 Trash catcher on small stream.

in Wisconsin streams has shown that trout are found utilizing a high percentage of these structures. Construction details and overall channel layout are provided in Figure 5.16.

Substrate Development

As previously discussed, current deflectors and low-profile dams can be used in a variety of ways to improve the substrate component of a stream habitat. These include the removal of fine sediment deposits, the collection of spawning gravels upstream from structures, and the development of gravel bars downstream. Boulder placement to enhance cover has also been discussed. Another useful tool in habitat reclamation can be the introduction of properly sized substrate particles to enhance macroinvertebrate production (as discussed in the previous chapter) and spawning success.

There can be a variety of reasons why spawning gravels need to be added to a stream habitat, including flood scouring, dredging activity, channelization, and natural deficiencies. For spring-fed creeks not subject to exceptionally high runoff flows, the addition can be made by first determining the size of gravel required by the fish population; second, selecting favorable locations for gravel

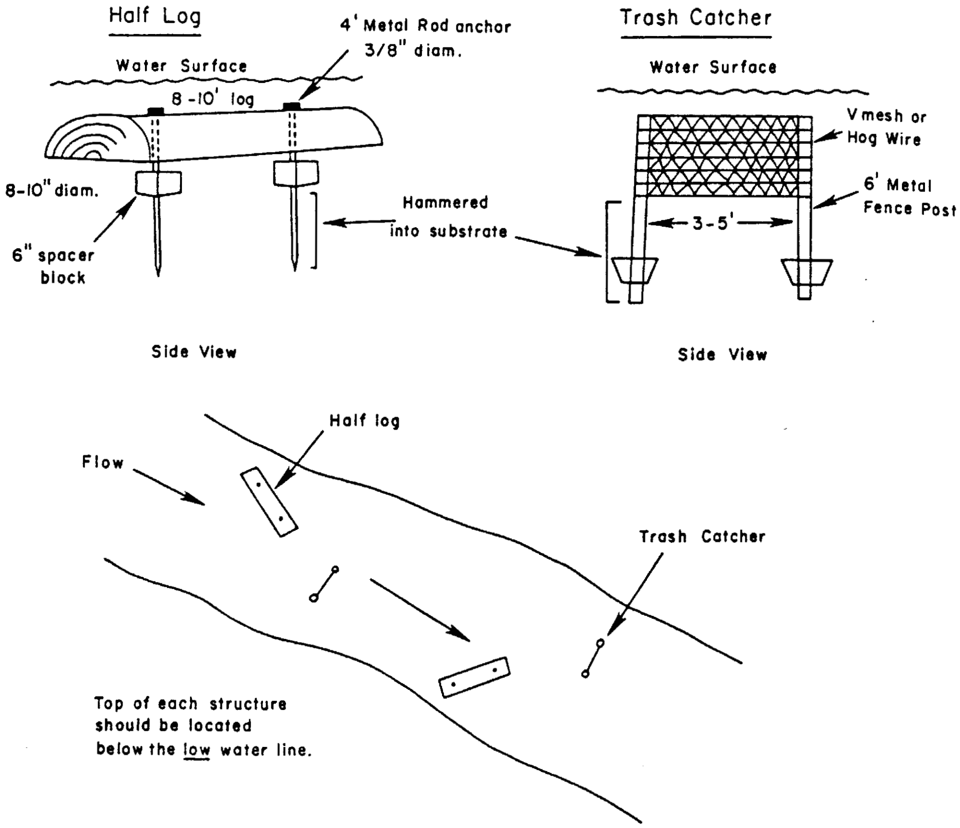


Figure 5.16 Design of half-logs and trash catchers on larger streams.

addition (pool-riffle interchanges are ideal); third, excavating the existing stream bed to a depth of 0.4 to 0.6 m to remove cobbles and other large particles that might interfere with redd construction; and fourth, filling the excavation with the proper sized gravels. Using a technique similar to this, the Wyoming Game & Fish Dept. (1982c) reported an increase in spawning activity of 4100% over ten years in Three Channel Spring Creek, a tributary of the Snake River.

On streams subject to high runoff, it will be necessary to install stabilizing structures such as gabions or logs firmly into the bed below the excavation to hold the gravels in place. The key to success will be the anchoring of the structures. Techniques to stabilize low-profile dams such as those described above should be employed. Both Fortune (1978) and Bender (1978) report successfully developing spawning beds in this manner.

Before proceeding with a spawning gravel introduction, Claire (1980) cautions that several factors should be given consideration. First, the reason why natural gravels are not available should be determined. If flow and gradient characteristics are such that the gravels are constantly being scoured out, introduction should not begin until suitable structures are in place to slacken the current. Second, if the watershed is in poor condition or is naturally prone to be a high producer of fine sediments, spawning success may be limited regardless of the temporary availability of gravels. Third, as the purchase and transport of gravels to the site can be expensive and time consuming, careful attention should be paid to selecting sites that are easily accessible and/or have suitable quantities of natural gravel available.

Bank Cover Treatments

The habitat value of streamside cover such as undercut banks, debris jams, and overhanging vegetation has been well documented in the literature and discussed earlier in this chapter. In habitat reclamation, there are four general types of treatments that can be applied to create or enhance available bank cover, including log/board overhangs (Figure 5.17), artificial overhangs of metal or fiberglass (Figure 5.18), tree/brush retards (Figure 5.19), and riprap (Figure 5.20). Each of these treatments provides excellent bank stabilization in addition to cover, with the possible exception of artificial overhangs. While each of these treatments can be applied

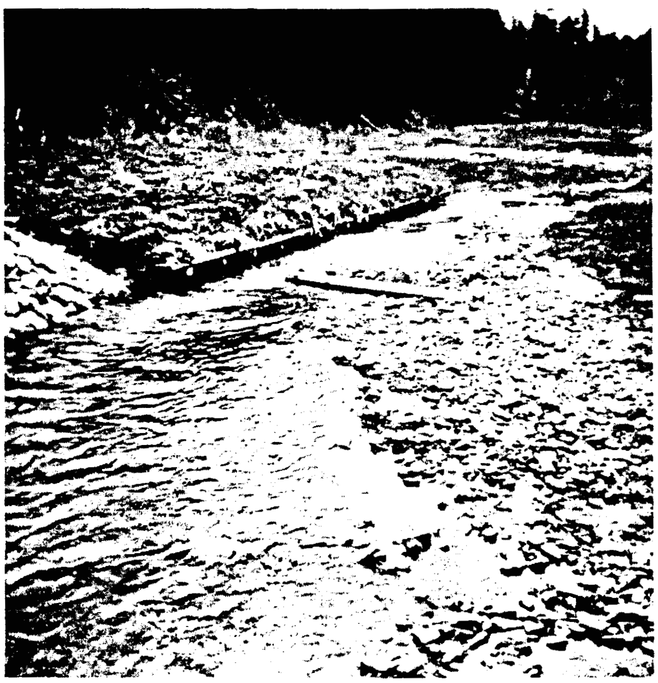


Figure 5.17 Log and board overhang.

Figure 5.18 Corrugated metal artificial overhang.

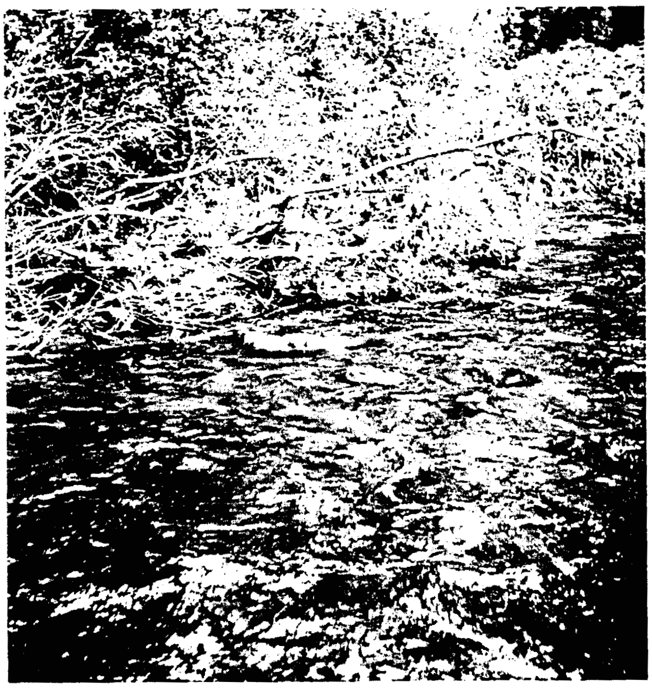


Figure 5.19 Tree revetment.

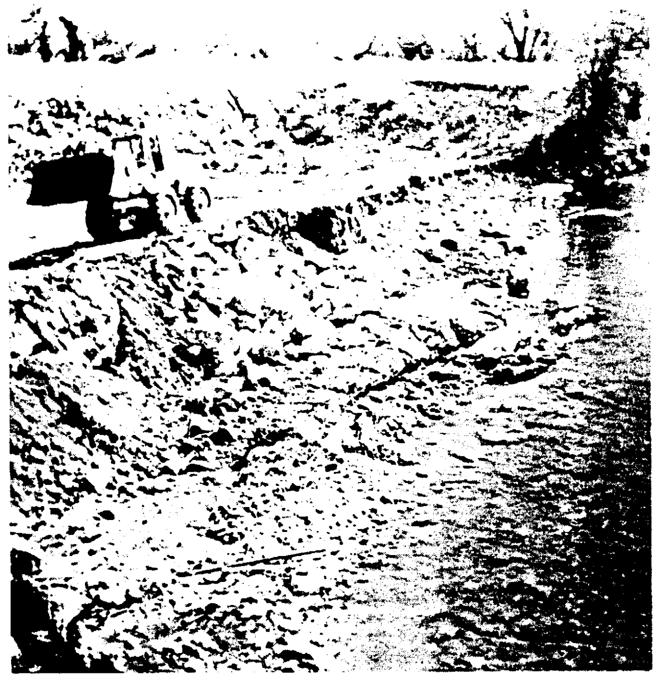


Figure 5.20 Riprap.

by themselves to enhance habitat, oftentimes they are installed in conjunction with other reclamation structures such as current deflectors or low-profile dams. If properly done, they can assume a natural appearance and blend well into the stream setting. Certainly, there is no place in river reclamation work for a bank treatment such as shown in Figure 5.21.

Log Overhang. The simplest type of log overhang is that described by Seehorn (1982). A cover log of suitable diameter (at least 0.3 m) and length is selected for the situation at hand. Several abutment logs are well anchored into the stream bank by digging and the cover log is pinned to these using rebar, thus forming the overhang. A variation of this would be to cut a long notch in the cover log (the notch will form the cover area for the fish), fit the log up against the bank to be treated (notched side down), and secure it to the stream bottom using 1.2 m lengths of rebar. Seehorn recommends placement of log covers on stream banks opposite current deflectors to prevent erosion as well as provide cover.

White and Brynildson (1967) describe a somewhat more elaborate log and board bank cover device, as pictured in Figure 5.17. General steps in construction are as follows:

1. Log pilings, spaced approximately 0.5 to 1 m out from the existing bank and approximately an equal distance from each other, are sunk (jetted) securely down into the stream bed.

2. Log or board stringers, securely anchored into the bank, are then run from the bank out to the pilings. Spikes or pins are then driven through the stringers into the tops of the pilings to secure them. This forms the support structure for the planks that serve as the overhang.

3. The planks are then laid over the stringers, parallel to the streamflow, and nailed in place.

4. Rock riprap is then applied over the planks as well as on the disturbed bank behind the device.

5. Soil and sod can then be applied on top of the riprap to complete the device.

While this type of overhang has been found to function well in midwestern streams having relatively stable flow patterns, results have been mixed in the West. The Wyoming Game & Fish Dept. (1982a) reports that while several have been successful, the tremendous stream flow fluctuation in Wyoming streams prevents them from functioning efficiently at all times.

Artificial Overhangs. Artificial overhangs constructed of corrugated steel and fiberglass were found to provide usable trout cover by Cooper and Wesche (1976). Figure 5.18 shows one such device installed while design detail is provided in

Figure 5.21 Car bodies for bank stabilization, ineffective in this case as well as aesthetically unpleasing.

Figure 5.22. Strap hinges were used in the construction to provide some degree of flexibility with changing flow and ice conditions. Investigations into the color of the overhangs concluded that a flat black or mottled brown rendered the structures quite inconspicuous, virtually invisible at times, depending upon light and background conditions. Anchoring of the structure was provided by driving the rebar pins securely into the stream bank. Overall, this type of artificial overhang was found to be effective, cost and time efficient, adaptable to a variety of bank conditions, and relatively stable. Installation must be done at low-flow to ensure that the structure will always remain under water. Several boulders placed under the overhang were found to enhance the cover provided and also served to protect against bank erosion. For locations where bank stabilization is the highest priority, overhangs of this type are easily used in conjunction with rock-filled gabions, as shown in Figure 5.23. As with any type of metal device used for river reclamation, particular attention must be paid to the aesthetics of the project.

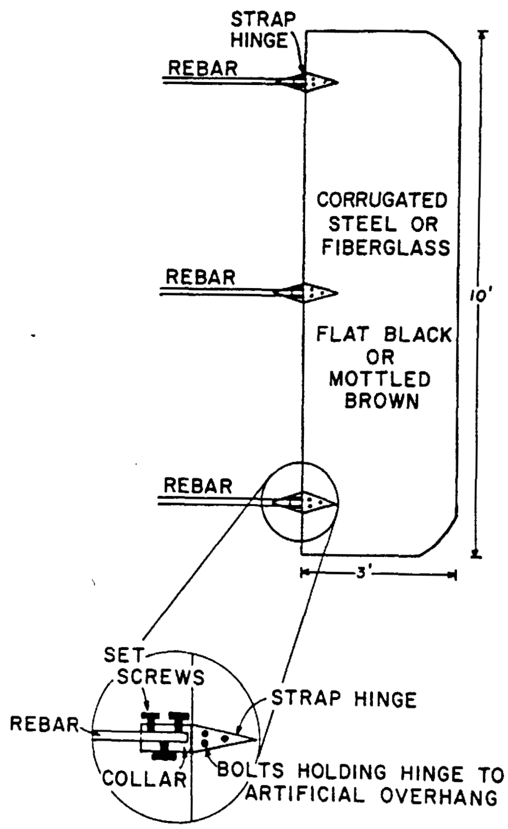


Figure 5.22 Design of artificial overhang.

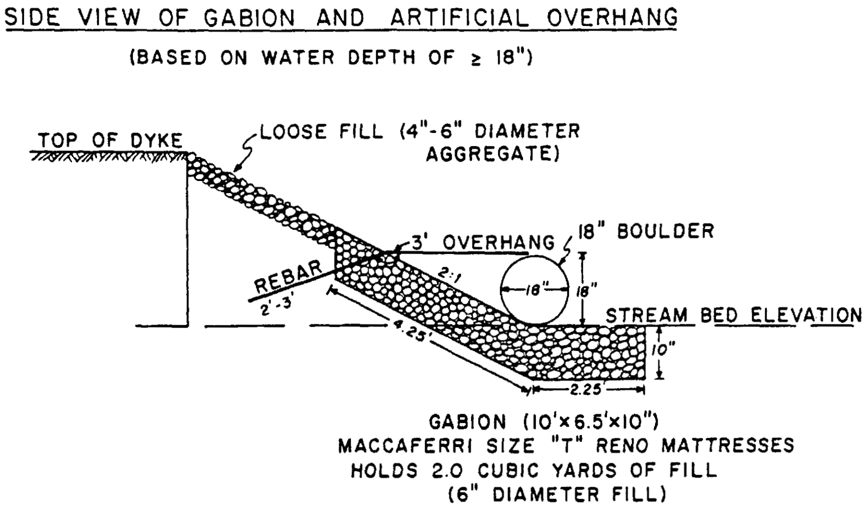


Figure 5.23 Combination of gabion and artificial overhang to provide bank stabilization and cover.

Tree Retards. A treatment that not only provides effective trout habitat but excellent bank stabilization as well is the use of tree retards (Figure 5.19). Sheeter and Claire (1981) found the use of juniper trees to be an effective method to stabilize high eroding banks on the South Fork of the John Day River in Oregon. The size of trees cut and used depended upon the personnel and equipment available. Generally, trees greater than 0.15 m in diameter required a tractor for placement. The junipers were placed, one per meter of bank, down over the edge, angling downstream, and their butts were tied to anchors located at least 1.5 m back from the bank's edge using #9 smooth wire. Two types of anchors were used, fence posts sunk deeply into the bank or a heavy cable line "dead manned" into the bank. Green trees with bushy crowns were preferred over slender ones. Using this procedure, the project was evaluated as a success. Mean water velocities near the bank were reduced by about two-thirds and silt deposits of up to 0.6 m deep were found in the tree tips the first year after placement, allowing native plant succession to occur. Only a 4% failure rate was noted, with improper anchoring and placement on outside curves the main reasons for failure.

The Wyoming Game & Fish Dept. (1982a) has also reported success using tree retards. Generally, conifer trees 9–18 m long and 0.25–0.4 m in diameter have been used, with the anchoring similar to that described above. If rock riprap is placed under the trees, the trees are overlapped about one-third. An overlap of one-half is recommended if riprap is not available.

Tree retards can be an excellent structure to install in newly channelized reaches. Generally, the materials needed will already be available at the site due to clearing activities; installation is relatively easy and not time consuming; excellent holding water can be immediately created to maintain a fish population while the new channel is developing and maturing; and, the result is aesthetically pleasing. Gore and Johnson (1980) reported that in a newly rechanneled portion of the Tongue River in Wyoming, such snags were the most frequently used areas by fish.

Riprap. A fourth method of lower bank treatment is by the placement of riprap (Figure 5.20). Not only does riprap provide fish cover and macroinvertebrate habitat, bank erosion can also be slowed or stopped, thereby allowing recovery of natural vegetation. Claire (1980) recommends that dense, angular, nonerodible pit run rock ranging in diameter from 0.1–0.8 m be used, with at least 50% of the material being in the 0.15–0.6 m size range. To improve the habitat and the aesthetic effects of riprap, the alignment should not be too straight or regular. For example, by varying the design only slightly, rock jetties, such as were previously discussed, can be formed. These can assist in pool deepening and habitat development, especially in new channels or channelized reaches.

To ensure the success of a riprap project, especially where long sections of bank are to be treated, it is strongly recommended that an engineer be directly involved. If this is not possible, advice should be sought from a source such as the State Highway Department. Their expertise can provide a more site-specific evaluation of such factors as bank slope; stream velocities; size, shape, gradation, and specific gravity of rock; and desired thickness of the covering. Such involvement will facilitate the development of the most time- and cost-efficient plan to meet the reclamation goals of the project.

Other bank treatments, such as revegetation and fencing, can also play a critical role in the success of any river reclamation project. Discussions of these treatments will be found in other chapters of this book.

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