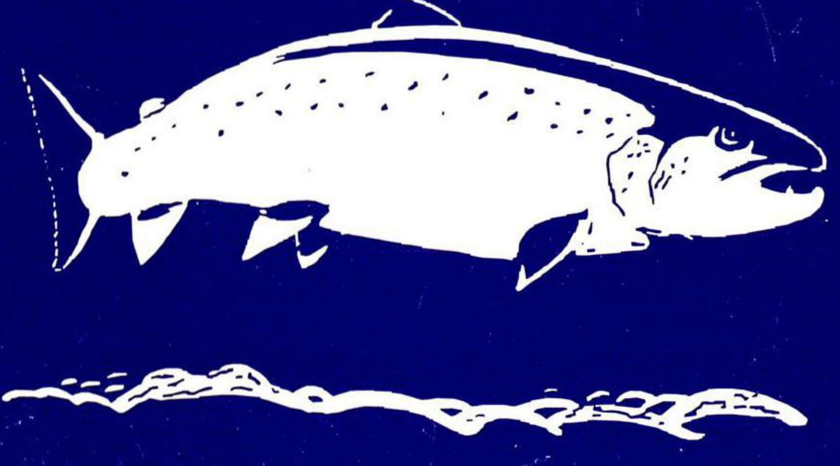
ATLANTIC SALMON TRUST

Habitat Restoration for Atlantic Salmon

Bensinger-Liddell Fellowship 1996/7

David W.J.Smart



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Acknowledgements

I would like to take this opportunity to acknowledge the support of the Atlantic Salmon Trust (AST) and Atlantic Salmon Federation (ASF) and thank them for providing me with the opportunity to undertake this study and also for their guidance and assistance throughout.

Thanks must go to my employer, the Central Fisheries Board in Ireland, for allowing me to take a month's leave after only being in employment for four weeks! Martin O'Grady of the Central Fisheries Board deserves my thanks and appreciation for giving me his advice on stream rehabilitation for salmon and also for commenting on this report. Don Duff of the US Department of Agriculture, Forest Service and Trout Unlimited and Mike Crowe of the Department of Fisheries and Oceans, British Columbia should be mentioned for taking so much time to show me so many stream rehabilitation programmes in various parts of North America. They should also be thanked for organising study trips, helping with accommodation and advising on my itinerary.

Many thanks are also due to all colleagues, fishery biologists, fishery managers, habitat improvement managers, fluvial geomorphologists, and engineers and others that I have met throughout the undertaking of this Fellowship, who have all helped or advised me in one way or another. Finally, I should like to thank Derek Mills and Jeremy Read in particular for their advice during the preparation of this Report and help with the final editing.

Foreword

The last decade has seen habitat improvement become a countrywide practice in the rehabilitation of streams and rivers for fish and wildlife. Although stream bank stabilisation and in-river structures have been incorporated into river restoration programmes for many years more emphasis tended to be placed on artificial propagation and stocking of running waters with hatchery reared progeny. The pendulum has now swung the other way and habitat improvement has taken the leading role in fisheries and wildlife management. A number of people and organisations have shown us the way forward, particularly Martin O'Grady of the Central Fisheries Board of Ireland, the Tweed Foundation and the Environment Agency.

David Smart, the author of this Manual, has had wide experience in habitat management. After gaining an M.A. in Geography at Glasgow University he went on to undertake an M.Sc by research in Fluvial Geomorphology at the same university. While a postgraduate student he worked part-time as a Research Officer for the university's River Management Research Group. After a short spell with the Tweed Foundation as Habitat Improvement Assistant he joined the Central Fisheries Board of Ireland to work under Martin O'Grady. He was employed under the EU Tourist Angling Measure of the Tourism Operational Programme. He went on to become Project Manager and Technical Supervisor on various EU funded Fishery Development Programmes, including the Lock Ennell and Lough Sheelin Stream Development Programmes, the River Erriff Angling Improvement Programme and the Upper Erriff Habitat and Tawnyard Catchment Enhancement Programmes. He returned to the Tweed Foundation earlier this year to help with the fencing and planting programmes and to work with Forest Enterprise on a Forest Streams Management Plan for the Tweed Catchment. While employed by the Central Fisheries Board he was awarded the Bessinger-Liddell Fellowship by the Atlantic Salmon Trust to widen his experience by observing stream rehabilitation work in North America and to produce a report on the subject.

This well illustrated and informative account that David has produced will serve as an excellent instruction manual to all engaged in this type of fieldwork and will also be a useful text for those involved in fisheries management training. I commend it to you.

Dr. Derek Mills
Chairman, Honorary Scientific Advisory Panel
Atlantic Salmon Trust

Chapter 1 – Introduction

1.1 Introduction

The overall long-term goal of any management policy for Atlantic salmon is the creation or augmentation of self-sustaining salmon populations. The objective of many fisheries managers at present is to increase the number of adult salmon returning to their native rivers to spawn. There is considerable evidence available at present to suggest that many rivers are producing the maximum number of smolts for the existing area of good nursery and juvenile habitat available within the river catchment. For example, work done on the Girnock Burn, a tributary of the River Dee and on the River North Esk, has shown that although there are fluctuations in the numbers of returning adult spawners, the number of migrating smolts tends to remain relatively constant. This shows that increasing the number of returning salmon may not increase the productivity of the river in terms of juvenile recruitment or survival. Unless there is an increase in the quality and quantity of juvenile (fry and parr) rearing habitat, any additional egg deposition or the release of hatchery reared fry or parr will be wasted and will not increase smolt production or ultimately future catch returns. Hence, if fisheries managers want to increase salmon production, one of the first priorities should be to increase the quantity of nursery and spawning habitat or its quality, or both.

The aim must be to increase the natural production and survival of juvenile salmon in order to increase the number of returning adults, by establishing the best possible environmental conditions in the nursery streams. Therefore, the goal of self-sustaining salmon populations is only attainable if sufficient freshwater habitat is present, in both quality and quantity. This then paves the way for increasing the numbers of returning adults to utilise this habitat.

1.2 What is the rationale for this report?

The basic freshwater habitat requirements of salmon have been known for a long time and biologists have utilised this knowledge when initiating various habitat restoration projects for almost as long. However, most of this restoration work, until recently has been undertaken in North America. Therefore there is nothing new about habitat restoration, but what is new is the need for the practical and concerted application of these principles in the UK. At present in the UK site specific problems are sometimes dealt with in an ad hoc trial and error manner, although not ideal, this can be successful with common sense and good management. A catchment wide approach has been shown to be far more balanced and, in the long term, more productive and should be considered for more wide spread application.

Most of the instream structural techniques that have been successfully used and documented in North America are suitable for moderate energy streams with relatively low channel gradient. The proposal for this Fellowship identified a gap in the literature concerning the stability and success of structural rehabilitation in higher gradient gravel-bed environments, which tend to be the preferred spawning habitat for Atlantic salmon. Several different engineering techniques have been tried in these conditions and they have had mixed success. But what is lacking is the documentation of these successes and failures and the dissemination of this information so that others can learn. Upland rivers are less forgiving, more reactive, have greater sediment transport rates and are often unstable compared to their lowland counterparts. They are also often more dynamic, particularly in terms of bed sediment transportation, even when they are in an undisturbed state. Badly designed stream restoration schemes will quickly be destroyed as the channel responds to imposed structures (i.e. dredged pools will fill in quickly). Compared to lowland rivers, the higher energy conditions in upland rivers mean that the options for structural rehabilitation and habitat creation are different and there are fewer to choose from. The development of sympathetic design procedures which are in harmony with local river conditions are needed to prevent excessive channel instability (remembering that a moderate degree of erosion is natural). In lowland rivers however, there is more flexibility with regard to possible structural enhancement measures because these rivers are relatively stable and only transport small amounts of bed material.

The general lack of documentation on both successful and failed projects was identified by the Scottish Salmon Strategy Task Force in their report to the Secretary of State for Scotland in February 1997 - *"there is a need for a code of practice on riverside and in-river engineering works."* (Recommendation 47). They also identified the importance of an understanding of instream engineering and its effects on the quantity and quality of salmon habitat. In their recommendations they also suggest that, *"Area Fishery Boards (amalgamations of DSFB's) should* *have the status of statutory consultees on all development proposals which might affect salmon habitat and fisheries, including the obstruction of rivers for whatever purpose and activities such as road construction, land drainage, river engineering and gravel extraction"* (Recommendation 45).

The initial Fellowship proposal was to identify and evaluate structural techniques that have been successfully used to restore freshwater salmon habitats in North America, and produce a guideline document (or code of practice) outlining conditions for their use in certain environments and highlighting the geomorphological reasoning for their use in particular locations. Since the original proposal, several guideline documents have been published such as *The Restoration of Riverine Salmon Habitats – A Guidance Manual* (Hendry & Cragg-Hine 1997), which have highlighted designs of structures and covered much of the theoretical background to their use and placement that had been previously misunderstood or ignored.

Most of the traditional habitat restoration techniques that have been implemented since the sixties, are still used today. There are few particularly new or innovative structural techniques used to restore degraded riverine salmon habitats. Many structures that are implemented at present in North America are only slightly modified versions of those used in the past. The difference with then and now, is that there is an improved understanding of structures and river morphology and how they interact, and it is this that needs to be encouraged in the UK. This report aims to cover recent changes of emphasis in stream habitat restoration in North America, and describes any new or modified structural techniques that are being developed by fisheries biologists in North America.

1.3 Itinerary

The Fellowship was conducted during two field tours to North America and information was also gathered whilst employed in fisheries, both in Scotland and Ireland. The first visit to North America was a fact-finding mission to the 10th International Stream Habitat Improvement Workshop in Corvallis, Oregon. This was an international gathering of fisheries scientists from both public and private interests that were involved or interested in stream rehabilitation. The workshop covered a wide range of instream habitat development issues including the stability of structures in rivers. Field tours were organised to both the Cascade Mountain Range and the Coastal Mountain Range to see completed rehabilitation programmes and works in progress. The primary aim of attending the workshop was to use it as a forum to establish contacts with those at the forefront of instream structural rehabilitation in North America.

A return study tour was organised on the basis of the contacts established at the workshop. This included visits to Mike Crowe of the Department of Fisheries and Oceans (DFO) in Kamloops, BC where a tour had been organised for Canadian Government officials and other interested parties. The tour included many recently developed sites on a tributary of the Upper Fraser River called the Salmon River. Other contacts visited during the Fellowship were Mel Sheng of DFO in Vancouver, BC, Bob Newbury a leading Consultant Hydrological Engineer in Gibsons, BC, Don Duff an Aquatic Ecologist with the US Department of Agriculture Forest Service and Trout Unlimited in Salt Lake City, Utah, Guy Sirois of the DFO in New Brunswick, Canada and Mike Rutherford of the DFO in Halifax, Canada.

1.4 Overview of Instream Structural Engineering

Traditional engineering works aimed at controlling bank erosion, flooding or land drainage usually result in detrimental simplification of habitats. Diversity is essential to maximise instream productivity. Unaltered natural streams normally have numerous pools and riffles, overhanging vegetation, undercut banks, fallen trees, other woody debris and boulders constituting good habitat complexity. These habitats are characterised by a range of physical conditions, such as variations in current, flow type, substrate characteristics and cover availability. When river channels are widened, deepened, straightened, relocated or stabilised to control bank erosion, flooding or land drainage, the alterations may commonly result in diverse habitats being replaced by a reach of uniform velocities with no depth and no cover, which is detrimental to the survival of juvenile salmon. Other ramifications are alteration of the natural channel morphology such as the pool-riffle spacing, the frequency of overbank flows, waer table heights, water temperatures and riparian vegetation growth. Also, excessive substrate mobility as a result of engineering works can lead to a collapse of macro-invertebrate populations, both in terms of biomass and diversity (O'Grady pers.comm. 1997). But it is the lack of depth, cover and diversity or in other words the provision of microhabitat for fish that is one of the most influential factors determining a channel's

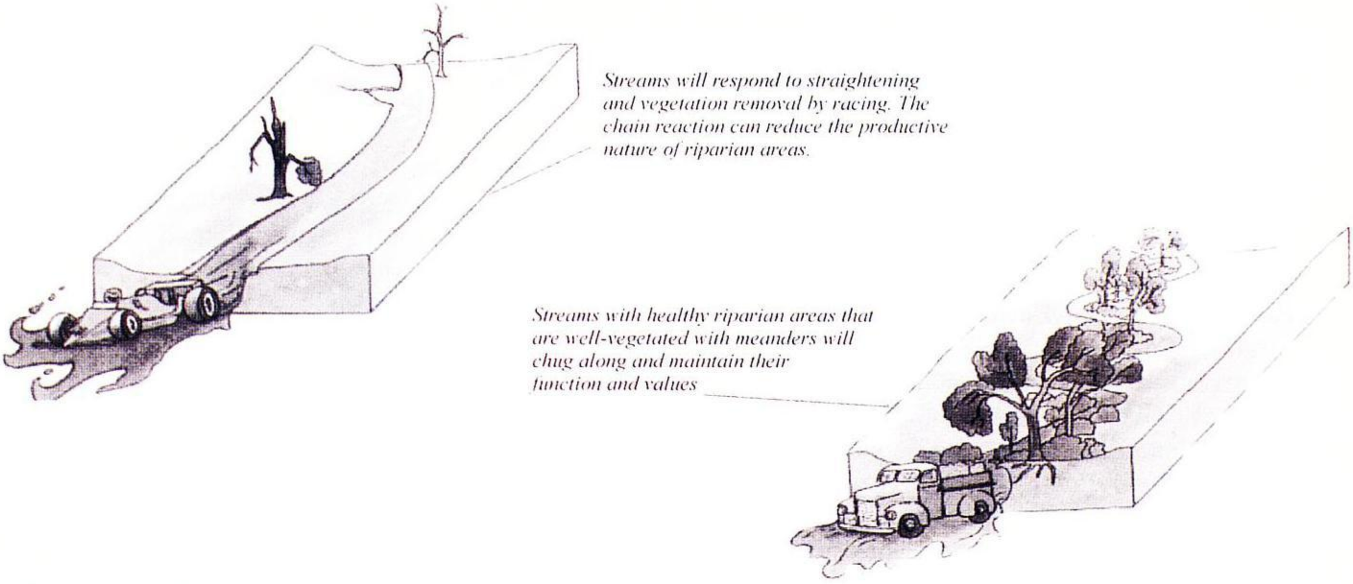


Figure 1.1 – The argument for stream diversity (adapted from Adams & Fitch 1995)

population carrying capacity.

The cartoon (Figure 1.1) shows the result of loss of habitat diversity. The diverse features in the channel increase the energy dissipation in the stream. As the current flows around boulders, logs and other features which together form what is called channel roughness, the flow slows down and loses energy. By producing a more uniform channel, removing the complexity and roughness, less energy is lost and the river speeds up and is more powerful, causing increased damage. It can also cause serious downcutting and even a retreat of surface waters into the groundwater table (Chaney et al. 1990).

Throughout society environmental awareness has increased, resulting in an attitude that is less willing to accept such environmental damage. In many situations the solution has been to install structures to restore the diversity of physical habitat, such as depth and cover, to rivers which have been modified or naturally degraded. The goal of river restoration using instream structures is to re-establish something close to the natural or pre-disturbance channel geometry by reinstating the pool:riffle sequence and producing a variety of habitats.

There is a well-developed range of habitat improvement techniques available to restore the physical features of fish habitat to streams and rivers. The published literature includes several hundred case studies. Various technical guides to stream habitat improvement (especially for trout) have appeared in recent decades (White & Brynildson, 1967; Slaney et al.1980; Hall & Baker 1982; Wesche 1985; Hunter 1991 and Hunt 1993) to name but a few! But, the bulk of the literature on stream enhancement is on North American programmes since the early 1930's. These techniques are transferable to rivers in Britain, but some adaptation is necessary to take account of the specific ecology of the river systems and to make allowance for the fact that, in a lot of cases, the stock being dealt with here, is a mixed stock of Atlantic salmon and brown trout.

A common mistake has been to regard stream habitat restoration as simply finding ideas ("recipes") in a guide book and installing the structures. This has been called "cookbook management" and has been shown to fail time and time again. "How to build a habitat structure is important, but not as important as why and deriving from the why, selecting the right structure for a valid ecological purpose and placing it properly in relation to channel form" (Orth & White 1993). This report aims to address this by highlighting some of the most important morphological reasons for using structures in particular locations.

1.5 Instream Engineering in North America

Freshwater habitat enhancement for anadromous salmonids has been practised in North America since the late 1800's. It is apparent from North American examples that the utility of various improvement structures is dependent on their proper placement after an assessment of their limiting factors. As each river has a unique combination of physical, chemical and biological characteristics, structural improvements need to be implemented on a site-specific basis. When considering transferring techniques from the US, it must be remembered that in Britain, financial, legal and technical restraints on most fisheries organisations would at present preclude a lot of the more elaborate practices.

The first large-scale habitat management in streams undertaken by government agencies began in the 1930's in Michigan. The apparent success of these efforts in moderate gradient rivers in mid-western and eastern North America was followed by several projects west of the Rocky Mountains. Many concluded that failure was more common than success in these higher energy streams of the Pacific Northwest. But rehabilitation continued at a substantial pace and several manuals for habitat improvement were produced by state and federal agencies. Over the years, modifications gradually made techniques more applicable in streams prone to higher flood flows. Many early projects were a success in the spring fed rivers with relatively stable flow in the mid-west, but were failures in the exceedingly high energy streams of the Pacific west coast. Thus most of the early work was done in the eastern USA, with many of these techniques being not directly transferable to west coast streams. Highly variable flow regimes, including frequent floods and droughts, and unstable eroding channels in upland streams resulted in a failure of habitat structures which were originally designed for, and were very functional in relatively low gradient east coast channels in the US.

Chapter 2 - Channel Morphology and Dynamism

Throughout the Fellowship it was noticed that in North America it is accepted that all stream rehabilitation programmes must start with an understanding of fluvial geomorphological "first principles". It is necessary to have an understanding of the geomorphological background and processes in a river to ensure the correct placement of any structure i.e. distance apart and frequency. "Physical conditions within stream channels can be modified to improve or increase particular habitat for salmonids. However, if such modifications of the channel are to have any degree of permanence and success, they must take cognisance of the principles of stream hydraulics" (Slaney et al. 1980).

2.1 Stream Classification

When considering the use of a structure in a stream, it must be compatible with the conditions in the stream. If it is not compatible, the chances are that it will fail or create another problem. Many stream rehabilitation projects use the various North American guidebooks to determine which structure to use to create a particular habitat condition. But what they failed to do was to establish if the structure was suitable for the river environment in which it was to be installed. Stream classifications have been devised by several experts in North America to help in the process of locating the right structure in the right riverine environment. One of the most popular and in use with many fishery bodies in the States, and also in Ireland is the stream classification developed by Dave Rosgen.

Rosgen's stream classifications and stream types are based on morphology and help in recognising features and standardising terms. Rosgen uses a generalised rating scheme to evaluate the potential effectiveness of fish habitat improvement structures based on the morphology of stream types. "They are only guidelines and are meant to provide general direction or highlight potential problems. They are not intended to be "fixed" or evolve into hard rules", Rosgen (1996). The classification is intended to allow :

- prediction of a river's behaviour from its appearance
- comparison of site-specific data from a given reach to data from other reaches of similar character; and
- a consistent and reproducible system of technical communication for river studies

The classification initially sorts streams into the major, broad stream types (A-G) at a landscape level. These geomorphological stream types, whilst developed in North America, are the same for streams anywhere else in the world, although flow patterns and other factors related to weather conditions may vary. At this level the system classifies streams from upland headwaters to lowlands with a stream type:

A - headwater
B - intermediate
C & E - meandering
D - braided
F - entrenched
G - gully

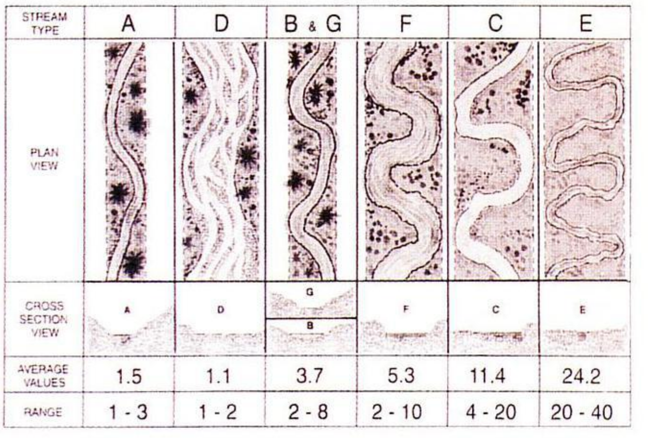
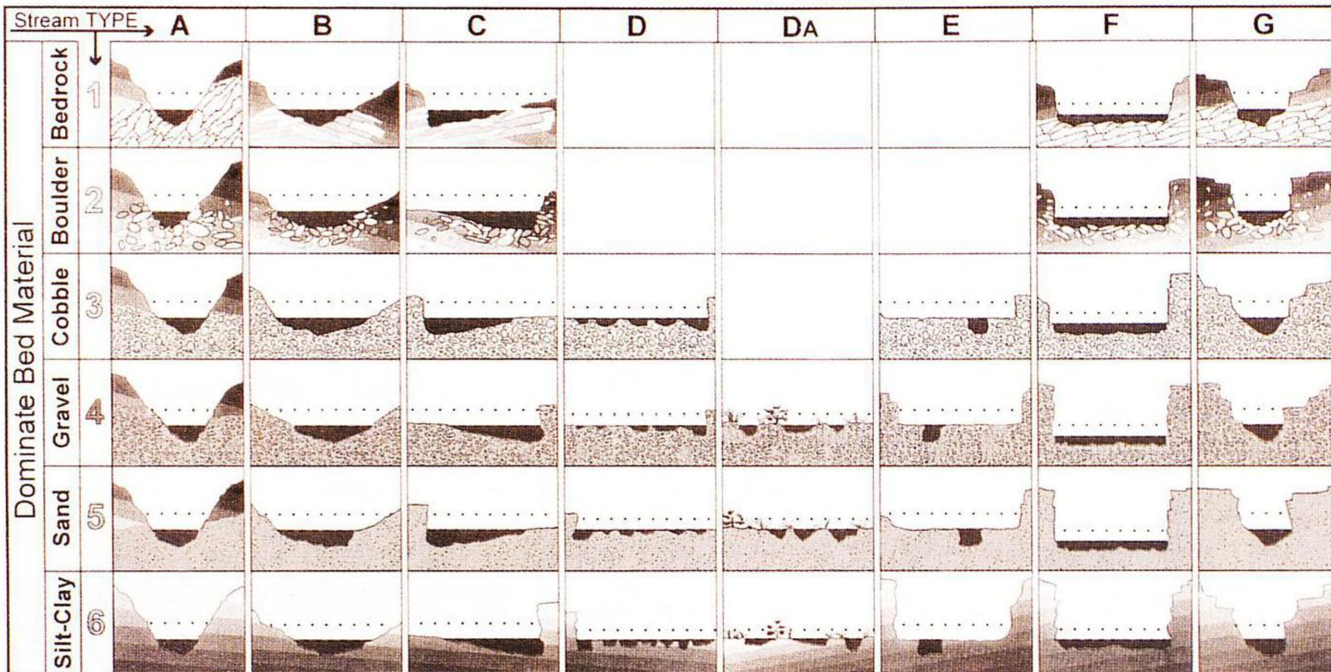


Figure 2.1a - Rosgen's Stream Classification Diagrams

The classification then breaks stream types into sub-types based on channel slope/gradient ranges and dominant channel material particle sizes, resulting in a hierarchical assessment of channel morphology (Figure 2.1a-c). This produces 41 major stream types with a list of structures that are suitable for each type of channel. Rosgen discusses the application of his stream classification system which allows an analysis of the compatibility of a proposed structure with particular stream types before the final selection and implementation is made. He produces what are termed generalised rating schemes, which evaluate the potential effectiveness of certain fish habitat improvement structures based on the morphology of the streams involved. The ratings for structures are : excellent, good, fair and poor, but they do not reflect on their biological effectiveness, costs or difficulty of construction. This summary over-simplifies the Rosgen system which includes other parameters. For more complete information consult Rosgen (1996).

Rosgen's system can help a project initiator select the structures best suited to specific characteristics



Stream TYPE	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	>1.5	> 1.2	>1.2
Slope	.04-.099	.02-.039	< .02	< .04	< .005	< .02	< .02	.02-.039

Figure 2.1b - Rosgen's Stream Classification Diagrams

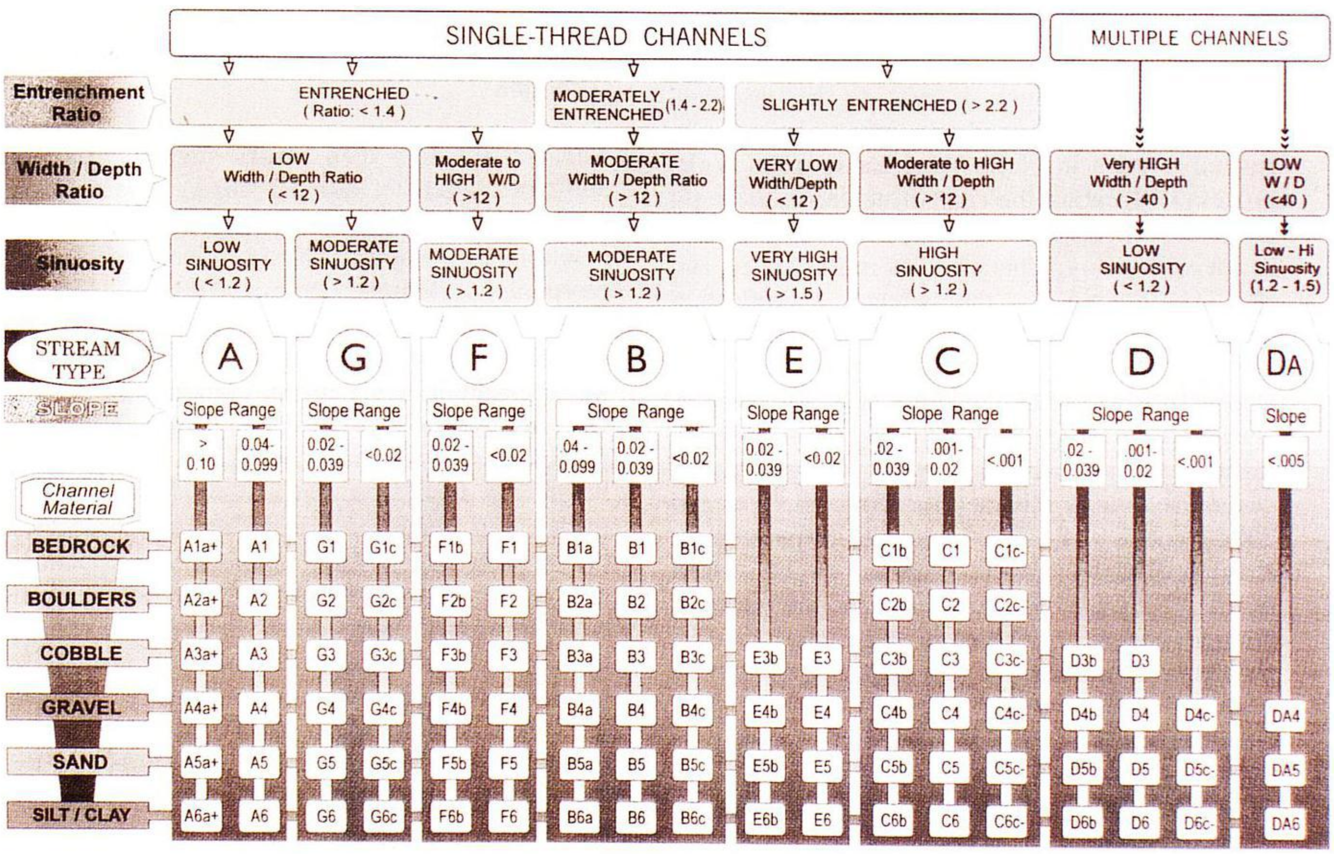


Figure 2.1c - KEY to the ROSGEN CLASSIFICATION OF NATURAL RIVERS. As a function of the "continuum of physical variables" within stream reaches values of ***Entrenchment*** *and* ***Sinuosity*** *ratios can vary by +/- 0.2 units: whilst values for* ***Width / Depth*** *ratios can vary by +/- 2.0 units.*

in differing stream reaches. What must be remembered when considering installing structures is that you should not be trying to make a stream into a type that is not its natural classification for purposes of increased salmon production. For example, an 'F' type channel should not be modified using structures to try and create a 'B' or 'C' type channel just because juvenile salmon prefer 'B' or 'C' type channels. An 'F' type channel, if in a degraded state should be restored back to its natural 'F' type condition. Similarly, with any degraded channel type, they should be restored back to their former natural pre-degradation type and not forced into a type that suits a particular species.

This classification system should not be used as a prescription for stream rehabilitation, but as a useful tool to aid in predicting how particular structures may perform under certain conditions. Some geomorphologists express caution about its limitations and point out that "working with geomorphic processes requires a deeper understanding than typology". On the other hand, some commentators would suggest that the Rosgen classification system over-complicates the issue by providing very detailed, complex and multi-variable descriptions. This may be so, but it is difficult to find a happy medium, in that by generalising channel morphology into fewer categories can over-simplify things. For example, many hydrologists, engineers, fluvial geomorphologists and river managers use the term gravel-bed rivers to describe rivers. As it is currently used, a "gravel-bed river" encompasses a range of streams in gravel or cobble that are wide and shallow, or narrow and deep, gentle to moderately steep, and include streams that have broad well-developed floodplains to stream channels that are confined and entrenched. Therefore, this generalisation often conveys inconsistent interpretations and is confusing, especially when the term covers such a broad range of streams.

2.2 Channel Dynamics

Many British upland rivers favoured by spawning salmon are neither meandering nor braided, they are "wandering" channels exhibiting some characteristics of each. They would tend to be 'B' and high 'C' type channels under Rosgen's classification. They can be considered dynamic in nature as former channels are visible on the floodplain. Many formerly dynamic channels have been modified by human activities to try to ensure that they remain stable in one part of the floodplain. Artificial straightening and confinement of channels can have unpredictable and damaging consequences in terms of flooding and salmonid habitat. The existence of past river channels on a modern floodplain provides an indication of the nature of the river system and the probability of future changes in channel position and form. It is important to note that natural dynamism in rivers exists as a means of the river dissipating energy. If this natural dynamism is inhibited by man-made alterations to the river, the energy will be lost in some other way, possibly by increasing the sediment transport rate and eroding the bed, or by eroding banks elsewhere.

When streams enter alluvial fans or valley floor alluvial deposits they become less stable and more dynamic in plan form. There has been a widespread tendency to over-stabilise channels in these locations due to a fear of channel erosion. Moderate channel erosion is natural and it is this that creates fish habitat. Hard stabilisation has been used to lock streams into unchanging courses to protect roads, buildings, agricultural land and other floodplain users but there has been no allowance made for the necessity of the river to erode. This only exacerbates erosion in other reaches where the channel has not undergone stabilisation. Physical and ecological changes are important aspects of river behaviour. Natural changes have allowed rivers to evolve over the centuries and to continue to evolve at present. Major channel features gradually evolve and they continue to change over time. River stability can be achieved by tightly controlling the physical features and flows, but such "engineered" stability is considered to be contrary to the ecological health of rivers.

Although a moderate level of channel erosion and shift is natural, what is unnatural is the increased levels of bank erosion and channel instability that are being experienced today, due to out of channel processes such as overgrazing, afforestation increasing rainfall and also increasing storm intensity (Smith & Bennett 1994). Fish and other organisms benefit from **gradual** shifts of the watercourse, but channel migration may destroy any instream structures installed in these types of channel. In America a solution to this dilemma has been to rely less on "permanent" structures, and place more emphasis on improving bank vegetation, which provides what is termed as "flexible stabilisation". The binding nature of the streamside vegetation through its flexibility and re-growth allows it to change interactively as erosion and deposition take place in the channel. At the natural rate of channel erosion, habitat features tend to "migrate" as the bends migrate because cross-sectional features are preserved in appearance, even channel movement is exacerbated, and the rate of bank erosion is increased, then channel migration is faster than the natural rate and the habitat features are lost. Thus any enhancement project should aim to limit exacerbated erosion rates and maintain a natural rate of erosion.

2.3 Formation of Riffles and Pools

In all rivers, even where the channel seems straight, the line of maximum depth and fastest flow termed the 'thalweg' moves back and forth from one bank to the other. As the flow in the river moves back and forth, lateral cutting of the banks results on one side, as alternating bars of sediment are deposited along the channel on the opposing bank. Between the eroding bends, the flow crosses the centre of the channel in what is called the shallow riffle zone. This pool-riffle sequence seems to be evident in most gravel-bed rivers, irrespective of the size of the gravel.

Working on a trout stream in Scotland, Stuart (1959) noted that there often exists a regular, periodic spacing of pools and riffles in natural gravel-bed rivers. Following the loss of this pattern to river dredging, Stuart succeeded in recreating pools and riffles by leaving piles of gravel on the stream bed at intervals appropriate to riffles. Since then, geologists have confirmed that the pool to pool or riffle to riffle spacing is generally consistent at five to seven channel widths in gravel-bed rivers (Leopold et al. 1964) i.e. if the river is 5m wide at bankfull level, then there should be a pool every 30m. This interval can be used as a guideline for the placement of habitat improvement structures that dig pools (Figure 2.2).

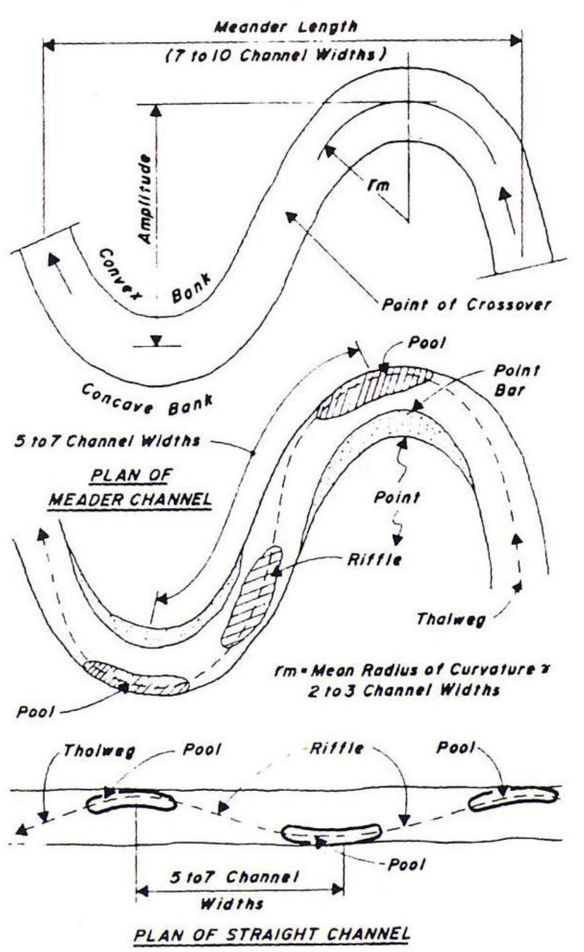


Figure 2.2 - Pool-riffle sequence in straight and meandering channels

The pool-riffle sequence in a river is one of the most important physical influences on the natural production of salmonids, as it is their preferred habitat. The pools provide holding areas and cover for both adult spawners and juveniles, and the riffles on cross-over points between bends provide spawning and nursery habitat. Wesche (1985) noted that food producing areas are a vital population determinant and habitat requirement for salmonids. Riffles have greater potential as food producing areas than deeper pools and they are the primary food producing area due to the velocity, substrate and depth characteristics. Many stream restoration projects involve the creation of deeper water for fish, but it is just as important to create riffles to improve food production. This alternating pool and riffle sequence, present in practically all channels having bed material larger than coarse sand, is or should be characteristic of most salmon producing streams in UK. Good juvenile salmon habitat requires moderate stream gradient and velocities over a diversity of pool, riffle and glide features, but also a variety of substrate types such as gravel, cobble and boulders. It is this variety of in-channel features such as boulders that creates what is called microhabitat. The provision of microhabitat is important for salmon as it isolates them visually allowing more juveniles to inhabit a reach of river, thus increasing its overall carrying capacity. It is the pool-riffle-glide sequence and diversity that should be followed in instream enhancement projects. The need for the pool-riffle-glide sequence can not be stressed enough, although it must be remembered that the percentage of riffle habitat should be higher in salmon producing rivers than for those with trout, as this is their preferred habitat.

2.4 Erosion and Sediment Control

Erosion and deposition are natural phenomena, which can improve as well as degrade fish habitat. A large number of upland spawning rivers may be considered as dynamically stable due to them undergoing continual scour and deposition at a natural rate, causing the channel to migrate across the floodplain, but resulting in little cross-sectional change. Eroding gravel banks provide a continuing source of gravel for the stream, which is suitable for spawning. High flows can move gravel bars, cleanse spawning gravels and form or deepen pools, all of which benefit salmon. Thus erosion and deposition should also be accounted for when manipulating a stream for salmonids.

Bedload stability is another important factor in overall channel stability. Uniformity of substrate size is a key element in determining bedload movement and its stability, and therefore, the reach stability. For two samples of bed material with the same average size of particle, the sample with more variation in particle size will be more stable, because the smaller particles will fill the voids and thus lock the larger grains in place. Inspection of river bed material can also allow an estimation of stream velocities likely to be encountered. If the channel consists of cobbles with very little pebbles and sand, the stream will regularly have velocities in excess of approximately 3 m/sec. Alternatively, if the maximum velocity of a section of a stream is known, a rough estimate of the size of bed material that will be relatively stable in that section can be determined. This can be important when using stone and gravel for instream enhancement purposes. Table 2.1 is useful for estimating velocities that usually occur in a river channel.

Table 2.1 - Minimum transport velocities for various size particles (source Slaney et al.1980)

Material	*Diameter*	*Transport Velocity*
Silt	*0.005 - 0.05 mm*	*0.15 - 0.20 m/sec*
Sand	*0.25 - 2.5 mm*	*0.30 - 0.65 m/sec*
Pebble	*5.0 – 15.0 mm*	*0.80 – 1.2 m/sec*
Gravel	*25 - 75 mm*	*1.4 - 2.4 m/sec*
Cobble	*100 - 200 mm*	*2.7 - 3.9 m/sec*

2.5 Seasonal Habitat Requirements and Channel Morphology

Preferred microhabitats of salmonids also change seasonally. During winter, juveniles tend to seek areas of lower water velocity, which must be provided for in any enhancement proposal. They seek shelter in the substrate and other dead water zones to conserve energy during this period of poor growing conditions, and this also enables them to cope with winter extremes such as floods, and in some instances ice build up. In winter when some upland tributaries may freeze over, juveniles will seek out areas (such as deeper pools) that will not freeze to the bottom.

Spring-fed streams, which maintain a more constant water temperature, also make good over-wintering habitat. A considerable amount of research and development work has been undertaken by the DFO in British Columbia into the design and construction of groundwater channels that can provide a considerable amount of good quality juvenile habitat. By digging down and tapping the reserves of water stored in the groundwater table and diverting it down constructed channels, it provides productive juvenile habitat that should be unaffected by the extremes of winter such as ice build up and flood discharges. In areas with heavy spring run-off, juveniles need habitat that provides shelter from these extreme flows, and this is provided naturally by secondary channels, backwater pools, shallows along the stream's edge, or protected areas behind instream debris.

Provision of over-wintering habitat, as has just been described, is one aspect of enhancement programmes that is constantly overlooked in the UK. In the US it has been found that one of the most common limiting factors to salmonid production is the lack of sufficient over-wintering habitat/flood refuge for juvenile salmon. Although winter conditions experienced in the UK tend not to be as severe as those in the US, over-wintering habitat is still an important factor in juvenile survival. Salmonid habitat surveys tend to be conducted when the water is clear and low during the summer months to allow the low flow habitat provision to be assessed. Rarely is winter habitat surveyed, but there are advantages in observing the river at high flows. It is important to get an insight into winter conditions and habitat provision in terms of flood refuges, but it will also give an idea of the conditions that any proposed structural rehabilitation will have to endure. Winter habitat surveys should be undertaken by fisheries organisations as a way of gathering more information prior to any development works.

Chapter 3 – Non-structural and Structural Enhancement

3.1 Non-Structural Enhancement

During the Fellowship it became increasingly obvious that there are differences in opinion within the scientific community about whether the traditional restoration technique of adding structures to channels represents an "improvement", compared to other actions that allow natural changes in habitat, such as re-establishing a zone of healthy riparian vegetation.

One side of the argument suggests that by placing permanent structures in a channel, we are attempting to lock the stream into a fixed location and condition. Many of the finest salmon producing waters are found in glacial or alluvial valleys which are characterised by channels that shift back and forth across the valley floor as they continue to adjust characteristics and locations in search of a state of dynamic equilibrium. Alluvial streams naturally develop and function by continual channel adjustments as flow and sediment loads vary. These changes should be gradual with the controlling factor being the bankside vegetation. The vegetation stabilises the banks allowing streams to withstand the wide range of dynamic forces that occur as flows fluctuate rapidly during high discharges and allowing the channel to evolve gradually, thus retaining beneficial morphological features.

Bank erosion is a natural process that creates pools with undercut banks on the outside of bends and also leads to the creation of eddies and quiet backwaters, which all improve salmon habitat. But what is unnatural is the rate at which some banks are retreating. For example, in Scotland several thousand kilometres of salmon spawning and nursery streams suffer from severely eroding banks, but it is not just in Scotland that this occurs, it is a common international problem. The problem is that due to upslope and riparian land uses, the erosion process and rate is exacerbated and has become detrimental. The rate of erosion is a function of the condition of the bank. If healthy riparian vegetation is present, the root systems of the plants will allow the erosion process to proceed and, at the same time, manage to hold the banks together leaving an undercut bank with overhanging vegetation. If the riparian vegetation is in poor condition then the erosion can be accelerated leading to bank collapse and channel widening, resulting in a severely degraded channel and the loss of habitat.

A common misconception is that protecting an eroding bank will remedy the situation. Too often the response is simply to provide structural rehabilitation and bank protection in the form of rip-rap or other 'hard' treatments, with no consideration as to why the bank is eroding. This prevents the natural erosion process and attempts to lock the stream into a stable course, which limits the ability of the stream to create habitat. Also the stream may focus its erosive energy on these structures, often leading to their loss. But in many cases, structures are placed in a channel where and when they are not needed. The choice of undertaking in-channel alterations is often guided by an inadequate knowledge of the complexity of riparian and river ecosystems and their interconnections. Structures are added to mitigate adverse channel conditions, but sometimes little attention is paid to the limiting factor to natural channel formation, such as the surrounding land-uses. Far more appropriate and a longer term solution is to eliminate degrading land-uses and encourage natural riparian re-vegetation, which allows a natural rate of bank retreat. To bridge the gap until the vegetation cover is sufficient, some fom of bank protection is usually necessary on the worst points of erosion where the natural erosion rates have been exceeded.

Many project managers rarely allow several years of vegetation recovery before identifying where structures might do the most good. Often the desire for a quick solution or the want for a high profile project drives people to choose structural solutions. In the US, scientists have now realised that in the rush to install expensive and sometimes counterproductive structures, project mangers have ignored what they now see as the primary management focus - restoring bank vegetation. As far back as 1967, White & Brynildson emphasised that vegetation should be managed first before implementing hard structures in channels. But still the desire is to artificially alter instream habitat for fish. Artificial structural improvements should not be substituted for responsible management of the surrounding land. In contrast to structures, riparian vegetation can maintain itself (if managed properly), as new plants continually replace those that die. Riparian vegetation allows streams to function in ways that artificial structures can not replicate. It is for this reason that there has been increasing debate recently over the use of structural enhancement rather than allowing vegetation to re-establish and subsequently allow the channel to recover under more natural conditions.

Channel rigidity is sometimes considered to be a desirable outcome of structure installation. This introduces a simplistic approach to a relatively complex ecological and geomorphic problem. Many people now believe that the dynamic nature of many upland salmon rivers, where large floods are common, means that the emphasis in treatment of habitat problems is and should be on vegetation management ('soft' engineering) than 'hard' instream construction. It is important to distinguish between "soft engineering" and "hard engineering". Soft engineering ("the use of natural sedimentary processes allied to the ability of vegetation to trap and stabilise sediment" Summers & Giles 1996) is more advantageous for fisheries purposes as it is the use of natural materials and forms to create the required channel diversity. It is anticipated that there will be some level of instability with this type of soft rehabilitation and it is imperative that knowledge of the desired ecosystem is applied in the design. In contrast, hard engineered channels are designed to be stable with a fixed geometry, using unnatural materials and usually for the single purpose of efficient water conductance.

Soft engineering has become increasingly popular in the US and is called "flexible stabilisation" by some, because the vegetation allows the channel to stabilise in cross-section but still to erode and migrate at a natural rate unlike structures. It is necessary to protect, re-establish and encourage the functional attributes of riparian vegetation, which is also called "bio-engineering"- in the US.

3.2 Structural Enhancement

The other side of the argument suggests that structures are necessary, as vegetation re-establishment may take decades before it is effective, and therefore structures must be implemented to ensure that the required channel stability and instream habitat diversity is provided as soon as possible in degraded channels. In channels that are braided, it is generally the case that they may never recover naturally. Braided channels are severely degraded, and although recovery does occur, it is extremely rare. They tend to get progressively worse and are not self-correcting (Berger 1991). In these cases channel restoration will not occur without structural aid.

3.3 Attaining a Balance

The answer seems to lie in attaining a balance between re-vegetation and structural enhancement. A restoration project should not involve structures alone, the channel and riparian area should be incorporated in the same project, by discounting degrading land-use practices. Structures should be used as "band-aids" that are implemented to treat the worst problems and quicken the natural repair of streams. They can provide temporary channel stability and diversity of habitat until such time as the vegetation has established and is functioning as a natural control of channel form. Bob Bilby (pers. com.1996) suggests that "habitat improvement projects that require instream structures are interim measures until natural processes become functional. Some stream ecological processes will require decades to become fully functional, in the meantime we can provide some additional help".

Structures only treat the symptoms of the problem and do not rectify the cause of the problem. The cause of the problem should be rectified to increase the long-term success. Structures should be employed with care and along with changes in land use or whatever the primary causal problem is. Therefore, structures and vegetative succession and regeneration should be used in parallel, as this will increase the longevity of the programme. The case for vegetative enhancement and natural repair of degraded streams is strong, but it acknowledges the value of structural enhancement as part of river restoration. Although the argument seems to favour riparian regeneration and denounce the use of structures to rehabilitate streams, there is no doubt that structures can play a vital role in a stream rehabilitation programme.

Chapter 4 - Catchment Management

The scientific community in the US has accepted that complex ecosystems and associated habitat features cannot be achieved via simple structural enhancement alone. Although the proposal for this Fellowship was to investigate structural techniques to rehabilitate high gradient rivers, the debate about the value of structures as a restoration technique that has emerged, has made it is necessary to put structural enhancement in context. Most enhancement projects over recent decades have been conducted on individual river reaches, but an understanding must be developed of where the project fits into the "big picture", which is the health of the entire watershed. It was very evident during the research trip that stream habitat management in North America has become holistic, and is now focusing again on consideration of the whole ecosystem of the river and its drainage basin or watershed, and operating on what is called the landscape scale, not just in the river itself.

The publication in America of White & Brynildson's (1967) *Guidelines for the Management of Trout Stream Habitat in Wisconsin* caused a mini revolution in stream habitat improvement at that time. They took a new approach by describing techniques to protect and manage bank vegetation before they described more traditional structural enhancement techniques, which was the first concerted effort by biologists in recognising the importance of the surrounding land in shaping the physical, chemical, biological and hydrological conditions in the stream. Fish habitat not only encompasses physical habitat within the river channel itself but also includes floodplain and bankside environments. This was the first time conditions outwith the channel had been considered in any great detail and it led to the birth of Catchment Management. Interest and investment in catchment management faded, largely due to landowner inconvenience and apathy. Although watershed or catchment-scale conditions were recognised as vital to retaining the health and productivity of the streams, it proved difficult to implement as management was complicated by competing land uses and ownership problems and therefore coming to collective agreement on catchment issues was difficult.

Integrated Catchment Management (ICM) has become fashionable again during the 1990's. The notion of 'Stream Corridor Management' is seen as the way forward in the US. It is a complete management package that acknowledges the importance of the entire watershed and requires the establishment of stable, low maintenance buffer zones along riversides, as well as implementing instream structures to improve the morphological diversity in the channel.

It is this catchment-wide view that is in need of more consideration and acceptance within projects in the UK. A limitation of many stream restoration projects in the UK is their failure to consider the stream and its riparian zone and/or floodplain as one system. The river and its catchment are an inseparable ecological unit, therefore any stream rehabilitation project will be effective only if the watershed is protected at the same time. The removal or elimination of land use activities that cause adverse impacts to riparian and aquatic ecosystems is of the highest priority if restoration is to be accomplished. Abusive land use practices can not be mitigated by structural additions or modifications to stream channels.

Many scientists believe that the survival of salmon in freshwater is as much down to management of people as it is to river and fish management. Without the removal or significant reduction of human activities in river catchments, which are currently having an adverse impact on riparian/ aquatic ecosystems, the restoration of aquatic habitats for fisheries can not be expected. For example, peak discharges in streams draining afforested areas in the Spey catchment have increased by 40% and the duration times have halved (Shearer 1992). Once the trees have grown the problem changes to one of reduced discharge, which can have a serious effect on summer base flows. This is evident in the Tweed Valley, where it has been shown that in adjacent catchments, the dry weather flow in an afforested catchment is only 50% of that in a grassland catchment (Fox, 1989).

Another example of detrimental human activities is in Ireland, where numbers of sheep have more than doubled from 3.3 million in 1980 to over 8 million in 1997. Higher stocking rates of sheep and cattle, reflecting increased subsidy payments, contribute to barer fields and hillsides which cause increased surface run-off. The resultant increased discharges and fluctuations in discharge can cause severe bank erosion and flooding. Lusby(1970) compared runoff from ungrazed and grazed watersheds in the US and results indicated a 30% reduction in runoff from the ungrazed watershed.

Chapter 5 – Stream Habitat Enhancement in the 1990's

5.1 Riparian and Riverine Interactions

Bankside or riparian vegetation is probably the most misunderstood component of riverine areas in terms of its effect on channel morphology. Only within the last decade have researchers and biologists developed a proper understanding of the controlling function of riparian zones in determining channel morphology. Riparian woodlands are the interface between two major ecosystems, land and fresh water, and have a great influence on not only the chemical and biological characteristics of a watercourse, but also the physical characteristics.

From a watershed management and a fisheries perspective, riparian areas serve many important functions in maintaining the health and productivity of rivers and streams and increasing their bio-diversity. Bankside vegetation plays a vital role in controlling channel morphology by roots stabilising otherwise erosive streambanks, especially in smaller streams, as the smaller the stream the more important vegetation is to stability. Vegetation helps to resist bank erosion and encourage flows to scour a deep channel rather than spreading laterally and thus produce deeper pools and stable undercut banks, which are important as shelter for juvenile fish. Also bank vegetation increases the structural complexity or roughness of the channel boundaries, thus increasing flow resistance, dissipating stream energy. Increasing flow resistance by using vegetation as an energy dissipater is effective as it acts over a continuous length of channel compared to structures, which dissipate energy at a single point, causing potential weak locations. Marginal and instream plants grow out into the channel during summer, which concentrates low flows. During the autumn they die back and therefore do not increase the flood risk, but they still provide a protective cushion between the underlying soil and the water.

Riparian vegetation plays a crucial role in determining water quantity and quality and also the level of sedimentation. When flood waters encroach on to the riparian area the vegetation serves to increase the roughness of the floodplain, which slows the water promoting infiltration or "soak in" and recharge of the groundwater supply or alluvial aquifer. Also, in healthy natural streams, the riparian area soaks up overland flow from heavy rain. This may reduce the initial flood flow from a high water event and reduce chances of flooding and bank erosion downstream. This 'sponge' effect stores water in groundwater aquifers which is retained and released slowly into the stream later in the season, preventing small streams from drying up during low flow periods.

A good riparian zone also improves water quality by nutrient cycling and retention and also sediment deposition and storage. Sediment is deposited as overbank flows spread out and slow due to the vegetation on the floodplain. This is the process of bank building and stabilisation. Vegetation quickly grows through the sediment, stabilising it and utilising the nutrients that are in the sediment. Also the riparian vegetation acts as a filter which reduces sediment and pollutant inputs to the river from surrounding land by overland flow.

When livestock intensively graze and walk on stream banks, or a cropped field is worked too close to the bank, the loosened soil eventually washes into the watercourse. Over time the farmer eventually loses valuable property as the banks erode and the channel tends to get wider and shallower. Without a riparian buffer strip to trap silt and absorb excess nutrients and pesticides, water quality can be greatly reduced, which helps neither the farmer nor fisheries interests. In agricultural areas, a buffer strip between an arable field and the water can boost crop production by holding moisture and by preventing wind and water erosion.

Juvenile salmon feed mainly on the larvae of aquatic insects and to a lesser extent, on terrestrial or land-based insects. The food web leading to these is extremely complex, but it is all connected to the vegetation in the riparian zone. Trees contribute directly to the productivity of the watercourse in two ways :

1. *input of terrestrial invertebrates falling from the canopy;*
2. *input of leaves as it forms the basic foodstuff for aquatic invertebrates.*

The energy contribution that trees make through these two functions should be particularly important in upland environments, where primary production may be limited by low water temperatures and a lack of nutrients. Many upland environments in the UK are now treeless, so the lack of riparian vegetation may further limit production in these areas. Bankside trees in upland areas also provide shade which is otherwise lacking, and they may also reduce water temperatures during the summer months.

Restoration of riparian vegetation and tree cover in upland environments is of vital importance in improving productivity in these harsher environments.

5.2 Establishment and Management of a Riparian 'Buffer Zone'

The acknowledgement of the importance of a healthy riparian zone to the productivity of the river has led to the re-vegetation of riparian areas and the creation of a buffer zone becoming a technique that is implemented widely in North America. It is for this reason that fencing has become one of the major stream restoration tools in the US. Fencing is in most cases a simple and straightforward way of letting nature take its own course to improve the habitat. It was apparent that fencing is used in three different ways in the US. Firstly stock can be completely excluded from valley floors, secondly stock can be fenced out of the immediate bankside area and lastly stock can be allowed to periodically graze inside the fenced bankside zone on a seasonal rotational basis. The bankside fence excludes grazing stock and allows natural vegetation recolonisation. This provides increased stability to the bank and channel and allows re-formation of instream features.

Different guidelines are given by different people, but the wider a buffer zone the better. They should never be narrower than 3m on either side of the waterway (cattle can stretch more than 1m through a fence to graze). Bob Newbury, a consultant hydrological engineer in BC Canada, suggests that a natural riparian zone, or influence of the river on the surrounding vegetation stand, is approximately 20 times the channel width. This means that on either side of the river, ideally there should be a buffer of riparian vegetation 10 channel widths wide. Although Newbury suggests that this width is desirable, it usually is not practicable. If possible, it should be at least three times the channel width on both banks. This recommendation is based on channel morphology relationships, which indicate that the average radius of a natural meander bend should be approximately 2.5 times the river width. Providing a corridor with a total width approximately 6 to 7 times the channel width, allows the river to migrate through consecutive meanders in a relatively natural manner without unduly disturbing adjacent property. Determining the natural channel width should be done in nearby sections of the river which have well-developed woody vegetation on both banks. In general, the river should be allowed to migrate within the established riparian corridor, but it may be necessary to initially control local areas of rapid erosion through the use of structures. In upland UK, native woodlands are deteriorating mainly due to overgrazing by sheep and deer, which prevent woods regenerating naturally. Riparian woods are favourite areas for wildlife, as they are for grazing livestock. Sheep and cows tend to congregate in riparian areas where the grasses are green and tender and water to drink is nearby, and hence overgrazing is a fundamental problem in riparian zones. The result is a steadily ageing wood with no recruitment of young trees. Riparian woodlands are often the only remaining woodland in an otherwise treeless landscape. This has serious implications for the survival of salmon, as the vegetation and trees in the riparian zone play a crucial role in determining the quantity and quality of spawning and nursery habitat. Therefore it is necessary to prevent grazing in riparian woods, and secure their future with a new generation of trees.

Natural regeneration of native species is the preferred method for restoring riparian woodlands, as it will result in a woodland that is better suited to the local environment. This natural regeneration is promoted by fencing off riparian areas and creating a buffer zone where grazing stock are excluded. Fencing a river bank is a rehabilitation measure of its own, and it has been used successfully as a stand alone strategy in North America's rangelands to restore degraded reaches in intensively cattle grazed pastures. It is a strategy that is aimed at allowing bank erosion to progress at a natural rate, by removing the cause of exacerbated rates of bank retreat i.e. overgrazing.

The problems with over-grazing are three-fold. Firstly, there is the problem of overgrazing in the wider catchment away from the channel, which causes increased run-off from the surrounding land leading to flashier floods, which exacerbate channel erosion rates. A second problem closer to the channel is that grass and any other vegetation on the river bank is cropped too short by grazing livestock. This prevents a stable root mass forming which should bind the bank together, preventing it falling into the channel (Plates 5.1 and 5.2).

Lastly, the hoof power of cattle and sheep can not be underestimated. Cattle exert about 10 times the weight or pressure per unit area as a caterpillar tracked machine. Therefore cattle grazing on river banks results in bank collapse and ultimately widening of the channel. Sheep also cause bank erosion to progress at unnatural rates by sheltering from weather and rubbing their backs under overhangs leading to bank destabilisation and the associated problems.

Evaluation of streamside fencing projects in Canada has shown that they assist in restoring bank cover and reducing erosion by excluding livestock from bankside zones, and that juvenile salmon production from the adjacent stream can be increased 2 to 3-fold. The long term benefits in terms of fish production more than offsets the cost of fencing (Slaney et al.1980).

It is important to manage this fenced buffer zone, as if unmanaged after a period of time the newly grown vegetation may become overgrown and encroach into the channel, reducing its conveyance capacity. The overgrowth can also form a dense canopy shading the watercourse and causing tunnelling of the channel, which can lower the productivity of the reach by reducing photosynthetic light penetration. Sunlight must reach parts of the watercourse to allow photosynthetic production. Also a dense tree canopy restricts the growth of bank vegetation thus reducing bank cover for fish and bank stability.

If the banks are becoming overgrown, a managed grazing regime may need to be worked out which will prevent excessive vegetative growth but limit damage to the banks from trampling and over-grazing. In Oregon, it has been shown that a five year initial rest period from all grazing is required after fencing to allow vegetation to re-establish, followed by a regime that allows one month grazing on the banks in early spring. Limited grazing rotations in fenced zones may be necessary to allow the bankside area to function optimally. This active grazing management strategy can be difficult to apply in certain situations where it may not be possible to work it in to the grazing strategy of the farmer or landowner in question. It is also difficult to implement where there is fragmented land ownership, such as in Ireland where a stretch of river bank may be divided up and owned by several different farmers. In this situation, collective agreements and the policing of these agreements would be difficult to come by and impractical to implement. But without a management strategy in place, the fencing may cause unwanted tunnelling problems in 15-20 years by which time vegetation and tree growth has proceeded unchecked and may have become overgrown.

Plate 5.1 - The effects of grazing on root mass

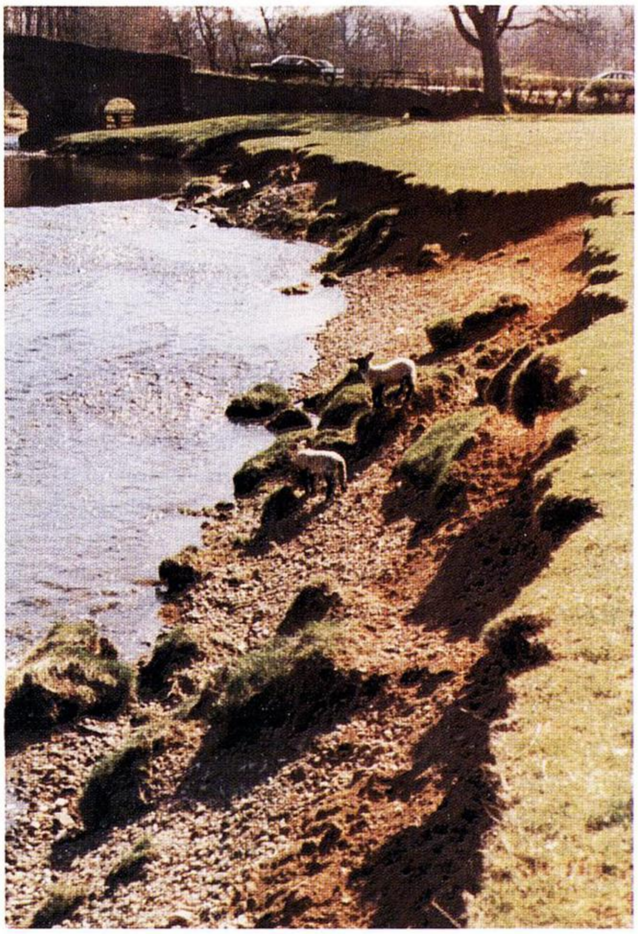


Plate 5.2 - Effects of grazing on bank stability

Where a channel has become overgrown, it has been shown that that selective cutting and removal of streamside trees can benefit juvenile salmonids (O'Grady 1995). But it is important not to reduce tree cover too far. In wide shallow channels the overhanging vegetation helps to moderate water temperature which is critical for juvenile fish survival. A tree removal programme should allow for trees to be removed in discrete stretches, with stretches left as cover and shade, often on the south bank. Trees should be removed over riffles to increase the photosynthetic production rate where the main fish food source in terms of aquatic invertebrates are located. Trees over pools are left to protect the bank and provide cover for holding areas. The 'ideal' is to have a dappled shade over the channel with patches of sunlight and shade. It is helpful to estimate the percentage of the stream that is shaded. Forty to sixty percent shaded at noon is considered excellent. The brush and branches that are removed can be used to provide temporary bank cover by wiring them to the banks or instream, which is a technique that is discussed later.

As part of active riparian stand management, it is vital to thin and coppice single hardwood stands and allow different species to be included to diversify the leaf litter reaching the river. The leaves of different tree species have different breakdown rates, some may take weeks whereas others may take months. Therefore it is important to encourage a mixed semi-natural woodland of native species.

On unimproved grass and heather moorland, a reduction in grazing alone may not be enough to ensure adequate natural regeneration and some additional planting may be required. In terms of preventing bank erosion, the roots of softwood trees such as willow and alder are the deepest penetrating form of natural bank protection and they have a high regenerative capacity due to rapid early growth. Willow are preferred to alder by many, as alder can take over an area, producing a monoculture which is to the detriment of other species. But alder is good at fixing atmospheric nitrogen making it a key contributor to the energy budget of upland streams. It is important to remember when planting, that trees on the north bank of a channel cast less shade than those on the south bank and some species, such as birch, cast lighter shade than others, for example oak or alder (Sheng pers.com. 1996). A mixed stand of native species should be planted to provide a productive riparian area.

It is not only vegetation on the banks that is necessary to maintain a healthy and stable bank environment, the benefit of a healthy stand of marginal plants can not be underestimated. They consolidate the lower parts of banks due to their roots, rhizomes and shoots binding the bank under the water. During summer low flow the marginal plants grow out into the channel and concentrate the reduced water flow into the centre of the channel. They also provide cover for salmon and trout and are extra habitat for the insect life that form part of the diet of juveniles. It has been suggested by some that they reduce channel capacity in high flows. However, they tend not to exacerbate flood levels, as during higher discharges they are flattened by the force of the higher flows and they also help to protect the bank by providing a protective cushion for the soil from the water.

The establishment of a riparian zone not only benefits fisheries interests, but can also benefit the landowner. The benefits can include receipt of compensation through various grant schemes including Environmentally Sensitive Areas (ESA's), Rural Environment Protection Scheme (REPS), Woodland Grant Scheme (WGS), Farm Woodland Premium Scheme (FWPS), Habitat Schemes, Set Aside and other compensatory payments for the exclusion of domestic livestock. Other benefits are stronger river banks meaning less risk of land loss due to erosion. Prevention through longer and stronger vegetation is a lot cheaper than engineering works to repair damage after it has happened. Tree and shrub cover also gives both shade and shelter to stock. The game value of land is also improved as nesting sites and cover for duck, partridge and pheasant are created. The buffer strip also reduces the likelihood of water pollution by silt and chemical run-off.

5.3 Bank Protection Afforded by Vegetated Banks

During a tour with the DFO on the Upper Fraser River in BC, Pete Doyle, an engineer with the Water Management Section of BC Environment, indicated the important function of bank vegetation in providing channel stability. Work he published in 1995 (Beeson & Doyle 1995), shows a comparison of bank erosion at vegetated and non-vegetated channel bends. They studied pre- and post-flood aerial photographs of 748 bends in four rivers with similar characteristics (Salmon River, Deadman River, Bonaparte River and Chase Creek) after major floods in 1990, to assess the effect that riparian vegetation played in reducing erosion. Bends without riparian vegetation were found to be nearly five times as likely as vegetated bends to have undergone erosion, and major bank erosion was found to be 30 times more prevalent on non-vegetated banks. 34 out of 35 bends which experienced major erosion greater than 45m during the 1990 flood were non-vegetated. This large study statistically proves that bank vegetation is effective in reducing erosion. Therefore they suggest that the establishment of riparian vegetation should be regarded as a priority in areas where a lack of it is exacerbating channel instability. Smith (1976) found that heavily vegetated banks were 20,000 times more resistant than non-vegetated banks. Streamside vegetation reduces the power of the stream, by slowing the water down through friction. A 5cm deep rootmat resists erosion up to 20,000 times better than bare soil streambanks.

Work done by Miles (1995) also investigated channel stability and its relationship to levels of bank vegetation on the Salmon River, one of the tributaries of the Upper Fraser River. The DFO and the Salmon River Round Table (a group formed of local residents and government agencies) expressed concerns over channel instability occurring along a 75km section of the Salmon River. The problem was the river becoming wider and laterally unstable which was evident from comparisons of air photographs. The stability of a river can be assessed by comparing, both historical maps and aerial photographs of the river. Changes in plan position of a channel, without the increase in path length, imply a quasi-stable or regime condition where erosion is progressing at a natural rate. If there is increased sinuosity it indicates exacerbated erosion rates and channel widening, whilst reduced sinuosity indicates deposition over the time period in question.

The most significant increases in river width and channel instability in the Salmon River occurred where agricultural practices (cattle grazing) had eliminated the riparian vegetation. The analysis of the air photographs indicated that 42.6km (28%) of the 154km river bank had little or no bank vegetation. An additional 33.5km (22%) had a woody bank vegetation which was less than approximately half a channel width wide. In total 76.1km (50%) was either unvegetated or poorly vegetated. Of the actively eroding banks, 65% was associated with unvegetated banks and a total of 71% was associated with banks which had either no vegetation or only a narrow fringe of woody vegetation. This indicated that the unvegetated banks were more susceptible to bank erosion. The air photos also indicated that eroded bank sediments were being deposited in and destabilising sections with vegetated banks downstream.

Channel widths on the Salmon River in 1995 were compared with 1951 air photographs. The analysis indicated that the average channel width in areas recently cleared of vegetation increased from 10.4 to 32.3m. This is an increase of 21.9m or 211% of the 1951 channel width. Average channel width in another section of the river that had a narrow band of riparian vegetation increased from 21.5 to 23.9m. This is a change of 2.4m or an average increase of 11% compared to the 1951 channel, which is a relatively moderate increase in channel width. However, in an area that was recently cleared on an actively eroding bend the channel width increased from 24m to 127m, which is 5.3 times the 1951 channel width.

The analysis indicated that riparian vegetation had been either reduced to a narrow fringe or removed from approximately 50% of the Salmon River. This had caused accelerated rates of channel shifting and a wider river channel, also resulting in a reduction in stream shade, a shallower river channel, warmer summer water temperatures and an increased sediment load, all detrimental to salmonid survival.

The solutions that were implemented were fencing, rip-rap (stone protection), tree revetments and willow spilling to control bank erosion. It was pointed out during field inspection that rip-rap tends to control bank erosion locally, but it is frequently associated with sediment deposition downstream and further bank erosion in the area immediately downstream. The tree revetments and spilling sites had variable success. These are types of bioengineering that are best employed as temporary measures to slow the worst cases of bank erosion and allow streamside vegetation to become established. The DFO suggest that the long term solution to channel instability problems along the Salmon River is to provide a vegetated riparian corridor, with this fenced corridor being sufficiently wide to allow shrubs and trees to grow to allow them to re-stabilise the banks. They consider a corridor width of 6 to 7 channel widths is required initially in some of the erosion prone areas. Over the long term, the establishment of growth of a variety of woody shrub and tree species within a riparian corridor will eventually reduce rates of channel shifting, stabilise sediment deposits and reduce channel width. The establishment and maintenance of a vegetated riparian corridor is thus seen as the long term solution to channel instability problems on the Salmon River.

Mike Crowe, a fisheries habitat biologist with the DFO in Kamloops, stressed that it is important not to over-react to incidences of bank instability. It must be remembered that gradual bend migration is a naturally occurring geomorphological process, which is essential for sustaining the cross-sectional profile. Thus, it can be the case that bank erosion should be left alone, as localised failures can often settle to a new bank profile. Over time, all streams actively work to erode their channels, which is an entirely natural process. However, when man, his machines or his animals damage a stream bank, the erosion process is speeded up which usually results in a wide shallow channel in alluvial streams.

Bank erosion can be a localised response to a local condition (e.g. along a sheep path), a response to river processes at the scale of the river reach (e.g on the outside of meander bends), or a general response to changed river conditions at a larger scale (e.g., where increased sediment supply or discharge levels into a river causes it to become more active in terms of bank erosion). Before undertaking bank protection, it is important to place any bank erosion problem in context by asking the following questions:

1 *Where is the bank erosion occurring? (i.e. is it localised or throughout a whole reach of river?)*
2 *For how long have the banks been eroding? (i.e how serious is it?)*
3 *What are the causes and processes of bank erosion operating at this location?*

It is important to establish answers to these as it helps to answer the most important question: why is the erosion occurring? It is not the aim of this review to discuss bank erosion processes, as this is done elsewhere (Thorne 1982), but it is vital to understand them.

Mike Crowe suggested that a rating system can be developed to determine whether bank erosion is problematical for a river or not. He estimates percentages of accelerated erosion, as indicated by unstable banks and high levels of sediment deposition, as this is what creates real problems. This system accounts for the fact that low levels of erosion on the outside of meanders is natural in a dynamic river system. Surveying the stream allows an estimation of the percentage of the stream that has stable banks (with little erosion), moderately stable banks (slowly eroding), and unstable banks (heavy erosion). Eighty percent stable is considered very good, and is the level a stream should be maintained at to provide stable and productive habitat. Fifty percent unstable suggests that erosion is probably a problem for the stream.

Bank erosion is probably the most common and most frequently tackled problem in rivers throughout the UK. There is a lack of knowledge about the basic principles of river and bank mechanics and too often, attempts are made to

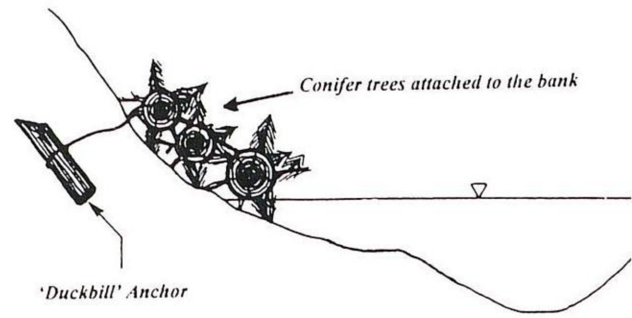


Figure 5.1 - Trees cabled to the bank as cover using the 'Duckbill' Anchor (adapted from Lowe 1996)

prevent further erosion by 'hard' engineering without any consideration of other treatments, which should include preventing the cause of the erosion, not just treating the symptom. Economical and effective techniques can and should be used to stabilise the worst eroding streambanks, and these can include re-vegetation, installation of revetment made of trees and brush, and creation of stone armouring called rip-rap. But, there is no 'flood-proof' stream bank protection; given a large enough flood, any man-made bank stabilisation can be washed out.

5.4 Tree Revetment

Rock rip-rap is the most common method of protecting eroding banks. It can be expensive and if not carefully constructed, not inherently "fish friendly". Over the last few years, a newer and more environmentally friendly technique known as tree revetment has rapidly become the favoured and most effective bank stabilisation measure in North America. Large conifer tree branches or tops (spruce, pine, fir) have been secured to the faces and toes of eroding banks to provide a temporary protective layer/cushion and prevent them eroding further. They can also provide good overhead cover for juvenile salmon.

Conifers have been used as they are bushier in nature, therefore offering greater protection to the underlying bank material and they are commonly available as surplus material from commercial logging operations. In some locations, there are suitable amounts of branches lying around on the bank or in the channel that can be used. In some rehabilitation projects in the US, Christmas trees have been collected from local citizens and then used as bank stabilisers. But, gathering and sorting through "recycled" Christmas trees requires additional effort and yielded fewer trees. Many trees were too small, in poor condition or had awkward branch configurations. Still, it was felt that the benefits of involving the community in stream conservation efforts, and "re-using" trees

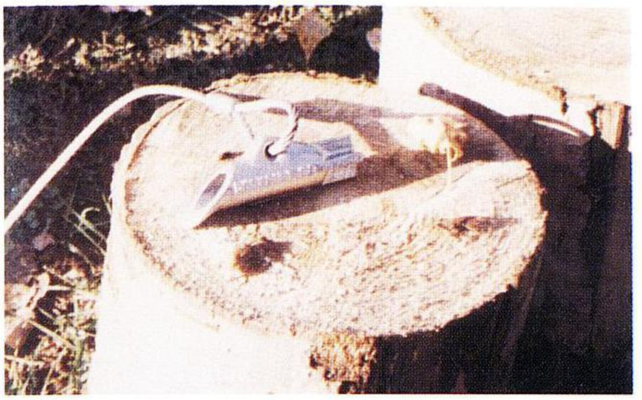


Plate 5.3 - 'Duckbill' Anchor

outweighed these problems.

The trees are placed on the eroding bank face and toe in an overlapping downstream formation., and with the trunk facing upstream. They are attached to the bank using anchors such as wire cable, lengths of steel reinforcing rod (rebar) or deadman anchors. It is important that there is complete coverage of the eroding bank, as gaps in coverage create small eddies which cut behind the revetment and lead to the bank being washed out. The overlapping trees can also be cabled together, which improves their stability. Various types of deadman have been tried and tested, but one of the most innovative and effective is a device called the 'duckbill anchor' devised by the DFO in British Columbia (Plate 5.3). The duckbill anchor consists of a length of wire cable fastened around the tree top. At the other end of the cable, is an attachment that can be hammered into the bank by inserting a length of rebar and pounding it into the bank. When the cable is at its extremity the rebar can be removed from the fitting and the fitting will swivel and act as an anchor embedded deep in the bank that will resist any pulling forces on the tree top (Figure 5.1).

A visit to the Strawberry Valley Restoration Project in Utah with Don Duff, a biologist with the US Department of Agriculture Forest Service and Trout Unlimited, highlighted this simple form of tree revetment and its success. The riparian area in the Strawberry Valley was used foremost as grazing for sheep and cattle, and the rivers in the valley drained into a reservoir that became a superb fishery for Kokanee Salmon. The condition of stream habitats in the valley directly influenced water quality and determined fishing success. The level of grazing on the surrounding hills and riparian habitats influenced the health of the stream. In the mid-1960's ranchers began applying herbicides to willows which grew along stream banks and in river corridors. Livestock operators felt the willows occupied valuable grazing areas and made it difficult for livestock to reach the water. But these willows are how nature protects against erosion. The willows were providing stability during scouring high flows, but also fish and other important aquatic wildlife were using the willows for cover. With the willows removed, stream banks became unstable and soil from surrounding lands ran freely into streams. Bare stream banks collapsed, and the clean and productive meandering streams became wide, shallow silt laden channels, unfit for most aquatic wildlife, and as a result the fishery declined.

New management, in the form of the US Forest Service, called for fish and wildlife habitat improvement through stream bank stabilisation, revegetation of riparian areas, improvements in water quality, rehabilitation of upland areas and a reduction in livestock numbers. Government funds to the tune of $3 million were provided for the rehabilitation of the land, to be spent during a period of 5 years, beginning in 1988.

The Forest Service undertook tree revetment on banks to protect against further erosion. Approximately 23 miles of streambank was reveted with juniper trees secured to the face and toe of the bank with steel rebar. The trees were to temporarily protect the banks against further erosion, allowing native sedges and willows to re-establish. The bushy juniper trees also slowed the water along the bankside which reduces its erosive potential and promotes sediment deposition helping to rebuild a stable bank. It is believed that this is the largest and most concentrated of any

Plate 5.4 - Tree revetment in the Strawberry Valley 8 years after construction

streambank restoration effort, using juniper revetment as the primary treatment. It was chosen because of its cost effectiveness, minimal level of human intrusion in the stream corridor, and the relatively short time it takes to get viable results.

Fencing was also undertaken. This was an important aspect of the rehabilitation as the livestock had to be properly managed and kept away from the bankside area to allow recovery of bankside vegetation. Plate 5.4 was taken in October 1996, which was eight years after implementation in 1988. This has left the bank totally restabilised and the trees are now 2 feet from the water. There is a stable secondary bank built up from deposited material, which is now colonised with overhanging vegetation. The channel is narrower and deeper than pre-works, with increased cover. This provides improved spawning conditions, as narrower channels increase the velocity of the flow, which removes fine sediment from spawning gravel. There is also better juvenile habitat with more cover and deeper water that allows them to survive extreme weather, and as a result the reservoir fishery has improved significantly.

This simple tree revetment has been taken a step further, by developing a successful technique that uses large logs (up to 10 inches in diameter) placed at the base of the bank to protect the toe, and then attaching the conifer tree tops or branches on top of these logs. The 'toe-logs' are primarily to protect the base of the bank sufficiently, and to allow the tree revetment to function correctly until bank vegetation is sufficient enough to stabilise the bank. They also allow a secure fastening position for the tree tops. This technique is sometimes called 'Log and Christmas Tree' revetment.

The toe-logs are secured to the base of the bank at low water level, by driving approximately 1.5 to 2m lengths of ¾ inch steel reinforcing rod (rebar) through pre-drilled holes in the log. Post-hole pounders, sledge-hammers and pneumatic or petrol driven jack-hammers are used to drive the rebar through the log and into the streambank until only 10-20cm remain. The remaining rebar can then be bent in the downstream direction to secure the logs to the bank. The hammering action whilst bending the last 10-20cm of the rebar can cause the bar to loosen its position in the bank. An alternative method, devised in Ireland to prevent this, is to fit a ¾ inch washer to the rebar before hammering takes place. The action of the hammering flattens the rebar head and the washer can not be removed. The rebar is then driven into the log to the point where the washer is flush with the top of the log, functioning like a rivet.

The tree tops or branches are then attached to the top of the logs in the same manner, but using only short lengths of rebar (20-30cm) drilled through the trunk, or even 6 inch nails. The tips of the trees can be cabled together to improve stability if necessary. It is recommended that the bushiest trees available are used when installing the tree revetment, and that the branches are not trimmed with the tips extending in to the water to act as fish cover. The best trees have more height (10 feet) than width, thus fitting well horizontally along the bank, and preferably newly harvested as limb loss will be less during installation. Plenty of trees should be used, as once the needles fall off, bank protection will be poor unless there is plenty of overlap. Each tree should be overlapped by about a half, like laying roof tiles, with the trunk of the tree top placed facing upstream and the branches downstream.

The underlying toe logs are aimed at preventing further excessive erosion at water-level at the bank toe, where the worst erosion occurs. With the toe of the bank stabilised, the top of the bank is allowed to crumble (slough) in high flows and as the material falls, it is caught in the branches of the trees attached horizontally on the toe-logs. This causes the bank to stabilise as the bank material settles on the trees and the bank angle is reduced. Eventually after time the trees are covered over by "would-be" erosion material. The idea is that with the toe stabilised, the slope will flatten due to bank sloughing and it should eventually support a good vegetation cover, which will protect the bank in the long term. The tree branches slow the flow of the water and allow sediment transported in suspension to settle out and collect, which builds up and helps re-form the stream bank naturally. Willows and grasses and other natural vegetation can re-establish themselves to further strengthen the banks. The silt that is captured in the trees provides fertile ground for new riparian growth.

Tree revetments have proved to be effective and stable in channels in Ireland with gradients of up to 2.4%, despite several floods up to 30 year flood events in the past three years. This gradient is commonly considered too steep for most structures. Tree revetments prevent lateral erosion, but allow vertical scour to progress forming a deeper channel and a slight undercut or shelf under the logs that acts as overhead cover. This is a return to the natural morphological cross-section evident on bends prior to degradation. Long bends are a feature of 'C' type channels. It has been found in Ireland that where log and tree revetments have been installed around long bends, they create stepped riffles in the channel that act as gradient breaks. These steps serve to slow the flow around the bend, thus reducing the erosive force and also increasing the bends habitability.

With the toe-logs in place, these structures are near-permanent fixtures in the stream, but the logs will

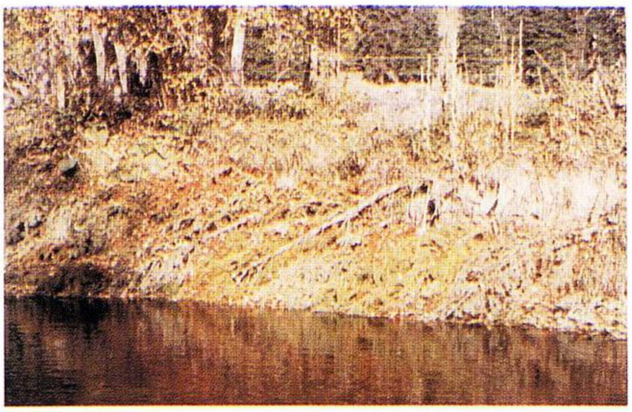


Plate 5.5 Example of tree revetment used in Canada

eventually disintegrate over time, by which time the bank should have re-vegetated and will have regained its natural stability. After an estimated period of 5 to 10 years, depending on the soil type and the water levels in the various streams, installed logs and trees should become covered under natural stream vegetation. Tree revetment is only a temporary fixture on the streambank to prevent unnatural rates of erosion. The aim is to provide immediate protection to the worst eroded areas until such time as the bank has stabilised, re-vegetated and is undergoing erosion at a natural rate.

The hydraulic and biological performance of different types of tree revetment in BC Canada is described by Sheng & Doyle (1996). A day was spent with the two authors in BC viewing some

Plate 5.6 Example of tree revetment used in Ireland

successful and not so successful tree revetment projects in the Upper Fraser River. They say that the early indications are that, in the absence of any abnormally large flood events, tree revetments that are well anchored to the bank will protect that bank from erosion for at least several years on gravel-bed streams. However, a longer term study (12 to 15 years) is required to evaluate the technique properly. Work on the Salmon River, a tributary of the Fraser River, has found that the effectiveness of the tree revetment technique declines as the gravel content of the bank increases. Larger than normal flood events can result in damage to tree revetments before they have established properly, and allow erosion to continue. The DFO (Department of Fisheries and Oceans) is at present improving anchoring systems for the trees, particularly for tying down the tips, which may help to extend their longevity. With the eventual breakdown of the individual trees over time, their value as fish habitat diminishes, as does the degree of bank protection they provide. Therefore the trees may need re-instalment over time. The DFO has designed improvements to the revetments over recent years including bank re-grading before installation, denser revetments, incorporation of some rip-rap into tree revetments, planting behind the revetment, and anchoring of tree tips. These all improve the medium term performance of the revetment.

Evaluation of fish numbers was undertaken in gravel-bed rivers in BC with tree revetments up to four years old, and the results show that as many as four times more fish were found at these sites than in nearby control bends without revetments. In some stream reaches in BC at low flow, it was found that tree revetments provide virtually the only cover. The dampening effect that the tree revetments have on flow patterns is self-evident, judging by the amount of silt that can deposit amongst the branches, and thus they provide a velocity refuge and overhead cover for juvenile salmonids. This benefit was assessed by electrofishing over a four year period spanning before and after construction and also in control sections immediately upstream or downstream.

In these streams in BC, on average, fish densities in tree revetments exceeded control sites by a ratio of 13 to 1 after development, with four of them being 21 times higher than at the control sites. However, juvenile fish densities seem to drop in the third year after construction, but still averaging 3 times better than controls on almost all streams sampled. This decline appears to be coincident with the complete

Plate 5.7 Example of tree revetment used in the United States

loss of needles and a minor loss of tree branches, so increasing velocity and reducing overhead refuge. Juvenile densities seem to be largely dependent on the amount and density of trees and branches that are actually submerged in the water. A few of the original tree revetments were installed with the trees barely touching the water during low summer flows, and fish densities were found to be very low. In contrast, the branches and tips of the trees in the most recent revetments have extended into the river 2-3m. This is providing significantly more habitat and bank protection and these sites are where some of the highest juvenile densities have been found. During spring under high water conditions on Deadman River, no fish were captured at the control site, but a mean juvenile density of $4.4/m^2$ was recorded at the revetment site.

This is backed up by evidence from the River Deel in County Mayo, Ireland. Monitoring of log tree revetment on this river by the Central and Regional Fisheries Board has shown that juvenile 1+ salmon densities were restored to natural levels only one year after installation, and were higher in reaches with log tree revetment than those left undeveloped (O'Grady & O'Neill 1997).

A major concern expressed in BC concerning tree revetment's fish habitat value is that of longevity. It is believed that they may need to be replenished with new trees after 10 years, but that depends on the rate of natural bank repair and the conditions that they have to endure. Weather and climatic conditions in Britain tend not to be as harsh as those in some parts of North America, and therefore trees used in revetments should have a longer life. But these milder conditions should encourage quick re-growth of overhanging and trailing bankside vegetation that replaces the loss of cover when needles and branches are lost. Tree revetments have not been in use long enough anywhere to ascertain whether tree replacement will be required. A 10 to 15 year long term monitoring programme should determine whether the pressure on an eroding bank protected by tree revetment gradually lessens over time. According to theory, as the meander pattern of a stream migrates down the valley, the erosive forces on the revetted bank should gradually decrease and move down the valley. When this happens, the repaired and re-vegetated bank slope behind the ageing tree revetment should be able to withstand the diminished erosive forces, hence the trees would not need replacing.

Another option that the DFO is testing at present, in the Salmon River, is to design part of the tree revetment as "debris catchers" to build up naturally occurring branches and other woody debris. Upon eventual loss of the branches, the hope is that the bank should have repaired/stabilised itself sufficiently to function itself without the tree revetment and be capable of being held together by newly established bankside vegetation. It is for this reason that the DFO sees it as imperative that planting of willow and other riparian plant species is incorporated into the revetment to ensure sufficient re-establishment of bank vegetation prior to disintegration of the tree and log revetment. Therefore it is also essential to fence out grazing livestock.

Sheng and Doyle, through the limited data that they had collected at the time of my visit, were able to suggest the severity of flows that tree revetments are able to withstand by calculating the 'stream power' (the energy available in a stream at any discharge).

Stream Power (as defined by Leopold et al. 1964) is
$\Omega = þ\ g\ Q\ s$

where þ is mass density of water ($1000\ kg/m^3$)
g is acceleration due to gravity ($9.8m/s^2$)
Q is discharge in m^3/s
s is water surface slope

From their calculations they suggest that stream power values below 1,500 will not significantly damage tree revetments on gravel-bed streams, however a stream power value greater than 5,000 will likely damage conventional tree revetments, with the severity of damage increasing with increasing stream power. It may also be necessary to include other factors that will dictate the longevity of tree revetment such as levels of channel entrenchment, as the greater the entrenchment the higher the shear stress and energy levels on the structure up to the bankfull height. Also differing climatic conditions must also be considered.

After four years of construction experience and monitoring of different tree revetments, the DFO in BC Canada suggest that trees should be anchored parallel to the bank and over-lapped one-third to one-half, and there should be no gaps between trees along the face of the eroding bank, with at least 1m of the branch being in the water. Lowe (1996) produced a manual entitled *Fish Habitat Enhancement Designs* in which he suggests that tree revetments are effective in streams up to 60m wide and where water level fluctuations do not exceed 1.5m. In Ireland tree revetments have been found to successfully withstand fluctuations of up to nearly 2m in channels with summer channel base widths of around 2m. In certain circumstances in Ireland tree revetments have remained stable and effective in channels with gradients up to 2.8% (O'Grady pers.com 1997).

In conclusion, it can be seen that tree revetment is less permanent than rip-rap in that it does not lock the stream in and although it is more labour intensive to construct, it should be cheaper (depending on the cost of rock for rip-rap) and in most cases it is of greater benefit to fish. When installed as a dense overlapping "thatch", such revetment can simulate beneficial aspects of trees that naturally lodge along current bearing banks. Tree revetment immediately creates fish habitat, which may be critical in streams that have long reaches with little or no cover or refuge. By trapping fine sediment it speeds the development of riparian vegetation, making it a particularly suitable technique for restoring habitat in streams damaged by overgrazing and other destabilising activities. The damaging activity should, of course, be halted before tree revetment is undertaken.

Where stream power is less than 1500, revetments will allow the protected bank to flatten and revegetate with time. However, high floods can still destroy these structures. Assuming tree revetment structures do not fail, their lifespan will be dependent on how long the trees take to break down or rot. Tree revetments are therefore temporary structures intended to reduce unnatural erosion rates and allow the development of streamside vegetation. But, to ensure their future as a restoration technique, improved anchoring and construction features should continue to be designed and monitored. Recording of this is vital, as such data will serve to better document the performance of different types of tree revetments in the wide range of stream conditions where they are used. Recording the annual performance, both physically and biologically of a variety of tree revetment designs in natural bend configurations, in streams of different size and power, over a period longer than the effective life of a tree (± 10 years), should provide a much better understanding of where tree revetments can be used beneficially. Improvements in the design of tree revetments can be made to further enhance the fish habitat through systematic testing and analysis, which may lead to a wider use in larger and wider streams.

5.5 Improving Cover or Microhabitat

Many upland salmon streams in the UK are wide and shallow and deficient in natural cover. Cover for hiding and security is crucial for fish, particularly in shallow streams. Cover consists of objects or channel formations that offer fish concealment from predators, visual isolation from competitors and refuges in which they can conserve energy or survive high flows. Interstitial spaces in coarse substrate provide these important refuges for juvenile salmon, but bushes and shrubs, reaching over and into the water also provide excellent hiding areas for juveniles and these are in short supply in many upland river systems.

Categories of Cover -

1 Overhead bank cover such as undercuts and objects associated with the streambank, under which the fish can hide, such as fallen and overhanging trees
2 Midstream objects, such as boulders trees, branches and aquatic plants
3 Deep water in small streams
4 Hydraulic features, such as areas of broken or turbulent water surface and masses of bubbles or foam

Large coarse substrate such as cobbles and boulders can provide visual isolation between juveniles in shallow upland streams. Juveniles also hide from both predators and high flows in the pore spaces under large cobbles and boulders. A varied or diverse substrate provides what can be termed microhabitat and this increases the juvenile carrying capacity of the channel, particularly for parr. "As juvenile salmonids defend territories by sight, tree debris and substrate diversity can isolate neighbours visually and territory sizes can decrease" (Bisson et al. 1987). The addition of large cobbles and boulders in areas such as glides in rivers where they may be deficient has proven to improve juvenile salmon populations in many different size moderate to high gradient channels in Ireland.

Tree revetments are another way of producing cover and isolation, but dead trees, bushes and branches or Large Woody Material (LWM) which fall into the water can also provide cover. In many cases there is a total lack of a healthy riparian zone and therefore there is no input of LWM cover from this vital source. In America and Canada, every effort is being made to preserve or enhance the beneficial aspects of cover provided by LWM wherever it is available. In many cases they are adding artificial cover structures that are simulating natural LWM, but all the time remembering that excess amounts of it can be detrimental to salmon production, for example, blocking upstream access or causing ponding and slowing the flow which in


Plate 5.8 - Cabled Boulders

turn encourages sediment build up.

Submerged material, bankside LWM and added boulder substrate should all enhance bed scour which deepens existing pools and creates new pools. They also create eddies which provide flow refuges for fish. Juvenile salmon hide in the eddies and wait for food items to drift to them, or they can dart out into the current to feed. The placement of LWM is one of the most effective ways of enhancing cover, as it creates overhead cover, but also it casts a shadow on the stream bed in which fish will lie during sunlit times. The woody material is also useful as extra substrate for aquatic invertebrates, which can be in short supply in many upland streams.

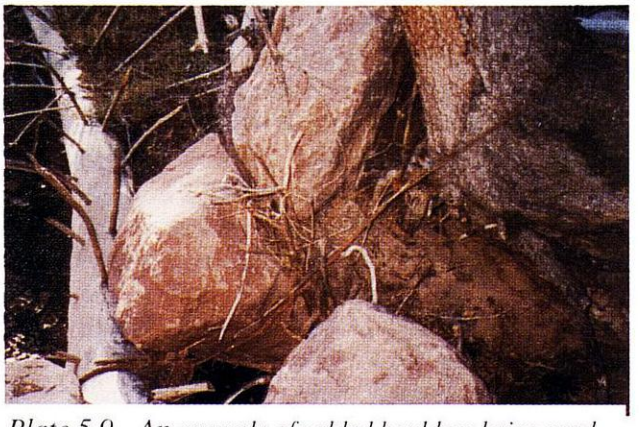


Plate 5.9 - An example of cabled boulders being used as anchor ballast

Several simple methods and devices are available to enhance this type of cover in streams. Many cases of using whole trees, large branches and root wads (LWM) anchored to bank faces and toes using anchors such as steel reinforcing rods (rebar), wire cable and the duckbill anchor were seen in North America. Another common technique used by the US Forest Service is to attach LWM to the bed in pools and glides to simulate natural cover. These are generally called submerged brush cover and they mimic natural instream material, which provides cover for fish. They can be used in pools, midstream in glides or in any stable area where the substrate is relatively coarse and not susceptible to high levels of sand, silt and gravel deposition, otherwise they will be buried. Traditionally split logs have been used as midstream half-log cover structures, as described by White and Brynildson (1967). Large crooked cull trees, branches or rootwads are now preferred rather than straight logs, as they provide an irregular surface, resulting in maximum turbulence and therefore better spot scouring and eddy currents. It is preferable to place them where they will remain submerged both in high and low flow, to reduce rotting and maximise their durability.

Submerged material can be attached to the bed in pools by using steel cable, lengths of rebar and in some cases in the US, ballast rocks. Ballast rocks are large individual rocks cabled together using steel cable and they are used to counteract the buoyancy of wood by using them as ballast to weigh the woody debris down and to increase the stability of the structure. In the Cascade Mountain Range in Oregon, the Oregon Dept. of Fisheries and Wildlife have created ballast clusters by bonding steel cable into rocks with polyester resin. Holes (25-30cm deep) are drilled into the rocks/boulders with a rock hammer/drill, and Hilti C-10 or Upat Molly Parafast polyester resin is injected into the holes using a caulking gun. Galvanised steel cable is then inserted directly into the rock and is held fast (Plate 5.8). This rock cabling technique allows large boulders to provide a stable anchor for logs, branches, trees and rootwads which are submerged in pools or even attached to the bank (Plate 5.9). The technique was also seen used to anchor boulders and other structures in bedrock reaches to create flow and habitat diversity and also to trap spawning gravel in some instances. LWM placement is a widely applicable technique and can be placed in nearly any type of stream. It has been shown many times that brush along current bearing banks and submerged in pools appears to provide shelter for more fish per m^2 than any other type of material. Thus it is important to incorporate brush or woody material of some sort into restoration projects, even if it is adding it to traditional structures as extra cover and refuge. Examples of various bankside LWM cover are shown in diagrammatic format in Figure 5.2a to f.

If it is whole trees that are being used, they can be felled directly into the channel, or trees that have fallen in naturally can be attached to large boulders in the channel or stumps on the bank to ensure stability. It is preferable that the roots of trees remain on the tree as they provide diverse flow and

Figure 5.2a

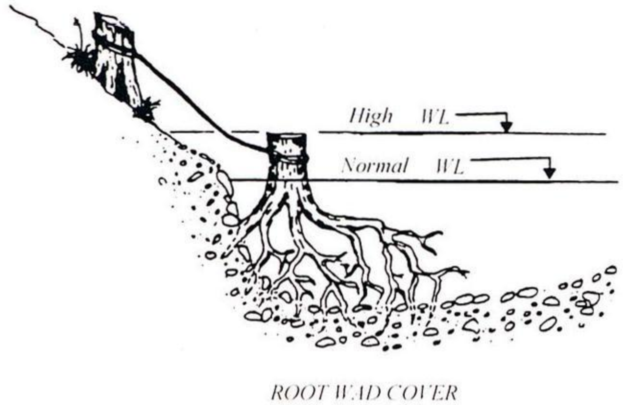


Figure 5.2b

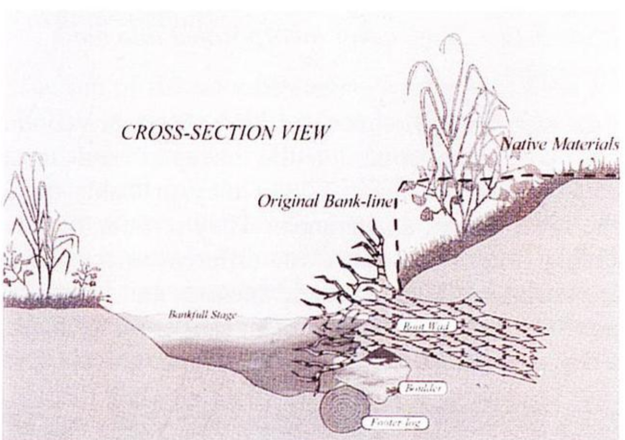
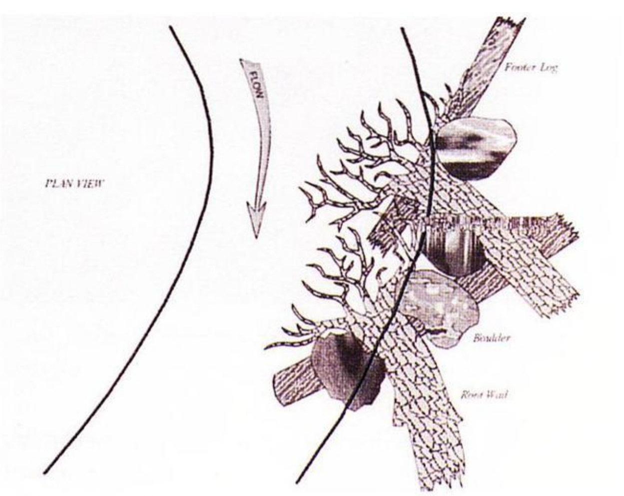


Figure 5.2c



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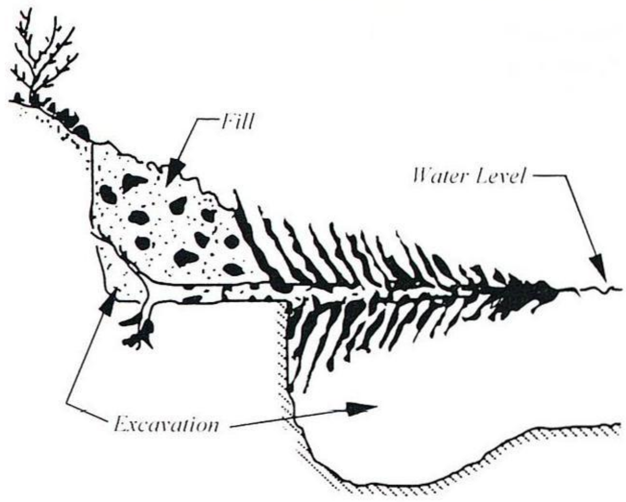


Figure 5.2e

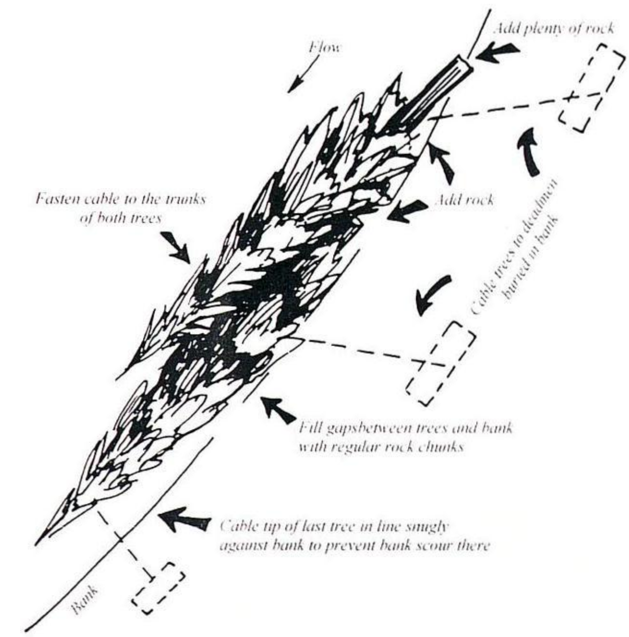


Figure 5.2f

Figures 5.2 a-f - Diagrams of bankside LWM cover

cover conditions. Trees and rootwads can be placed in any stream that is large enough that their installation will not cause bank erosion due to disruptions to the flow. But the greatest benefits are probably realised in wide shallow rivers or in large rivers with unstable substrate, as the trees, rootwads or branches may help to stabilise the substrate.

Trout Unlimited have used rootwads extensively in restoration projects in the States. Plate 5.10 shows a rootwad used on Mill Creek in Utah to stabilise an eroding bank and to provide cover for juveniles. It is buried with the stump in the bank and the roots into the stream, with boulder anchors for stability.

Plate 5.10 - Bank cover incorporated into bank revetment

Newbury & Gaboury (1994) incorporated cover structures into fishery enhancement projects that consisted of felled spruce trees placed in excavated cuts in the streambank. Excavated material from the pool and bank and even rip-rap material was used to cover and secure the overhanging tree. This technique is shown in Figure 5.2e and Plate 5.12 on the Seschwapp River in BC Canada. These particular trees are 6m long and keyed 3m into the bank. In this particular instance they were used to improve holding water for adult salmon, but a similar technique on a smaller scale would be just as suitable for juveniles in smaller streams (Plate 5.11).

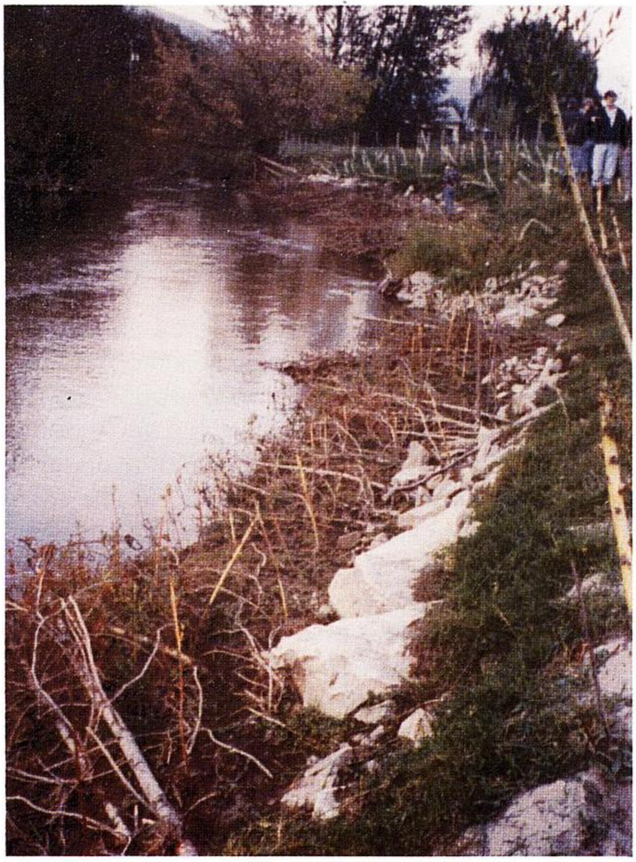


Plate 5.11 - Bank cover incorporated into bank revetment

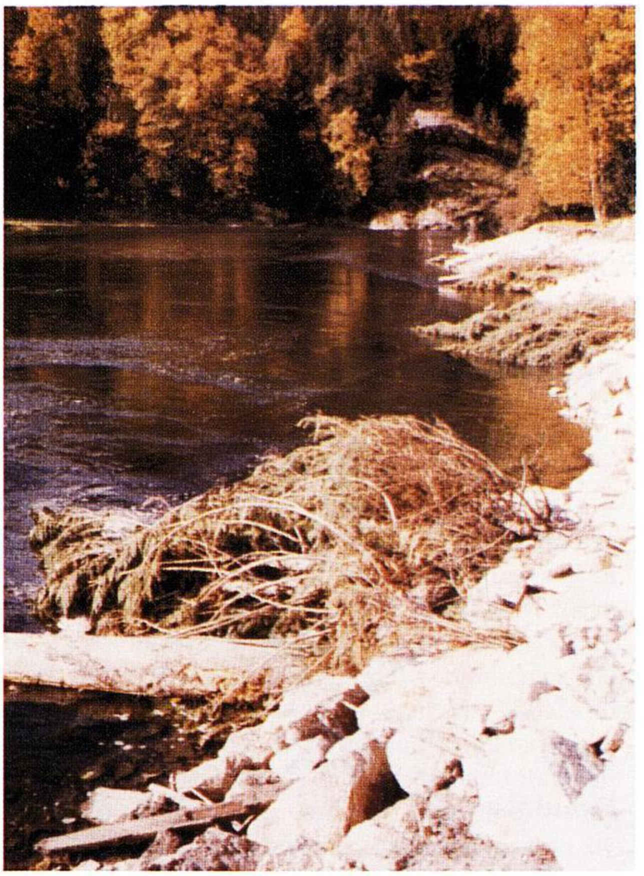


Plate 5.12 - Bank cover incorporated into bank revetment

Submerged LWM cover and LWM bank protection and cover are some of the cheapest and most effective habitat devices, and they probably have the most natural appearance. They provide quality hiding places for fish of different sizes from terrestrial, aerial and aquatic enemies and territorial conflict and they can protect an eroding bank. They also function to trap spawning gravels and

Plate 5.13 – Example of LWM placement in Oregon, USA

can help focus the current, flushing fine sediment and creating scour pools creating a diversity of habitat. They can be used in a wide variety of stream types and have less impact on channel capacity and flow characteristics than other structures, with minimal maintenance. They are easy to install and can be easily adjusted if necessary. But, if improperly installed they can catch excess debris, altering the flow or partially damming the flow and causing backwatering upstream. Also, if improperly placed they can deflect flows to unstable banks and cause erosion.

5.6 Placement of Large Woody Material

Coarse or large wood material (LWM) in channels, not only provides cover for fish, but plays a crucial role in determining channel morphology, which has only been realised in the last decade or so in the Pacific Northwest of America. In the mid-1900's, removal of log jams and other woody accumulations was widely practised in streams and rivers in North America to restore channel conveyance capacity, reduce impoundment and eliminate barriers to fish migration. Recent research has increasingly indicated that LWM and submerged debris accumulations can enhance salmonid production by stabilising channel morphology and by increasing the juvenile carrying capacity of some rivers due to increased cover availability.

The job of fisheries biologists working up until the 1970's in North America was barrier removal such as debris jams. This practice began to be questioned in the late 1970's as researchers demonstrated that LWM also plays a key role in stream channel mechanics and substrate dynamics as well as improving the salmonid carrying capacity. Large single pieces of logs, root wads, boulders and other wood accumulations in the substrate result in more complex stream features and substrate distributions. LWM physically alters local flow patterns and channel characteristics by changing the dissipation of stream energy and generally creating local channel scour and deposition. Woody material creates pools, increases channel complexity, creates slack water allowing fine sediment storage, acts as a substrate and food source for aquatic organisms, as well as providing cover for fish. It also traps gravel for spawning, traps and holds other organic matter and can increase channel stability. It is for this reason that programmes of woody debris removal by state and federal agencies in North America have been halted.

Something that is frequently overlooked or misunderstood is that LWM originates from the riparian zone, and thus the riparian area plays a vital role in influencing channel morphology. Trees naturally shed twigs and branches and occasionally entire trees fall into watercourses (depending on availability). Logs and smaller woody matter can enter channels by wind throw and bank erosion, but in the US the logging industry and also beaver activity can be a primary cause of trees and other woody material ending up in the watercourse. Unless they threaten life or property or they are causing an obstruction or tunnel the channel, trees and other organic debris should not be removed from rivers, as they play an important role in the freshwater ecosystem. However, where exceptional quantities of wood material accumulates following commercial forestry operations for example, debris removal may be necessary. In some situations, rather than removing large pieces of wood that are blocking a channel, it may be an advantage to pull them to the bank, using an excavator if necessary, and secure them as protection and cover for fish, as stream edge woody material is superb for hiding and feeding cover for many fish. The Forestry Guidelines in the UK state that all tree debris from forestry operations should be removed from watercourses. Excess accumulations should be removed, but with guidance from experienced fisheries bodies post-harvest surplus woody material can be placed in strategic locations to stabilise channels, create pools, flush out fine sediment, accumulate spawning gravel, narrow over-widened channels, protect banks and provide cover for juveniles.

In the Pacific Northwest of America, the policy of removing LWM has ceased. This has been replaced with a programme of adding wood material to enhance existing traditional structures to enhance their aesthetic appearance and also to provide extra cover. They are also actually placing LWM in locations in the channel to simulate natural LWM accumulations and to add not only cover, but physical structure and stability (Plate 5.13).

The use of LWM in enhancing the productive capacity of streams was highlighted at the 10th International Stream Habitat Improvement Workshop in Oregon. In the Coastal Mountain Range of Oregon, sites were visited where the placement of LWM to improve instream habitat was incorporated in commercial logging operations. At Bark Creek, the efficacy and stability of LWM placed during logging operations was highlighted and shown to be more cost effective and longer lasting than constructing traditional instream structures. At Mill Creek the placement of LWM was demonstrated using both a hydraulic excavator and using a horse drawn operation. Sites were visited at Shotgun Creek, Mill Creek and Quartz

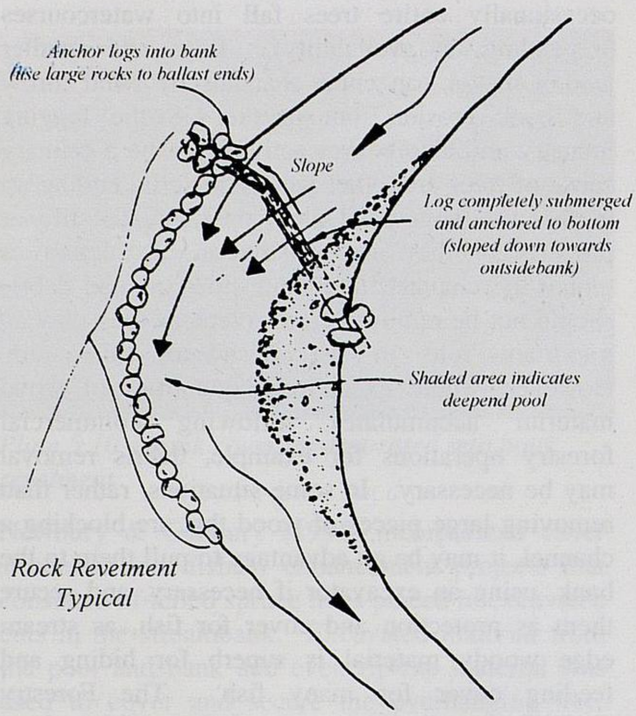
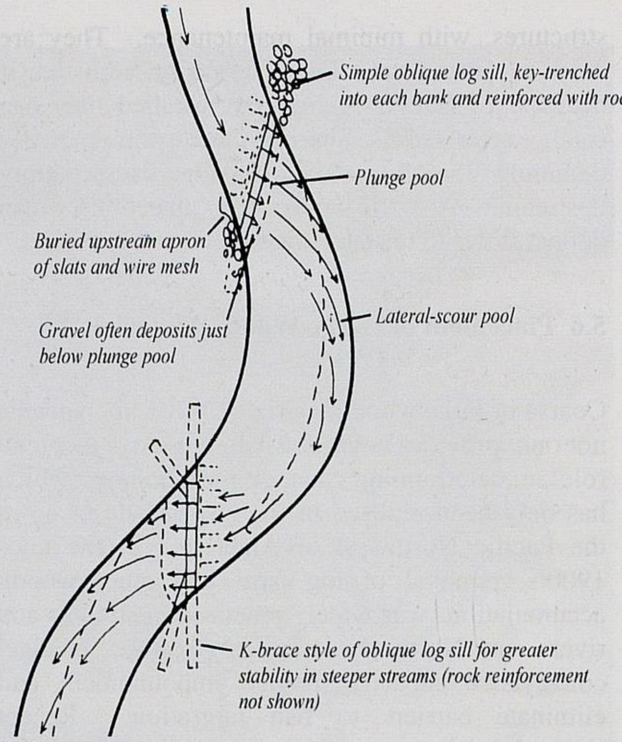


Figure 5.3 - Digger log location



Creek in the Cascade Mountain Range where extensive placement of LWM has increased the available habitat for juvenile salmon. At Shotgun Creek, there were 181 pools over a 4.8 mile reach in 1983, but most pools were shallow and lacked fish. In 1993-4 the Bureau of Land Management added 149 structures (260 pieces of LWM) to simulate natural LWM in the channel. By 1996 there were found to be 223 pools with sufficient depth and cover and also natural pieces of LWM had accumulated, making 482 pieces of LWM. Unfortunately, although morphology changes and habitat provision were observed, fish populations were not monitored at this site.

At Quartz Creek a similar programme of LWM placement was implemented. The objectives were to re-establish natural volumes of woody material, increase the hydraulic heterogeneity, create a stepped bed profile in a relatively high gradient reach (3.7%), provide increased cover for fish, increase flood refuge and create sediment stores. Large pieces of timber, no less than 1m in length and 10cm in diameter, were placed in the channel in a variety of arrangements to simulate random accumulations of natural LWM. Large retentive backbone structures were used in some locations to trap other woody material. Full channel log jams with key anchor logs, upstream pointing V's, large lateral deflectors, cover logs with root wads and parallel bank logs were used to create plunge pools, fine sediment stores, spawning gravel traps and lateral scour pools with good overhead cover. Some LWM pieces were anchored with cable at both ends and some were only cabled at one end so that they could rise, fall and swing with differing discharges. Fish numbers were monitored by a favoured American technique involving visual counts by snorkelled divers. At three different locations in Quartz Creek the fish numbers all increased post restoration from 56/100m to 80/100m, 62/100m to 130/100m and 78/100m to 195/100m.

In Canada the DFO have also acknowledged the importance of LWM in maintaining stable channel form. For example, in a severely degraded river on the Queen Charlotte Islands in BC with only cobble-bedded riffles, few pools and no cover, the strategic placement of LWM caused substantial increases in pool number, pool area and habitat complexity after the first winter. The importance of LWM in stabilising channels is also acknowledged by the DFO in Halifax. Mike Rutherford, a habitat biologist with the DFO in Halifax, suggested that the single most important piece of habitat restoration work they have done for Atlantic salmon, is placing artificial LWM in rivers.

5.7 Digger Logs - Replacement of LWM to create physical habitat

In 1994, the DFO in Halifax undertook an investigation (Rutherford et al. 1994) into spawning and rearing habitat for Atlantic salmon. They compared highly productive salmon habitats with those of poor production in gravel bed streams of similar size and flowing over the same geology, to discover what the reason for the differing productivity was. They found that the major difference was in the amount of large organic material embedded in the substrate. Well-developed and diverse habitats had an amazingly regular pattern of embedded hardwood logs approximately six channel widths apart at what can be termed the riffle-pool join. This riffle-pool join is where there is a change in channel gradient at the downstream end of a riffle, where the river should scour a pool. The imbedded logs interacted with stable vegetated banks, gradient, substrate size and flows to sort and stabilise gravel and scour pools that are needed for high productivity. The lack of healthy riparian stands and some forest management practices in Canada do not allow for the regular input of large hardwood material to streams. Thus 'digger logs' have been developed by the DFO as a restoration technique from this observation.

The purpose of a digger log is to create a pool in high gradient reaches that are wide and shallow and devoid of depth and cover. In straight channels the logs should be installed just downstream of obvious breaks in stream gradient (i.e. end of riffles at the riffle-pool join), with the pools being scoured on alternating sides of the channel. In meandering channels, pools are formed on the outside of bends, so the digger log should be located just upstream of the bend at the tail of the riffle so that the pool is scoured in the correct location (Figure 5.3). Historically these have been natural structures as Rutherford et al. (1994) discovered. Old trees would fall into the stream to be moved by the current to particular locations where they became set into the substrate and eventually formed a pool downstream. Particularly in steeper gradient streams, steps formed by log jams and accumulations of large rock are important in stabilising the channel, creating areas of slow current, trapping sediments such as gravel and causing plunge and lateral scour pools. If the obstacles that create these steps are removed, the channel develops a faster current and the channel erodes. Changing land-uses and forest management practices have limited this process and the lack of these inputs have reduced channel dynamics, and therefore the productivity of the streams. So to improve fish habitat the stepped form should be enhanced or restored by installing digger logs to substitute for the lack of these natural formations.

In some restoration guidebooks, digger logs are referred to as low oblique sills, low barriers, low dams, low weirs, check dams, drop structures, overpours or cross log revetments (Hunt 1993). In the case of the DFO in Eastern Canada, logs have been used as diggers, but boulders could be used to construct the same feature if they are more readily available. Hardwood logs should always be used, instead of softwood, as they stand up considerably better to abrasion from gravel and sand substrate particles. The logs should be one quarter to one third of the bankfull height in diameter and keyed well in to the bank and the streambed. They can be anchored behind any large rocks or tree butts if they are in the correct location, to add to stability. The height of the structure is quite important, as too small a log will not effectively dig a pool, producing habitat little better than what already exists. But if the log is too big it is likely to cause a damming effect upstream.

The log should be secured to the bed using 1.5m lengths of steel re-inforcing rod (rebar) and washers as described for tree revetment. The upstream edge of the log should be lined with chainlink, geotextile filter cloth and covered with stones to create an apron/ramp preventing undercutting of the log. Stones can be removed from the downstream pool and placed upstream on the ramp or apron, which should ideally be at a slope of 3:1. The log should be installed at 30° from perpendicular to the current, as this angle produces the best turbulence for sorting the substrate materials and is the angle of natural riffles, and therefore produces the best pools. The pool that a digger will create will be on the same side of the stream as the point of the log furthest upstream. The structure should be angled such that the end of the log that is near the outer bank is lower elevation than the other end. This ensures that at times of low flow the current is concentrated in the outer part of the channel. A large boulder can be added to the pool to provide extra cover for fish and to maintain scour in the pool.

Scour downstream of the digger removes small particles, leaving the coarser material in the pool. This is important for salmon, as juveniles seek shelter in the substrate during winter. Thus the bed must be coarse enough so that fish can hide in the interstitial spaces. Many species of invertebrates which salmon feed upon utilise these spaces and also the substrate in the riffle upstream. Therefore digger logs should indirectly increase the food base for salmon. As the pool forms downstream of the logs, the depth of the water provides extra cover for fish. Although this is not as effective as vegetative cover, depth allows visual isolation, which increases the number of territories available, allowing more fish to occupy the area. The area directly upstream of log can be used by salmon as a spawning area, as good gravel accumulates here and there is good movement of water through the gravel at this location, but if the damming effect is too high, siltation may occur.

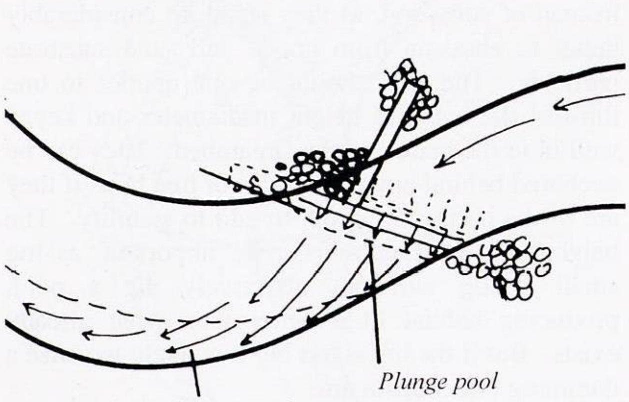


Figure 5.4 - Digger log with deflector to narrow the channel

Digger logs will create pools downstream of the structure, with the size of the pool dependent on the stream gradient. The pool size is also dependent on the size of the stream and the volume of water being carried in the stream. A gravel-bed stream with a gradient of approximately 0.5% will develop a 1:1 pool-riffle sequence, which is ideal trout habitat. Higher gradient streams have more riffle than pool and are therefore better suited to salmon. As the gradient of most streams will vary, a mix of habitat suitable for salmon and trout will be created.

The diagonal digger is considered by some to be one of the best structures for increasing productivity in high gradient salmon streams, as it works well on straight reaches and bends and is simple to construct. It reduces stream velocity because of its long length, dissipates the kinetic energy of the water and recruits large amounts of gravel. It has also proved to be very stable causing little bank erosion. When properly placed these have proven to be one of the best and most successful structures on stream bends in gravel bed rivers. With the digger log, the flow is spread or diverged across the face of the log due to it being a larger area than the natural stream width. This decreases the velocities and kinetic energy, ultimately creating a stable structure. The digger log has become the primary structure of Fish Habitat Restoration Projects in the Scotia Fundy Region of Canada. It would appear that beavers have long realised the natural dynamics of a stream. In North America, it is not unusual to find a beaver dam exactly where you want to locate a digger log. Beavers seem to use the change of water flow that occurs when the thalweg reaches the bank at the riffle-pool join, as an ideal place to construct their dams, and it appears to be a stable location.

In 1994 Brierly Brook, a tributary of the West River in Nova Scotia which had seen a rapid decline in the population of Atlantic salmon, was chosen for enhancement by the DFO as it was seen as a worst case scenario. The decline was coincident with a series of instream modifications carried out in the 1960's and 70's and to some extent still today, such as channelisation, flood relief and urban development amongst others. The riparian zone was small to non-existent with a young stand of trees. The channel had become wide and shallow and this was a major factor causing population decline. Summer water levels meant that there was no depth and cover for juvenile salmon and the channel readily iced over in winter. Based on the observations of Rutherford et al. (1994) which are outlined above, a plan was implemented to mimic large organic debris, which embeds itself at the change in gradient from a riffle/ run to a pool. Digger logs were the most common device used, but if the width of the channel dictated (i.e. >8m), digger logs were used in combination with deflectors (Figure 5.4).

Digger logs were generally sized to ¼ of the bankfull height (average 20cm). They were placed across the stream on a preferred angle of 30° from the perpendicular, but where the banks were eroding the angle was reduced in the belief it would lower the pressure on the bank. The logs were carefully placed so that they were sited at breaks in the gradient, usually at a distance apart of 6 channel widths. This pattern was established in reaches with narrow bank widths and followed without change through the wider reaches. Past experiments with digger logs found that if this pattern of six channel widths is not followed, the effectiveness of each log is reduced, some wash out and others are buried.

Twenty-five digger logs were placed in total. Paired and single deflectors were used in seven cases where the channel was over-widened. Deflectors had a 30°-60°-90° triangle base with the 30° at the upstream bank and the 90° instream. The instream point of the deflector is located on the digger log so that the width from the point to the far bank is the design channel width. The deflectors are placed on the most downstream end of the digger log. The distance between paired deflectors on a digger should also be the design channel width. Double deflectors are used where the

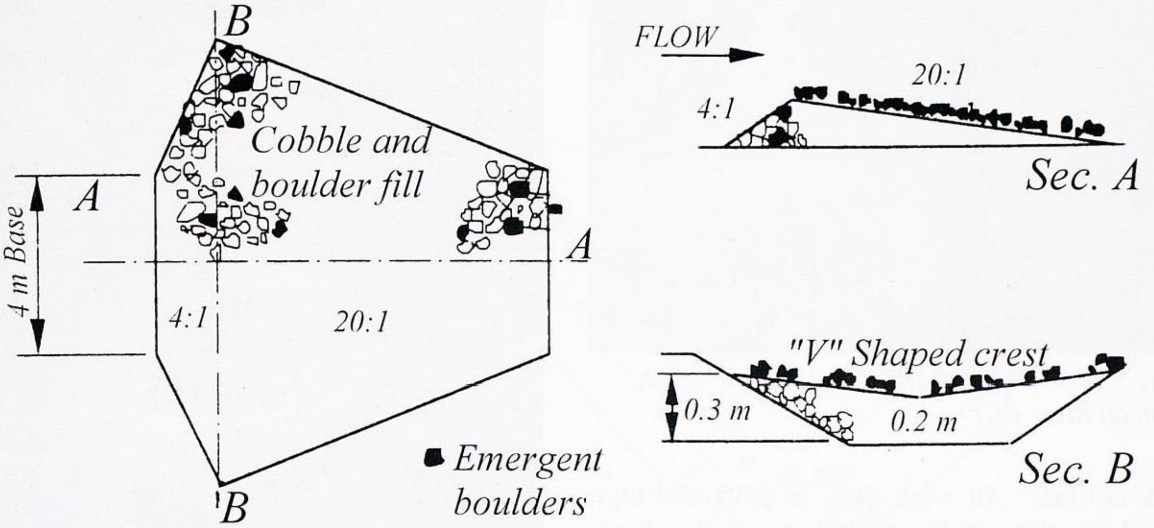


Figure 5.5 - Example of a Newbury Riffle (adapted from Newbury & Gaboury 1996)

channel width is very wide and both banks are eroding. If a stream is over-widened, with the width being 20% or more than the calculated average width, a deflector should be installed on the downstream end of the digger log. As water comes down off the deflector it is guided back toward the middle of the stream which accentuates the role of the digger. A digger log creates a pool immediately downstream of the log, a deflector however starts to cut a pool some distance downstream. The result of a digger/deflector combination is a much larger pool. Whole trees can be used in combination with digger logs as deflectors to narrow the channel. These trees act incredibly well as sediment traps as the branches slow the water causing the stream to drop any suspended sediment between the tree and the bank

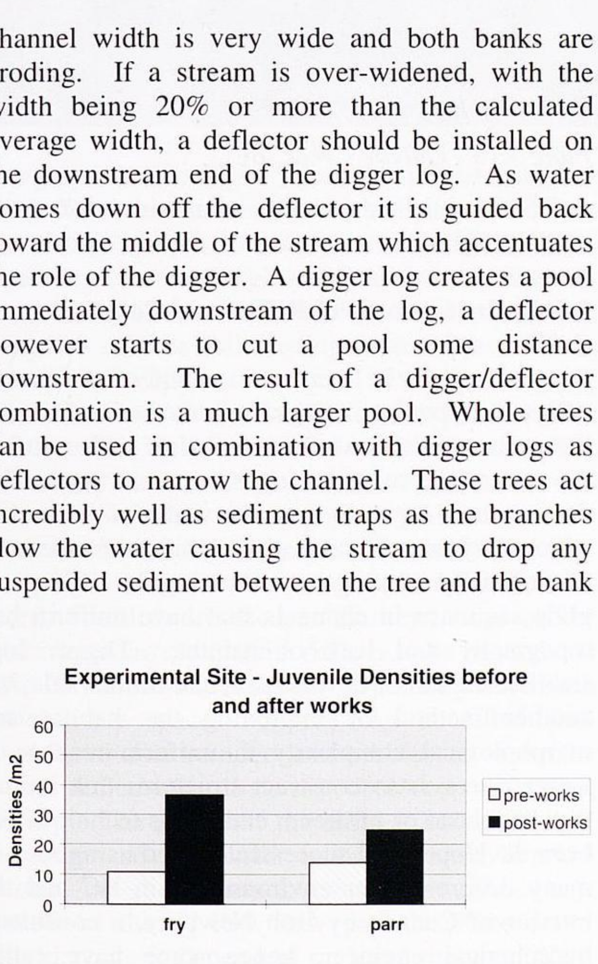


Chart 5.1

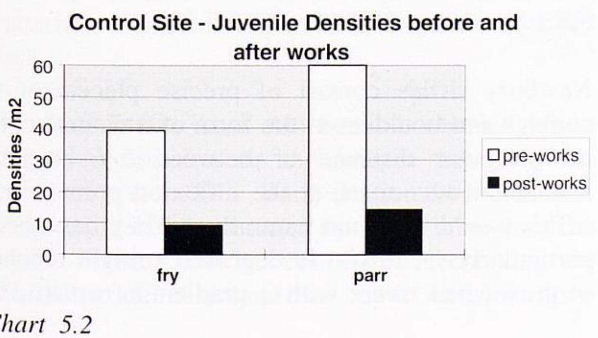


Chart 5.2

on the point bar, so narrowing the stream.

All digger log devices on Brierly Brook were laid out to create pools on opposing sides of the stream to fit and emphasise the meander pattern. The diggers created pools, which provided depth and cover for use in low summer water levels and the deep water in pools meant that during ice-over in winter, juvenile habitat was provided under the surface ice, whereas before due to the shallow channel ice formed rapidly as the water froze to the substrate. In 1992, one of the worst winters on record, the river had very little ice build-up and several sections stayed open, whilst other rivers nearby had a bad year.

Experimental and control sites were set up prior to construction and electrofishing surveys were undertaken and other parameters were surveyed. The results of the electrofishing surveys before and after works are shown in Chart 5.1 and 5.2. The experimental site experienced a large increase, whilst the control site had a significant decrease in juvenile densities over the same period. The drop in juvenile numbers in the control site was thought to be related to the longest recorded cold snap during the winter of 1992. Survival in the wide and shallow control site was thought to be have been much lower than the experimental site, due to ice attaching to the substrate. In the experimental site the structures created deeper water allowing less of an ice build-up and thus providing better juvenile winter refuge.

The conclusions from the Brierly Brook Experiments are that digger logs are very effective in improving habitat, especially diggers at 30° angle from the perpendicular. There is no evidence to suggest that placing them at this angle will cause

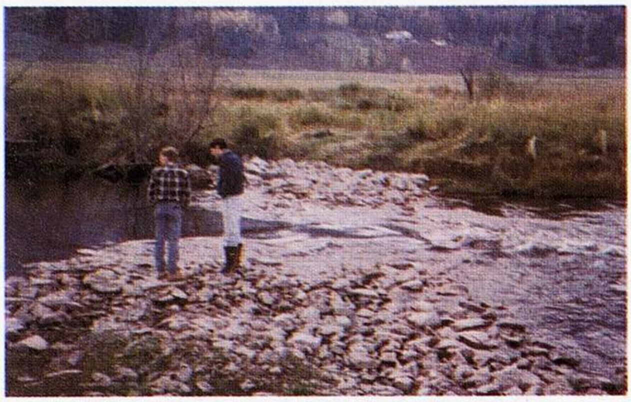


Plate 5.14 - Newbury riffle in a straight reach (Salmon River BC)

bank erosion. All work done in 1993 had logs placed at this angle, regardless of the bank condition. The digger logs cause the water to scour the bed with a plunging flow during low flows and dig outward as the flow increases, producing two to four standing waves downstream during high flows. Fine gravel, sands and silts are

Plate 5.15 - A Newbury riffle reducing bend erosion by backwatering upstream

deposited on a bar which forms to narrow the channel along the bank adjacent to the downstream end of the log where a natural point bar would be. During low flows these areas can be seeded to speed up deposition and improve stability. The hardwood digger logs remain wet throughout the year and gravel should build up upstream of the digger ramp which should be suitable for spawning. Digger logs are expected to remain intact for 25 years.

Digger logs are also considered to be the most effective structure by the US Dept. of Information in the Pacific Northwest of Oregon (Anderson et al.1984). This is because they could be installed in straight reaches and on bends and were simple to construct. They found that digger logs reduced stream velocity due to their long length, dissipated the kinetic energy of the water and recruited large amounts of gravel. They proved to be very stable with little bank erosion, and all were successful

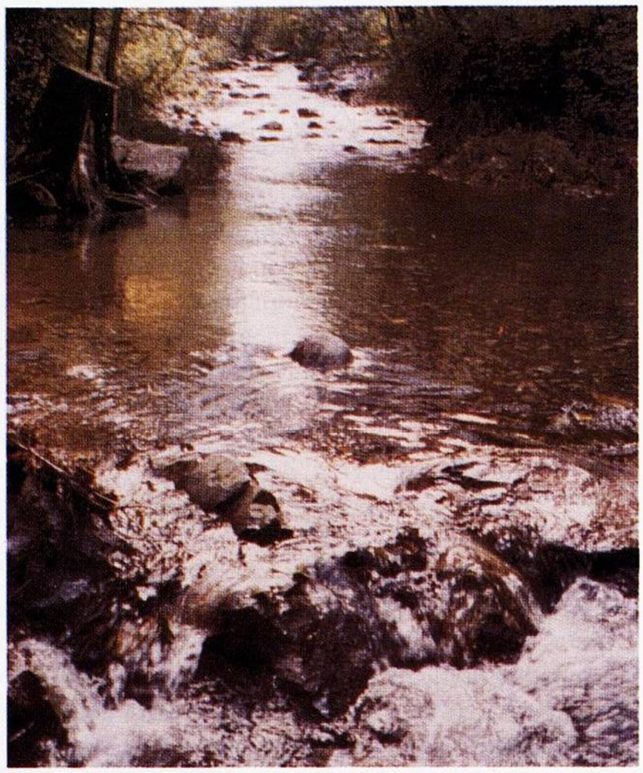


Plate 5.16 - Oulette Creek, BC

and both adult and juvenile salmonids extensively used the habitat.

5.8 Re-Instatement of Riffles and Pools

Digger logs can be seen as a method of re-creating riffles and pools in degraded reaches. The log forms the stable downstream edge of riffles and as the water falls over the log it creates a pool. But the length of logs can limit the width of channel in which they are effective. There are other methods of artificially creating or re-instating the riffle-pool-glide sequence in channels that have uniform bed topography and lack of habitat. Digger logs stabilise the tail or downstream end of the riffle, but another method of improving the habitat and morphological complexity in uniform reaches in larger rivers, is to construct structures that imitate the riffle head or upstream end. This technique has been developed and successfully used using rock in many different river environments in BC and the interior of Canada by Bob Newbury, a consultant hydrological engineer, hence some have called them Newbury riffles.

5.8.1 Newbury Riffles

Newbury riffles consist of precise placement of cobbles and boulders in the form of a natural riffle at a regular distance of between 5-7 bankfull channel widths apart, at the inflexion point where riffles would be found naturally. They have been particularly successful in degraded straight reaches in gravel bed rivers with a gradient of up to 3%.

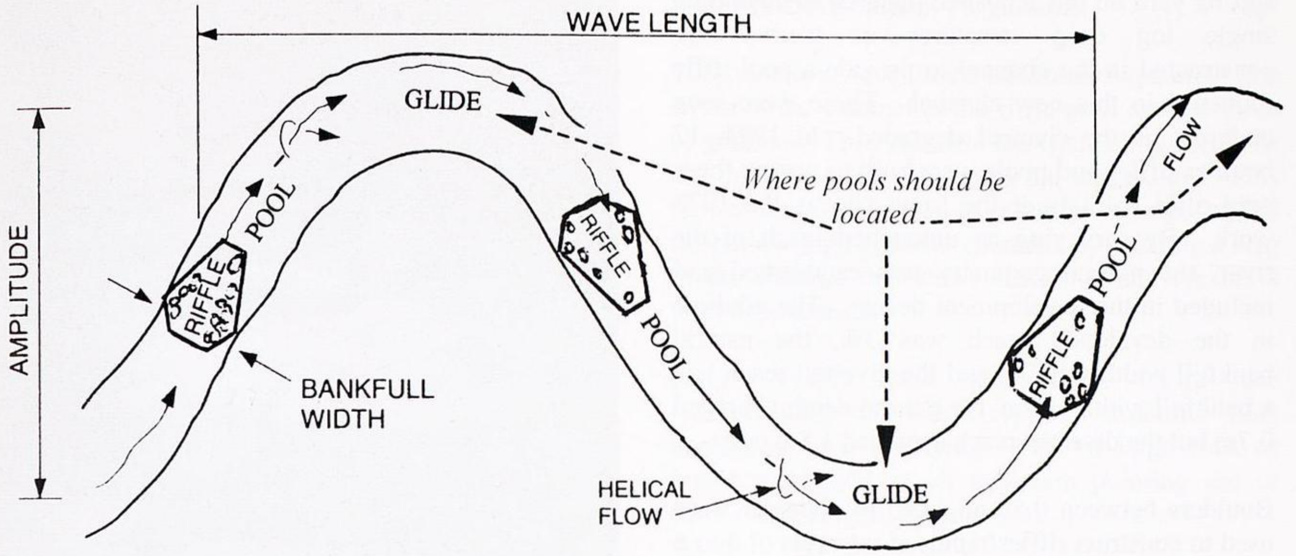


Figure 5.6 - Example of incorrect Newbury riffle placement

They have also been successful in gradients as low as 0.1%. The riffles are usually built with a 4:1 (25%) upstream and 20:1 (5%) downstream slope, but this can vary depending on the location, with steeper faces in higher gradient reaches (Figure 5.5). The crest elevation of the riffle is set to allow a shallow depth of water to be impounded upstream to create a glide. Gravel favourable for macro-invertebrate production and spawning purposes may be collected upstream of the riffle in the glide, which is a good location for egg incubation due to the throughflow of water. Also as the water falls over the boulders in the riffle crest and down the face of the riffle, it will maintain or even create pools. This allows the natural riffle/pool/glide sequence to be constructed.

Large boulders are used as the key stones on the bed where the crest of the riffle is to be located and also on the downstream face. Once they have been placed, the spaces between can be filled with slightly smaller boulders and cobbles, to create the same dimensions that are observed in natural riffles. The centre of the riffle is set lower than the edges so that water is concentrated into the centre of the channel, which is particularly beneficial during low flow periods (Plate 5.14). Boulder size is dependent on local site conditions, but it usually ranges between 0.4-1m diameter for the key stones. Materials can be local bed material, collected fieldstone or suitable quarried rock.

Newbury riffles have also been successfully used to prevent erosion on the outside bends in the Salmon River in BC. Bank erosion on the outside of meander bends is aided by gradient around the bend. Erosion can be reduced by decreasing the channel gradient around the bend, which is done by backwatering around the bend using a Newbury or artificial riffle at the downstream end of the bend (Plate 5.15). The riffle is located so that it causes a degree of ponding in the pool around the bend upstream. This ponding increases the cross-section of local flow in the bend, therefore leading to decreased eroding velocities and less pressure on the outer bank. As with Newbury riffles in straight reaches, a pool will be maintained or created downstream from the riffle when placed at the downstream end of a bend. But, if the design of the riffle and also its location are not carefully thought out, the artificial riffle placed at the downstream end of a bend to back water around the bend to reduce erosion, may form a pool in a location where, in the natural situation, a riffle would be, as shown in Figure 5.6.

When considering re-instating riffles using assemblages of rock, Newbury stresses that it is vital to collect data from natural sections of stream upstream or downstream from the reach in question. This will determine what is the natural pool-riffle-glide sequence, and also what widths, depths and bed slope should be created. The location of new pools and riffles must correspond with the natural meander geometry of the river to ensure that they function correctly. Newbury & Gaboury (1994) outline the correct procedure for surveying natural reaches of river, designing artificial rock riffles and installing them in the correct formation and location.

Bob Newbury undertook a development programme using artificial riffles on Oulette Creek BC. In 1978 the lower 0.5km of this river was relocated into a straight channel to the edge of its alluvial fan to allow the construction of a log sorting yard on the deposited material. Alternating single log drop structures or weirs were constructed in the channel to provide a pool-riffle sequence in this new channel. These were soon undercut as the channel degraded. In 1994, 12 boulder riffles and pools were built to restore these pool-riffle habitats at the same site as the 1978 work. By surveying an untouched reach of the river, the natural geometry was established and included in the development design. The gradient in the developed reach was 3%, the natural bankfull width was 7m and the diverted reach had a bankfull width of 9m, the natural depth averaged 0.7m but the diverted reach averaged 1.8m deep.

Boulders between 0.5 and 1.5m in diameter were used to construct riffles/rapids at intervals of 3 to 6 times the channel width of this steep gradient salmonid stream. They were built with a 1:1 upstream face and a 10.1 downstream face with a central notch depth of 0.3m below the height at the banks. This rehabilitated reach was visited with Bob Newbury in October 1996 (Plate 5.16). All riffles were stable and functioning well, with significant pools formed downstream and spawning gravel collected on the upstream face. Observations have been made of adult Pacific salmon holding in the pools and spawning in the gravel upstream. No data on fish numbers were available at the time of the visit. Previously, due to the high gradient in this reach spawning gravel was unstable and pool formation and holding water for adults was poor.

5.8.2 Rubble Mats or Rock Chutes

Similar structures to Newbury Riffles have been constructed in other development programmes to try and re-instate riffle-pool-glide sequences. In Australia they are called rock chutes and in Ireland they are referred to as rubble mats. They consist of sized and graded rock (large gravel, cobble or rubble) placed on a prepared section of the stream bed to mimic a natural riffle i.e., at gradient breaks usually at the riffle-pool join (Figure 5.7). They are effectively used to reduce the overall gradient in a reach by providing a step in the channel, but without creating the deep plunge pool that a weir or digger log would create. This is due to its gentle

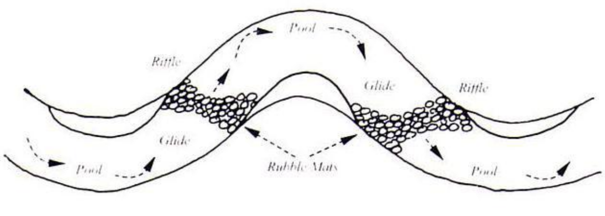


Figure 5.7 – Rubble Mat or Rock Chute

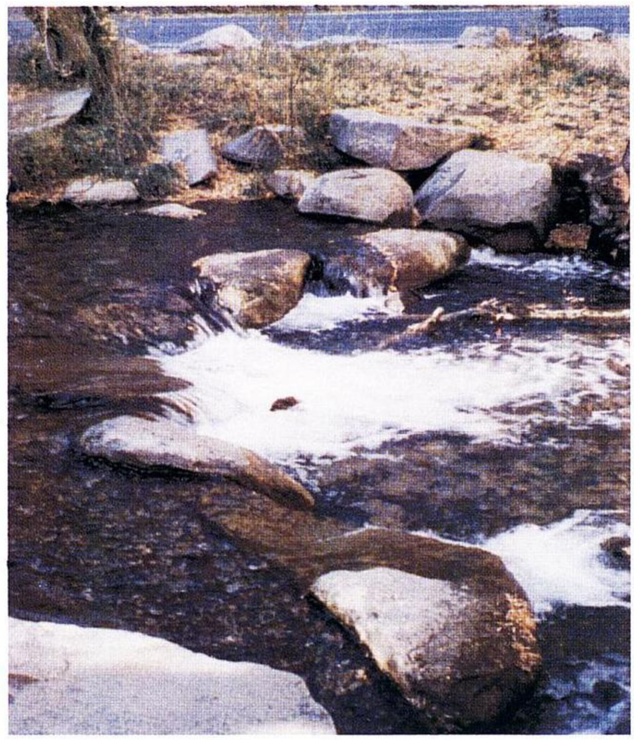


Plate 5.17 - Rock Horseshoe Weir

sloping nature unlike the drop of a weir. By breaking the gradient, they should create a limited amount of backwatering upstream which dissipates energy and can be effectively used to reduce bend erosion and improve the glide habitat. It is for this reason that they have also been successfully used in Ireland in series around long shallow bends in low 'B' and 'C' type channels to reduce bank erosion.

Rubble mats are fundamentally the same as Newbury riffles in that they are located at the inflexion or cross-over point between alternate pools. The difference is that rubble mats are constructed at a slight angle (usually 30°) across the river to ensure that the flow is directed to the outer bank of the bend downstream, similar to that of the digger log. It is rare to find natural riffles aligned perpendicular to the banks, they are normally slightly skewed. This skewing of the flow helps to generate secondary flow currents in the bend which in turn encourage further scouring of the pools and it allows a greater width for flow and energy dispersal.

As with the Newbury riffle, the upstream face of the rubble mat should be steeper than the downstream face to create a hydraulic head and the profile should dip in the centre to concentrate low flows. Similarly, the riffle material should be coarse enough to maintain its stability as the material locks together. Larger boulders and cobbles should be used as the core material, and covering this with appropriately sized gravel, slightly coarser than the local bed material size. In

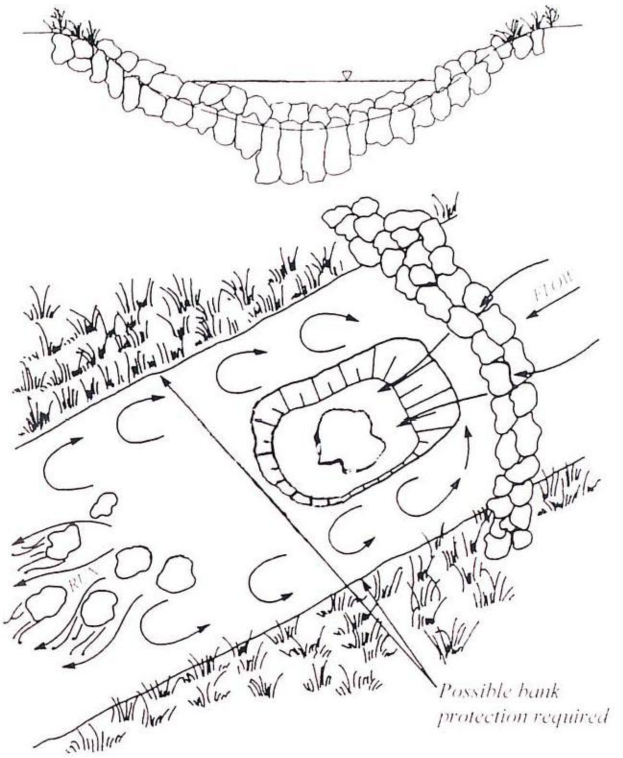


Figure 5.8 - Rock Horseshoe weir

Ireland they are typically built one channel width in length, but it is somewhat dependent on local channel conditions (O'Grady pers.com. 1997). Individual riffles and the pools that they create or maintain should be between one and three channel widths long and spaced at about six channel widths apart.

O'Grady et al. 1990 found very substantial increases in salmonid numbers (juvenile Atlantic salmon and both brown trout juveniles and adults) in reaches following rubble mat construction. The pools between each rubble mat are also functional as resting places for adult salmon (O'Grady pers. com. 1997). They also provide substrate for aquatic invertebrates due to their shallow water depth and turbulent flow similar to natural riffles. Rubble mats have been successfully used in Ireland in channels from 1m to 30m in width.

5.8.3 Rock Vortex or Horseshoe Weirs

The construction of Rock Vortex or Horseshoe weirs is another method of trying to enhance habitat in degraded high gradient channels by recreating the riffle-pool-glide sequence. They are both modifications of the more traditional drop weirs that have been developed by fisheries interests in America. Several good examples of these were seen in Ashley Creek, Utah implemented by the US Forest Service Fisheries Development Programme. They are also being installed in channels in Ireland by the Central and Regional Fisheries Board under the EU Funded Fisheries Development Programme.

They are low level rock structures, spanning the width of the channel at the riffle-pool join or break of gradient. They stabilise the channel by acting as the tail of a riffle similar to the digger log. This type of structure is used to create or enhance habitat in shallow high gradient channels by creating a step in the channel that slows the flow, and creates a pool downstream.

Rock Vortex and Horseshoe weirs are fundamentally the same type of structure, both consisting of a low-lying series of large rock or boulders aligned in an upstream pointing arc or semi-circle (Figure 5.8 and 5.9).

The Rock Horseshoe weir is constructed in a horseshoe shape with the boulders sloping down from the bank to the middle of the channel. The highest rocks at the channel margins should be keyed well into the bank to prevent outflanking. The rocks spanning the channel are wedged together in this upstream 'horseshoe' formation similar to that of a bridge arch, to give the best stability. Each rock should be dug into a trench in the bed, overlapping with the next one in the structure. The central rocks should be the lowest point in the structure creating a notch to concentrate the main flow in the middle one third of the channel. The notch and horseshoe shape forces low flow into the centre of the channel downstream where a deep pool is created by a plunging scour at high flows. The largest rocks should be in the

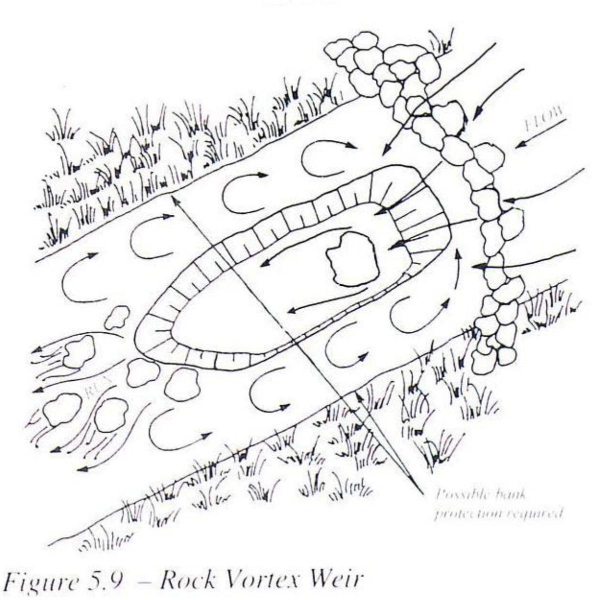


Figure 5.9 – Rock Vortex Weir

notch in the middle of the channel jammed together tightly in a trench and bedded deep into the substrate. A layer of footer rocks should be laid underneath and slightly downstream to act as a stable platform for the crest rocks. The upper rocks in the notch should not be more than 0.6m above the stream bed. In high flood discharges, the flow should pass over the top of the structure with little effect on the water profile. Constructing the weir at low level ensures that it is flooded out during high discharges.

The Vortex weir is also built in an upstream horseshoe formation with the rocks sloped down to the centre of the channel. There is no notch created in the centre of the vortex weir. Instead, the crest rocks or upper layer of rocks above the footer/base layer are set in an alternating sequence across the channel with gaps between each rock. They are laid in an interlocking arrangement, which some refer to as an array of 'dragon's teeth'. In low flow, the water flows through the gaps between the rock in the upper layer, and the horseshoe shape pushes the water into the pool in the centre of the channel downstream. But during higher flows the water is forced through the gaps between the rock and creates 'jets' of water that scour a pool in the centre of the channel downstream. These jets dig a longer pool than the plunging effect of the horseshoe weir. Similar to the horseshoe weir, the vortex weir should be built to a level that ensures that it is flooded out or passed over in flood conditions.

Both the Horseshoe and Vortex Rock weirs are particularly sensitive to a carefully selected location, proper alignment and construction procedures. They are most commonly installed on small, steep-gradient high energy headwater streams (<9m wide) with a slope of 0.1 to 10% (preferably 0.5-3%), but they have also been successfully constructed on larger rivers (up to 20m wide), to dissipate energy and create adult holding pools. They are best placed in straight reaches at the lower end of a steep break in gradient at the riffle-pool join, but they can also be used at the downstream end of bends to dissipate energy around the bend, similar to Newbury Riffles.

They must be constructed only in high gradient zones to avoid excessive backwatering/ponding and subsequent flooding problems upstream. Weirs are not designed for pool formation above the structure, but rather to form a plunge pool downstream in reaches devoid of pools.

The concern about weirs causing flooding by

Figure 5.10 - The incorrect and correct shape for an excavated pool

ponding upstream can be addressed by constructing them at a low-lying level. Both types of weir should be constructed in low flow to ensure not only that they do not cause backwatering, but also so that they are flooded out in high discharges. If they are not flooded out, they may create a hydraulic jump, such as a standing wave. The presence of a standing wave during high flows indicates that the structure is too high and it can create instability to the structure itself and also to the banks, both upstream and downstream. They should be placed low in the channel profile, with the highest point being no higher than 30cm above the water surface at low flows (or <¼ of the bankfull stage). They should be built to function in low flow by concentrating the flow into the centre of the channel. As the water level rises the effect of the structure on the water profile should reduce. In half bankfull channel discharge, the scouring action of the flow should still be centred in the middle of the channel due to the semi-circular shape. At bankfull discharge, the structure should be totally flooded out, with it having no effect on the water profile. The structure should not be visible during high flows as the flow passes over the top of it.

When placed in series at intervals of between 3 and 6 channel widths apart depending on the gradient, they reduce flow velocity and dissipate much of the erosive force of water as it plunges over the sequence of structures. In continuous steep gradients, a major benefit of the structures is that they break up the gradient, which provides resting areas for fish. The structure causes the water to slow and deepen upstream, creating a glide in which adult salmon have been seen to hold, as well as in the pool downstream. The slacker water upstream of the structure and at the edges of the plunge pool downstream act as a trap for organic material which is used as a food source by invertebrates which the fish then feed on. The scouring of the plunge pool downstream of the weir can provide a constant supply of loose gravel at the tail of the weir pool, but also they can hold gravel upstream, which are both locations that are suitable for spawning.

The construction of weirs is important, as any misalignment or loose rocks may either result in partial failure or complete failure of the weir to perform to expectations. The rocks in the weirs should be keyed tightly together and wedged into each bank, forming a support structure. The most common cause of ineffectiveness is when the central rocks in horseshoe weirs or the alternating upper layer of the vortex weirs roll out of position and into the pool downstream. There is a very strong need for exactness and precision in forming the slope to the centre of the channel. The rocks must slope from the mid-stream point of the weir gradually upward towards the bank where there should be a line of rock embedded along the face of the bank to protect it form erosion during high overtopping flows. The rocks must be placed starting at the centre of the channel and working out towards each bank in an arc downstream. Each rock in the base of the weirs should be placed in an excavated trench and then firmly jammed into the previous rock to ensure a tight fit and to prevent water flowing between or under the large rocks and to prevent movement during high flow conditions.

Once the rock weir has been constructed the pool may need to be excavated downstream (as with any weir construction). If the streambed is hard and will not scour easily, it may be necessary to consider excavating the pool to speed the process along. The weirs force the flow into the centre of the channel, which should maintain the excavated pool. Each pool excavation should be about three channel widths long with similar lengths of unexcavated bed in between before the next weir and pool. It is important to imitate the natural pool depth that would be scoured over time, which is usually 1.25 times the height of the waterfall at the weir. This is the depth to which free-falling water will eventually erode and is the depth which provides the quiet water at the bottom of the pool that is most beneficial to fish. There is a tendency to excavate the pool in a 'bath' shape, but it is preferable that it is a 'saucer' shape so that it is self-maintaining (Figure 5.10).

Upon completion of the pool large random boulders or even an anchored tree can be placed in the pool to provide shelter. When functioning correctly they can extend pool length by circa 25% and help to gather spawning gravels (O'Grady pers.com. 1997). No armour rock should be needed on the upstream side of the weir in most cases, but a modest length of protection is advisable on both banks downstream. A major advantage with Vortex weirs and to a lesser extent with Horseshoe weirs is that they create far less back eddies than straight timber weirs, therefore less bank protection is required. Trees can also be planted at intervals to provide dappled shade, both upstream and downstream of the weir.

Timber weirs have traditionally been a favoured technique to produce pools in reaches previously devoid of them, but they are less effective and more unstable than rock weirs in particularly high gradient streams. They are prone to failure in upland rivers due to end cutting, undercutting and wash out of the logs, although in some upland situations they can be used effectively. The deep back cutting plunge pools and undercutting/ destabilising of the timber structures, particularly with V-notch weirs, are not so evident with rock weirs. Another advantage of rock weirs are their roughness, which seems to aid in the accumulation of more gravels than timber weirs (Duff 1997 pers. comm).

The objective of these rock structures, as with other weirs, is to create instream cover or holding water, take excess shear stress away from the banks and direct it to the centre of the stream to maintain lateral stability but increase vertical erosion/scour and provide a natural sorting of gravel for spawning purposes upstream and downstream. They function extremely well in flood flows by providing scouring flows to maintain the pool downstream, whilst creating no risk of overbank flooding due to its low elevation.

Cooper & Knight (1987) compared electrofishing results from pools below weirs and natural scour hole pools in unstable streams in Mississippi. The results favoured weir pools rather than natural scour pools. They speculated that habitat created by structures was more stable than natural scour holes which undergo frequent cycles of filling and scouring. This stability resulted in more consistent successful spawning and recruitment and ultimately higher yields. But there are examples of failures of these types of structures. They may fail in high energy rivers at high flows, and can be unsuccessful where there is an excessively high sediment load, and where they are improperly located. As an example, on the River Neath in South Wales, a number of blockstone weirs were installed to compensate for the loss of habitat diversity when the river was heavily dredged. Many of the new weirs were constructed between bends where riffles would naturally be located and, not surprisingly, they have since become submerged by gravel deposits.

5.8.4 Random Boulder Placement

The placing of random boulders in weir pools helps to maintain scour, provide cover and a resting location for fish and therefore improves the reaches fishability. Placing large boulders, individually or in clusters in streams is a simple, unobtrusive, cheap and one of the most successful techniques used to create salmonid rearing habitat as well as to improve the fishability of angling water. They have been used since the 1930's and are popular due to them maintaining the natural appearance of the river, are a low intervention technique forcing natural channel alterations and they require little maintenance. In Irish rivers O'Grady has found random boulders to be successful in maintaining stable pools in channels with gradients of 0.1% to 1.5% and over a range of basewidths from 1m to 10m. They have functioned well in individual circumstances to provide 1+ salmon and trout habitat and also in enhancing angling for adult salmon and trout.

Boulders can be used in series around bends to guide the flow away from the outer bank. They act as roughness elements, which change the distribution of hydraulic forces over a stream bed as the water flows around the obstacle. This causes scour, which aids in expending energy from the flow and if positioned correctly should reduce erosive pressure on the outer bank. In high gradient streams there is an area of deposition downstream of the boulder, where fine particles are suspended by the upwelling current whilst larger particles fall out. This sorting may produce relatively clean gravel suitable for spawning, but the slower flow in the lee of the stone is also a refuge for fish, and therefore boulders are a key resource to fish habitat.

In fast flowing high gradient streams, boulders can provide mid-channel "pocket water" or microhabitat for juvenile fish to utilise when actively feeding. The size of feeding territories depends to a great extent on the amount of visual contact which the fish have with one another and the amount of food. In wide shallow upland rivers with little water depth and cover, the boulders create scour pools with deeper water, they create cover for visual isolation and they provide more substrate for invertebrates. The provision of a diverse microhabitat with scattered boulders restricts visibility and allows a greater number of territories to become established, so increasing fish numbers. A study done on the Tracadie River in New Brunswick, Canada found that randomly placed large angular rock placed in-channel in a wide, shallow stream increased the number of juvenile Atlantic salmon dramatically, from no fish present to 25-50 fish /100m^2.

The minimum size of rock to use depends on maximum velocities at the site and the type of reach in question, but generally 0.5-1m diameter boulders or larger are utilised. A good guide to the size requirement of rock is to look for any large

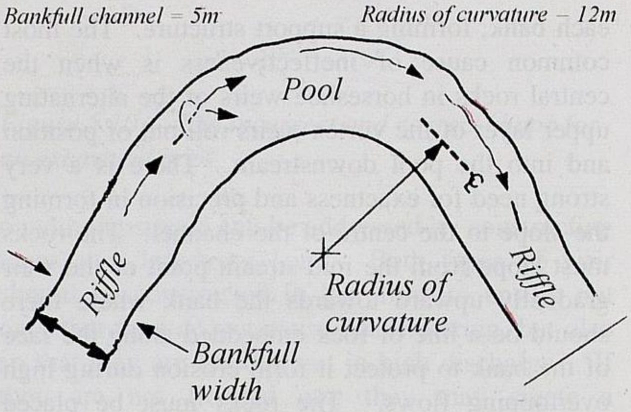


Figure 5.11 - Radius of curvature

moss-covered boulders that occur naturally in the channel. The old saying "a rolling stone gathers no moss", tells you that the moss-covered stones are not mobile in the discharges experienced in the river. Therefore these stones indicate the size of rock that should be used.

5.9 Bank Protection

In North America, much emphasis is now put on the fact that the universal application of heavy engineering methods is no longer acceptable. This is especially so, when undertaking bank protection as dynamic channels continually erode and migrate at a natural rate. When designing bank protection, not many projects consider these basic erosional processes and conditions as well as the needs of the fish, which can be their downfall. It is necessary to establish which bank protection techniques are appropriate in different circumstances, remembering that re-vegetation should be undertaken if possible. In some circumstances where the erosion has progressed too far or the bank is retreating at a rapid rate, some form of tree revetment (discussed earlier) or hard engineering may be necessary to recreate a non-existent bank and prevent further erosion.

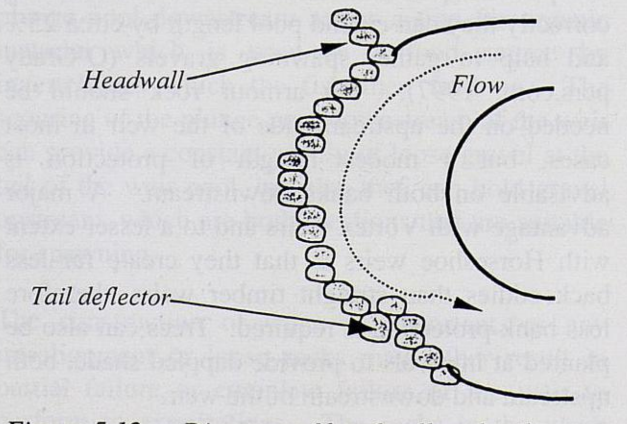


Figure 5.12 - Diagram of headwall and tail deflector

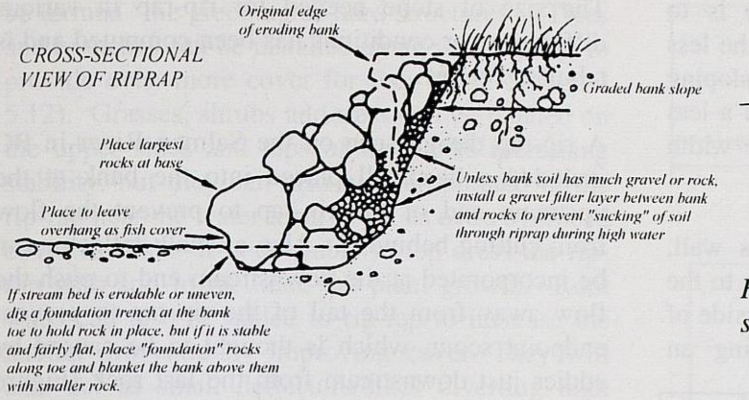


Figure 5.13 - Rip-rap Design

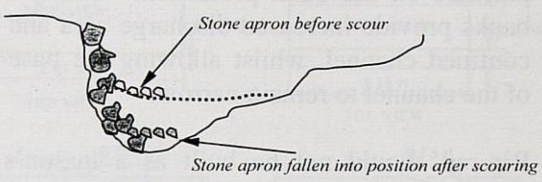


Figure 5.14 - Construction of rip-rap with stone apron

5.9.1 Stone Protection (Rip-rap)

The use of bulldozers and other machinery to armour the outside of river bends with cobbles and gravels pushed from the stream bed is a favourite technique for those unfamiliar with river mechanics. This practice is inappropriate as it will seldom last, it is usually needed to be repeated annually and it disrupts the sediment transport regime or the river leading to further damage occurring as the river tries to heal itself. Another popular technique is the use of large rock or boulders to protect the bank, which is called rip-rap. This technique has been successfully used for many years in many countries to prevent any type of bank erosion. Rip-rap can have a direct bearing on the amount of fish habitat available in that it prevents lateral erosion, whilst promoting vertical scour, which causes deepening of the channel around a bend forming a pool, and it also provides hiding places within the crevices between rocks. Although successful, it is now realised that it should only be used in the worst cases,due to the rigidity of the stone protection and the dynamism of the channel being in conflict with each other. There are many cases where rip-rap has been unsuccessful in protecting the eroding bank and has fallen into the channel or destabilised. There can be many reasons why rip-rap may fail, but some useful guidelines to constructing rip-rap were provided by visits to various successful rip-rap installations in BC, Canada.

It is understood that the radius of curvature of most natural meander bends is approximately 2.5 times the channel width. When visiting Bob Newbury in British Columbia, he stressed the importance of this in reducing bank erosion when constructing rip-rap on the outside of bends in meandering channels. Investigations of the kinetic energy of flow cells in meander bends suggest that the minimum energy expended by the spiralling flows occurs when the radius of curvature of the bend is between two and three times the bankfull width of the stream, with a median value of 2.4 (Chang, 1988). Therefore to minimise outer bank erosion on a bend, the rip-rap should be constructed so that the bend has a radius of curvature of 2.5 the channel width. Bob Newbury asked trout anglers to record where they caught fish, by both description and diagrammatic format. By subsequent surveying of the sites that fish were caught, Newbury discovered that the most successful and productive sites for angling were at bends that had a radius of curvature that was 2.5 times the channel width. This relates to the flow around these bends having less power, therefore the fish expend less energy. This is important to note if a bend has to be re-instated as part of the rehabilitation of a degraded river. By constructing the bend with a radius of curvature of 2.5, erosion on the outer bank should be minimised and the chances of success for anglers ought to improve.

There are no universally applicable rules to determine the length of rip-rap, or any other type of bank revetment, appropriate to a particular site. Erosion on the outside of bends tends to move downstream with time. Therefore, it is desirable to continue protection downstream beyond the limit of the present erosion. An extension of at least two channel widths is suggested as an appropriate guide to allow successful erosion protection. Any bank protection project should account for the fact that inmost situations, the point of maximum attack on an eroding bend is two-thirds (66%) around the bend. The upstream limit of erosion protection is generally easier to locate. As a guide, erosion protection should extend at least one channel width upstream of any existing instability.

It is important to observe the material composition of both the bed and the banks before undertaking bank rip-rap, and assess whether the rock will remain in location. Alterations to the bank slope are generally required with any stabilising technique. Rip-rap is usually not effective on banks steeper than a 2:1 slope, but if appropriate, steep banks can be graded to a more suitable angle such as 1.5:1(35°). A good rule of thumb is to remember that the more gradual the slope the less pressure on the bank protection. Gently sloping banks provide increased discharge area and a less confined channel, whilst allowing the base width of the channel to remain narrow.

Rip-rap should not be built as a mason's wall, neither should the rock be tipped directly on to the bank. Rock should be placed from the riverside of the bank in an interlocking fashion using an

Stone size (m)	*0.15*	*0.30*	*0.45*	*0.60*	*0.90*	*1.20*
Velocity (m/sec)	*2.16*	*2.53*	*2.89*	*3.66*	*4.39*	*5.49*

Table 5.1 - Velocities needed to move different sizes of rip-rap stone

excavator. The rocks at the base should be dug into a small trench in the bed to prevent undercutting and ensure stability. The remaining rocks should be placed on top of the foundation rocks as jumbled pieces or 'organised chaos' (Figure 5.13). This will allow numerous angles and openings between each piece. These 'nooks and crannies' on and between the stones and the quiet back eddies formed by protruding rock faces are available for colonisation by aquatic insects and vegetation and also as shelter for juvenile fish. The larger and more irregular the rock the better, both for building and creating habitat. Quarried rock has therefore usually got an advantage over gathered field stone, as the angular material interlocks better creating more stable rip-rap. Similarly, the rock should not be single sized, but should be a graded mixture if possible.

For rivers in Victoria, Australia where rip-rap is required to protect an eroding bank, a series of equations have been incorporated into a computer software package called "RIPRAP". This generates a table of median rip-rap diameters (in mm) for a range of bank angles and flow depths around those that you specify. For most design conditions the angle of repose or slope for the bank is given at 41-42° for angular rock >0.1m in diameter.

Commonly specified bank angles for re-grading and rip-rapping are :

1.5 horizontal : 1 vertical = 34°
2 horizontal : 1 vertical = 27°
2.5 horizontal : 1 vertical = 22°
3 horizontal : 1 vertical = 18.5°

The size of stone needed for rip-rap in various different river conditions has been computed and is tabulated below.

A rip-rap design seen on the Salmon River in BC included a headwall placed into the bank at the upstream end of the rip-rap to prevent the flow from cutting behind it. Also a small deflector can be incorporated at the downstream end to push the flow away from the tail of the rip-rap to prevent endpoint scour, which is thought to be caused by eddies just downstream from the last rock (Figure 5.12). When installing rip-rap around an eroding bend, some say it is advisable to remove the opposing point bar or crown of gravel on the inside of the bend. This will take the pressure off the new protection to allow it to settle. Eventually, new deposits usually form on the inside of the bend to take the place of the removed gravel, which may happen very quickly if a long series of eroding bends are rip-rapped.

Where possible, attempts should be made to soften the aesthetics of rip-rap or any other hard engineering through selective planting or what can

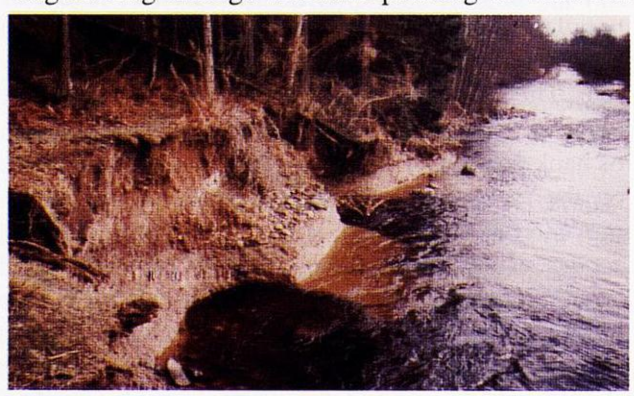


Plate 5.18 - Eroding bank before Rip-rap protection

Plates 5.19 - Eroding bank after Rip-rap protection

be termed "the greening of hard structures". Trees and branches can be installed along with rip-rap, to provide even more cover for fish (Plate 5.11 and 5.12). Grasses, shrubs and trees can be planted on the upper sides and tops of the banks increasing stability, but they can also be incorporated in the rip-rap near the water level to act as extra overhead cover for fish. It is desirable to top dress the rip-rap with soil to facilitate the plant growth. Root wads can also be added to rip-rap to increase the habitat provision by improving cover. They will also act as small deflectors/dikes diverting high flows away from the banks and creating small pockets of backwater that provide fish resting areas. These additions will also break up the secondary flow cell around a bend which add to stress on the outer banks.

Many rip-rap failures are caused by undermining of the toe of the rip-rap by scour during high discharges. Alberta Environmental Protection, in collaboration with the DFO in Canada, accounted for bed scour at the design stage by extending rip-rap protection below the bed level by placing rip-rap in an excavated trench or by providing extra rip-rap (rock apron) at the toe of the bank (Figure 5.14). This apron should drop down and provide protection as toe scour proceeds. But its success is unpredictable, as the settling pattern of rip-rap is unpredictable, although the DFO in Canada suggest that an armour rock apron must be provided in all rip-raps.

Rip-rap failure can also be due to loss of bank material from behind the rocks, causing slumping. A filter layer may be required beneath the rip-rap, to prevent bank material washing out through the protective stone layer, particularly when rip-rap is constructed over fine bank material. A granular stone filter layer can be used or an appropriate geotextile (such as Terram) can be an alternative to prevent material wash out. Traditional revetments have used filters consisting of several layers of stone aggregate, which may be graded or single-sized. Their installation is expensive and time consuming and can be difficult to place on the steeper banks. The Terram filter cloth allows

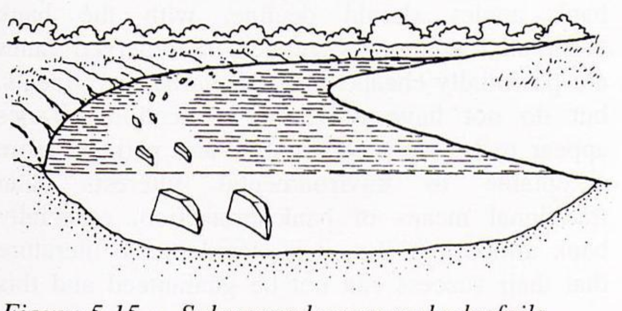


Figure 5.15 - Submerged vanes or hydrofoils

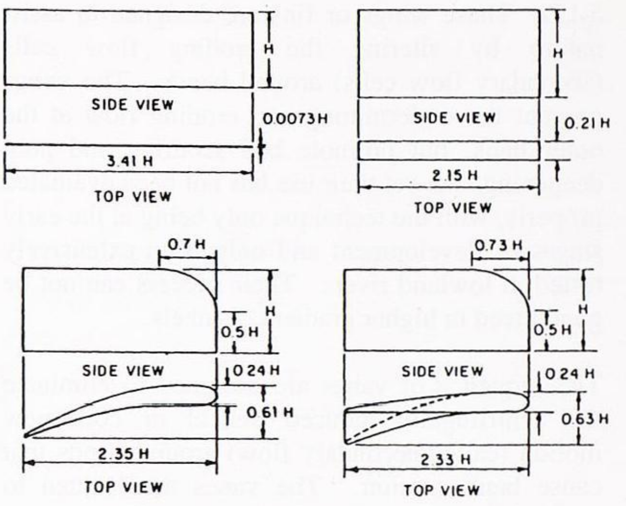


Figure 5.16 - Plan and side view of submerged vanes/hydrofoils

better construction on steep banks and is cheaper than the gravel filter layer. Also it being permeable, allows easy dissipation of water pressure from within the bank, but prevents bank erosion and the loss of the finer bank material behind the rip-rap. But after time, the material may become less porous as fine material can block the pores.

Caution is recommended with geotextiles. Several rip-rap failures and partial failures have been observed where rock has slid on the filter material. Therefore it is essential to ensure that the maximum resistance is developed between the rip-rap and the cloth which can be done by avoiding preparation of the bank to a smooth and even surface before placing the cloth and not stretching cloth tightly over the underlying bank. Also geotextiles prevent the deep rooting of surface vegetation and any rooting between the rocks.

5.9.2 Submerged Vanes

Stone rip-rap and other types of traditional bank revetment provide direct protection to the bank, by physically isolating the bank from eroding currents. This provides stability by increasing the erosional resistance of the bank. In contrast, an alternative is to provide indirect protection by modifying the flow adjacent to the bank. Potentially eroding currents adjacent to the bank can be deflected away, reducing the velocity and energy of the flow such that the erosional forces acting upon the bank are reduced and bank failure prevented.

A technique using what are called submerged vanes or hydrofoils is being developed in the US. It is a technique patented in the US involving a series of short submerged wing-type structures placed in the outer half of the channel around a bend (Figure

5.15). These wings or fins are designed to assist nature by altering the eroding flow cells (secondary flow cells) around bends. The wings prevent the undermining and eroding flow at the outer bank, but promote bed scouring and pool deepening. As yet their use has not been evaluated properly, with the technique only being at the early stages of development and only been extensively tested in lowland rivers. Their success can not be guaranteed in higher gradient channels.

The sequence of vanes are designed to eliminate the centrifugally induced helical or corkscrew motion (called secondary flow) around bends that cause bank erosion. The vanes are located to generate convergence of surface water in the centre of the channel inside the line of the vanes, which should cause bed scouring. Material eroded from this zone should then be deposited in the original scour hole adjacent to the outer bank. As shear stresses against the outer bank and toe region and the bank height are reduced due to the vanes distorting the secondary flow cells, bank retreat can be prevented and the natural bank preserved. Large boulders can be placed in series around bends to simulate the submerged vanes, as they can also reduce bank erosion by deflecting the flow away from the bank.

The simplest construction is to install a series of submerged vanes or small foils, (a large board or fin constructed from wood or other material such as flat faced stone) at an angle of between 10 and 17° to the flow. At angles greater than 20°, the vanes affect the overall roughness characteristics of the stream flow and flow separation occurs, producing large scour holes near the upstream ends of the vanes, which decreases stability. The optimum angle is about 15°, which can produce a change in pool depth of the order of 10%. The height of the fin should be 0.2-0.5 times the water depth at the design flow or 20-30% of high water flow depth. Eroding flows near the bed are directed away from the bank towards centre channel, whilst faster surface flows overspill the vane towards the bank. It is for this reason that they must be implemented in deep water as the vanes should remain submerged even at low flow.

Vanes were tested in the US (East Nishnabotna River, Iowa) as a prototype system. Each vane consisted of three wooden planks, 7.6cm x 30.5cm x 366cm, held together in a vertical position by two 20cm x 90cm steel H-piles driven into the streambed. The planks were fastened to the piles by straps and were prevented from floating by anchor plates (Odgaard & Spoljarec 1988). Three different shapes of vane were tested: a vertical flat plate, a cambered foil with flat surface and a cambered foil with twisted surface (Figure 5.16). The vanes tested in Iowa caused a reduction in velocity near the bank of generally 10-20%, by nullifying the erosive secondary currents. They also moved the maximum velocity line nearer the centre of the channel, promoting vertical scour in the pool and reducing lateral erosion at the bank. A relatively small number of vanes can produce bend flows that are practically uniform flow across the channel. The alteration of secondary currents was dramatically demonstrated in experiments in which surface floats were placed on the flow near the upstream end of bends. For the flow without vanes, the floats were soon transported near to the outer bank, while in the bends that had vanes they retained their initial distribution. The most important finding was that a vane system designed according to the guidelines produces changes in flow depth by transporting sediment sideways rather than downstream. Thus it redistributes the bed sediment in the transverse direction, without changing the overall channel characteristics; and the vanes do not change the channel's cross-sectional area. Sediment from erosion is under normal conditions transported downstream and deposited in areas where it diminishes channel capacity.

Submerged vanes have been successfully used to reduce bank erosion on sand and gravel bed rivers with widths ranging from 20 to 55m. To date they have been used on rivers that are ostensibly in regime, i.e. where the river migrates across its floodplain whilst maintaining a relatively stable meander pattern. But they are unlikely to be successful where the river is in major disequilibrium. In upland rivers hard structures are required to withstand the likely discharges and associated sediment transport, which may increase the construction costs. More research is required to assess the potential for submerged vanes to reduce bank erosion in upland high gradient gravel bed channels.

By changing the flow pattern adjacent to the bank reducing erosive forces they should obviate the need to protect the bank, therefore the natural channel character is maintained. Over time the bank angles should decline, with the bank eventually becoming vegetated. Submerged vanes are potentially cheaper than all harder revetments, but do not have universal applications. Vanes appear to be more economical and perhaps more acceptable to environmental interests than traditional means of bank protection, especially bank armouring. But, it is stated in the literature that their success can not be guaranteed and this procedure may need to be used in tandem with other bank protection remedies. The vanes being submerged are not visually obtrusive and are also effective in improving instream habitat. But, there is little practical experience of vanes and only limited amounts of research has been done, therefore detailed consideration is needed and technical advice should be sought before considering the use of these structures. They are an innovative technique and seem to have potential to be effective and should therefore be investigated further.

Environmentally, submerged vanes or other indirect techniques that alter the eroding flow are preferable to revetment methods such as rock rip-rap, as the banks of the river are left undisturbed and natural re-colonisation is allowed to occur. But even better still is to determine whether the erosion is due more to a catchment scale phenomena rather than a localised erosion problem, and by treating the cause it should lead to a more long term solution than treating the local symptom.

Chapter 6 - Structure Design, Siting and Construction

6.1 General

This report does not cover the more traditional structural techniques that have been used to restore degraded habitat in upland high gradient channels. It was felt that many other guidebooks have illustrated the pros and cons of structures such as deflectors, weirs, cover shelves, and channel constrictors etc. The report has highlighted that although they are still useful and effective in providing diverse hydrological and biological conditions for the benefit of fish, they and other structures should only be used where deemed absolutely necessary.

The most important point to note out of the whole report is that, structures should be viewed as a 'splint' or temporary aid to a stream in repairing itself to its former pre-degradation state, whereby it can then function as a natural stream without the aid of structures. They are best used when it is felt that a degraded channel would take too long to restore itself naturally, once the cause of the degradation has been ameliorated. They can been seen as bridging the gap by repairing the wound until it is healthy, or can be seen as just speeding up the recovery process that may take decades to do naturally, or they can restore braided channels that are in a non-recoverable state. It is also essential that if structures are needed, placement should be considered fully in geomorphological terms, as to where they should be located and what each structure is trying to create. Scientists in the US are now beginning to accept this view and it is time that more proponents of structural rehabilitation in the UK took the same view.

However, investigations have shown in many different countries that structures can improve salmonid populations significantly. In America, monitoring has shown over seven years in three South Dakota streams, that traditional structures have increased populations of salmonids by 94%, 214% and 404% following the installation of wing deflectors, random boulders and bank rip-rap (Kazyncski 1996 pers.comm.). Work currently being carried out by the Central Fisheries Board (CFB) in Ireland has also shown that proper use of various structures in shallow channels with no depth and no cover, can increase salmonid populations due to the structures increasing the carrying capacity. Assessment of the effects of various structures on mixed stocks of Brown trout and Atlantic salmon is also ongoing by the CFB, in an attempt to establish if they favour one particular species. Initial observations seem to indicate that they do not (O'Grady pers.com 1997).

Experiences in Scotland, Ireland and North America have shown that, where structures are necessary, there is no need for a great variety of them for stream habitat enhancement. An experienced person, who recognises and acknowledges the natural characteristics of a river and has an understanding of fish habitat requirements, can accomplish a great deal with only a relatively few simple structures. History confirms this, as the literature shows that there are really only certain things that can be done to a stream or river to make it more accommodating for fish. This is borne out in the fact that one of the first stream enhancement guidebooks (White & Brynildson 1967), is still considered to be the most relevant by many fisheries experts. The traditional structures that they described are still the most frequently implemented 30 years later, although there are some additions such as rubble mats and log/tree revetment.

The problem is that not enough evaluation of the traditional structures is undertaken and documented. The efficacy, stability and side effects of these structures in high energy environments are somewhat unknown, i.e. what are the physical impacts of such structures. Many project managers have implemented structural rehabilitation in high gradient channels, but few have scientifically monitored the physical changes to channel morphology as well as the biological changes. This lack of documentation is being addressed by the Central Fisheries Board in Ireland, where a physical monitoring programme for instream structures is underway at present. This should aid in outlining how different structures can alter channel morphology and indicate which are feasible or unfeasible options to consider in high gradient channels, but more widespread monitoring needs to be initiated.

When considering a problem in a high energy gravel-bed river, it is important to note that the problem is probably not unique, similar rivers with similar problems usually exist in the same catchment or elsewhere. But, no two streams are exactly the same, each has its own distinct character and its own special problems. Although some basic similarities among streams exist, general enhancement recommendations should be coupled with individual judgements. Each stream should have its own tailored management plan. When planning a habitat project it is vital to use what has been termed "hydraulic intuition" (Klingeman

1996). This intuition should have been developed by careful review of past projects and thoughtful consideration of causes of project success or failure.

When installed, structures must work with the natural forces and dynamics of the stream, and not against them, by guiding the natural stream flow and energy to scour and deposit where required. They must utilise natural fluvial processes and should be aimed at simulating natural features of the channel form and flow. Structures change channel morphology but they can also alter substrate characteristics by turning over stones and releasing fine sediments that have become impacted in the stream bed. This creates interstitial spaces between stones which increases the porosity of the substrate. In nutrient poor rivers, primary production comes from leaves, needles, twigs and other debris that falls into the channel. This organic material becomes broken up and settles in these interstitial spaces in the substrate where it is decomposed by bacteria and eaten by aquatic insects. Also as structures flush sediments from the substrate the exposed surface area of substrate material, which is the habitat for many aquatic invertebrates, is greatly increased. So, not only do structures physically enlarge the amount of usable fish habitat, but they also indirectly increase the aquatic invertebrate habitat and populations, providing more food for fish, and food availability has been identified as a key limiting factor to fish production.

6.2 Structure siting and location

When designing a project that involves the placement of structures, attention should be focused on their location to ensure stability and longevity, the design and size of each structure in order to create the required habitat, how this may vary between different types of river, and the effect on the discharge capacity and morphological stability of the river.

The importance of having accurate design in a project cannot be overemphasised. If the basic design is completed incorrectly, structures start to work against the stream and its natural dynamics. If this has occurred the results are likely to be unpredictable and unpleasant. An incorrectly placed structure can cause many problems some of which are bank erosion, structure instability, redirection of the current to a new stream bed, or simply dead water pockets where they should not be or no pool formation. Structures placed too close together may cause the downstream structure to be washed out by the upper one or create pools in undesirable locations. Trying to get the water to do too many things in too short a distance, or too many unnatural things is a recipe for disaster. Also too few structures may not create any discernible difference to the stream in terms of habitat provision. It is vital to walk the stream and layout where the structures should be located prior to installation of any structures Information should be obtained along the length of a reach rather than at a single point where a structure is to be installed. Devices in streams must be located to avoid backflooding the section immediately upstream, as riffles can be flooded out and pools reduced to a velocity which is no longer conducive to rearing salmon. In general, stream devices should guide the current rather than dam the flow.

When siting structures, consideration must be given to the ability of the stream to accommodate such structures. There tends to be a desire to increase the number of pools beyond their natural spacing. Riffle-pool channels with a pool spacing of 5-7 bankfull widths apart are often converted to step-pool channel with the spacing based on 3-4 channel widths. This places demands on the stream that are beyond its potential and natural stability. The natural stream form must be maintained and the addition of any devices to improve rearing habitat must compliment this natural stream configuration. Therefore it is necessary to determine the average natural width of the channel in various locations, remembering to observe if the channel appears over-widened or narrowed. This average can then be used to determine how far apart pools should be located, using the basic formula of one pool approximately every 6 channel widths, regardless of whether the stream is straight or meandering.

It is also advisable to record the pool-riffle ratio for the reach. This is a comparison between the percentage of the stream that is pool habitat to the percentage that is riffle habitat. This gives a rough measurement of how well a stream provides a mixture of resting/security habitat in pools, along with food producing and spawning areas in riffles, helping to identify reaches that are deficient in pool or riffle habitat. A 1:1 ratio is sometimes given as the ideal, but healthy streams may have ratios that are much higher or lower, and good salmon producing streams tend to have a higher ratio of riffle habitat.

Next, natural pools must be observed to determine which side of the stream and distance downstream, you should be trying to create pools. If two consecutive pools are observed in a natural reach of the channel, measure the distance between them. They should be within 5-10% of the calculated distance (6 channel widths apart), if not there may have been a mistake in calculating average channel width. Structures should be spaced to avoid large areas of uniform conditions. It is therefore suggested that a minimum spacing of three pool lengths between structures that create pools. White & Brynildson suggest that a recommended maximum pool length is five channel widths.

If instream works are being considered, measurement of instream conditions are necessary. The most important of these is to calculate whether the stream has a high, moderate or low gradient before considering instream works. Gradient, being a measure of the slope of a stream, is measured as a percentage. If the stream drops 1m in elevation over a 100m stretch, it has a 1% gradient. Meandering streams on valley bottoms are generally low gradient (<1%); streams flowing through mountains as rapids and/or step-pools are generally high gradient (>4%). Moderate gradient streams cover the range in between. The gradient of the stream will influence the kind of restoration technique that can be implemented, with instream structures being most effective in moderate gradients.

The US Dept. of Information (Bureau of Land Management) in the Pacific Northwest of SW Oregon suggest that reaches with gradients of less than 2½% and preferably less than 1½% are suitable for the implementation of instream structures. Literature reviewed by Hamilton (1989) indicated that salmonid populations generally declined or showed no change after structural habitat work in streams having gradients of about 2% or more, whereas success was much surer in gradients of around 1% or less. Hunt (1988) suggested that structures have been particularly effective in small and medium sized streams with an average channel width of <50ft (15m) with gradients of 1% or less.

A general rule of thumb for site selection, given by the DFO in Canada, is that gradients less than 0.5% or greater than 2.5 - 3% provide poor structure location, although in Ireland gradients as low as 0.1% have been successful. High gradient stream reaches (2.5 - 3% or greater) are very difficult to control. Structures must be close together to control velocities that sweep through these reaches, or the flow can be widened by installing a diagonal structure where the flow spreads out (diverges). In a natural situation, these channels are usually composed of bedrock or large bedload material because of the erosive velocities. Much of the early work in these high gradient environments resulted in structural failure (washed out), or failure to produce the required habitat. But, in high gradient streams it is possible to make a step pool sequence that slows the flow and reduces the gradient creating habitat for fish. The pools that are formed as water plunges over large rocks or logs that create a step may look turbulent, but near the bottom they are quiet, protected resting places for juveniles.

When considering installing structures, reaches with low bank heights are preferred as this ensures an overflow plain during high discharges. The ability of flood waters to spread onto the floodplain often relieves pressure on structures. High banks constrict flood waters, which means velocities (energy) are not dissipated. This high energy and pressure can cause structural damage or failure. Therefore, the lower the flood banks in a reach the more suitable it is for structures. It can be frustrating to the designer where all of the other criteria such as stream width and gradient appear suitable but high steep sided banks would cause too much pressure on the structure. Also when considering installing structures in any stream, a channel that is considered "workable" should not have a water depth of more than one meter. Any water deeper than this poses great problems when installing structures.

The substrate size should not be too big if good results are to be expected. If the stream substrate is composed of boulders >30cm in diameter, structures may not have the desired effect. On the other hand if the substrate is too small, material of suitable size may need to be added to the stream to complete the structures and improve stability. It is important to note that the substrate in rivers is both vertically and horizontally structured. In terms of the vertical structure, the surface substrate is considerably coarser than the sub-surface sediments. This is called armouring. This should be acknowledged when considering implementing structures that induce the formation of pools, as the structures will tend to produce pools that are much larger than expected if they are designed with reference to the surface layer sediments alone. This is because the scour required to produce the pool exposes the sub-surface sediment which is more easily eroded causing the pools to enlarge. Structures are going to be most effective in streams that have a sediment impacted substrate.

If the stream bed looks to be mostly cobble, pull a stone from the bottom. Notice if a plume of sediment forms and then gets washed away when the rock is moved. If a plume exists, the stream is sediment laden. It may be difficult to pull a sediment impacted stone from the bed if the stream has been impacted for a long time. This is because the silt takes on a very hard form like a weak sandstone. In channels where the bed consists of hard boulder clay or is very impacted, then it may be necessary to dig the pool after construction as the structure may not be able to scour the pool itself, but it will be able to maintain a pool dug by machine. As a last note on structure siting, no matter how well planned structure sitings are, in most projects there will always be some surprises!

6.3 Size of structures

Structures should be sized to produce the desired aquatic habitat at normal and low flows with minimal effect on maximum channel capacity. They should be low enough that their effects on the water surface profile will be almost completely drowned out at near capacity discharges. Upland structures must always be drowned out in high flows to prevent excessive erosion. The upstream pooling effect of structures is minimal if sized correctly and they should pose no threat to channel capacity and therefore they do not place the channel or riparian area at risk from flood events.

A problem that may be encountered when installing structures is trying to decide on the structure size when the water level is extremely low. You may decide on a level and then return during high flow to find that the structure is so low in the bed that it is doing no good, or causing damage. There is also a danger of not making structures long enough. In high flows the current may erode around the bankside ends of the structures. It is important during construction to take note of where the vegetation begins on the bank and extend the structures past that level. High flows will usually prohibit much vegetation from growing below this "high water mark".

It is of great benefit to incorporate hiding places into instream structures to increase the provision of habitat and also to ameliorate the aesthetic properties of the structure. Live vegetation can be used as well as integrated arrangements of brush shelters, logs, boulders, rip-raps or angular rock, and specially built overhangs. Structures will also become more stable if willows are planted at their bankside ends and this improves the provision of cover and aesthetic properties of structures. Various materials can be used to construct instream structures, but the selection of appropriate materials is determined by environmental, engineering, economic and availability considerations.

6.4 Planning

Prior to undertaking any fishery development work on rivers, baseline information needs to be collected via physical habitat surveys and fish stock assessment. These surveys allow the assessment of limiting factors, which prevent the stream being more productive. As the limiting factors are identified, it is important to focus on the causes of the problems instead of the symptoms. If sedimentation is a limiting factor, the cause of the sediment inputs should be determined. Are slower currents in an artificially widened channel allowing sediments to settle over the stream bottom? Or is the problem excessive erosion resulting from poor land-use practices, or a combination of both? By identifying the causes, effective projects can be designed. In many projects instream works may not be the answer, as they fail to address more fundamental land or water management problems. In this case effort should be focused on changing the damaging land-use.

Once the baseline information has been collected and analysed a draft stream enhancement plan can be constructed. It is important that this plan is seen as a draft because during the implementation of the plan some of the instream conditions may change requiring the alteration of the original plan. Although the plan should be adhered to where possible, it may need to be tailored to suit actual on site conditions. The plan should incorporate a catchment wide appraisal to ensure that a balance is achieved and that any instream work is put into perspective in the 'big picture'. The draft enhancement plan should also include some form of cost/benefit analysis of the works once successfully completed. It has been found in Ireland that the cost/benefit concept appeals to administrators and financial contributors as they can relate to it, and it enhances the chances of attaining funding (O'Grady pers.com 1997).

Chapter 7 - Funding and Policies in North America and the UK

7.1 Canadian Federal Policy

In Canada, the Department of Fisheries and Oceans (DFO) introduced a new Fish Habitat Management policy in 1991, which was designed to achieve a 'Net Gain' of habitat for fisheries. In short, it has three main goals covering **conservation, restoration** and **development** of fish habitat. They aim to **maintain** the current productive capacity of fish habitats, **rehabilitate** the productive capacity of fish habitat in selected areas, and **create** and improve fish habitats. Policies and programmes initiated by the Canadian Federal and Provincial governments have been successful and are progressive and should be considered for adaptation to the situation here in the UK.

Based on the 'Net Gain' principle, DFO has developed a series of Habitat Conservation and Protection Guidelines. In order to comply with the Fisheries Act anyone planning to conduct any type of work in or near water have certain legal obligations that are outlined in guidelines entitled Fish Habitat Conservation and Protection - what the law requires. Project proponents must provide the DFO with all plans, specifications, studies, procedures and other information required to permit an assessment of the potential impact of the project on fish and fish habitat. Under provincial laws, a license or approval must be obtained before any work can be done on a stream. Any work within a stream or waterway requires a Water Rights Permit from the DFO. This is only forthcoming when they have approved the techniques used and the installation of any habitat improvement devices. This procedure has been recognised as a must by the Scottish Salmon Strategy Task Force in their 1997 report to the Secretary of State for Scotland, and must be implemented quickly.

The DFO regards everyone using the outdoors as having a responsibility to protect and maintain that which they use. Fisheries Officers are responsible for the enforcement of fisheries regulations, but in a province such as British Columbia (BC) the job is an enormous one due to the vastness of the province. They have an emergency free-phone number that can be called by members of the public to report violations such as poaching and exceeding the bag limit or catch quota or more importantly (with regard to this report) damaging fish habitat and polluting the environment. They offer rewards of up to $2,000 to those providing information leading to convictions. This goes along way towards preventing the destruction or pollution of fish habitat.

7.2 Canadian Provincial Policy

In British Columbia, basic license fees (except for the disabled) for hunting fishing and trapping include a surcharge for the Habitat Conservation Fund (HCF). This fund enables the acquisition, preservation and enhancement of valuable fish and wildlife habitat. The HCF implements a wide range of projects to benefit a diversity of species. Project proposals are submitted for funding application by provincial biologists, conservation organisations, private industry, landowners, volunteer groups and even members of the public. Over the past 12 years, the HCF has provided approximately $19 million for more than 1000 projects throughout BC.

The DFO in BC launched the Salmonid Enhancement Programme (SEP) in 1977, which is a joint federal-provincial programme aimed at increasing the numbers of salmonids in BC waters and creating awareness of salmonids and their habitats. Community involvement and partnerships are an important part of the programme. Stream Stewardship Schemes have been introduced which provide training and support in watershed restoration projects. Many volunteer projects, under the supervision of the DFO, clean up streams and plant vegetation. Others monitor streams for siltation or pollution. More than 8,000 volunteers have carried out enhancement activities. More than 70 communities throughout the province have initiated 'Streamkeeper Groups' under the sponsorship of the DFO. The SEP sees themselves as responsible for the future of the salmonid resource and a vital part of the SEP is encouraging children to become directly involved in efforts to

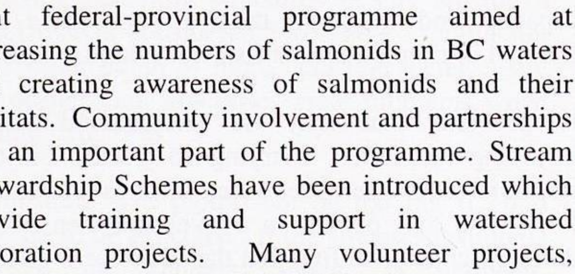


Figure 7.1 - Salmonid Enhancement Programme marketing logo

preserve and protect salmonids and foster a sense of stewardship towards the environment through streamkeeper groups. Some classes raise fish until they are ready to be released in nearby streams, others may "adopt a stream" taking responsibility for its general health and upkeep.

SEP activities are wide-ranging covering hatcheries, fish-ladders, spawning channels, incubation boxes, research, habitat improvement and community interaction and information dissemination through a series of Public Involvement Programmes (PIP). Emphasis is placed on increasing the natural production of salmon, and not merely boosting the population with hatchery reared juveniles. The initial phase of the development programme ran for seven years at a cost of $150 million in federal funds and $7.5 million from the BC government.

On the east coast of Canada the situation is different. Guy Sirois of the DFO in Moncton, New Brunswick suggested that funding for stream restoration is not as high in Atlantic Canada compared to BC. Most habitat work that is undertaken is usually on a consultative/advisory basis for mitigation purposes, such as when a new highway or reservoir needs to be built. Therefore, effectively the DFO is carrying out habitat protection or prevention of loss or deterioration, rather than a pro-active enhancement programme like there is in BC with the SEP. But, conservation and rehabilitation of Atlantic Salmon is a major priority of the DFO on the Atlantic Seaboard with programmes directed at education and awareness, commercial license retirement in Newfoundland and the Maritimes, stock assessment and enhancement, marine habitat improvement, tourism infrastructure and promotion.

The Atlantic Sportfishery Enhancement Programme is a scheme introduced to encourage grassroots participation in restoring the Atlantic salmon on the eastern seaboard of Canada. The Atlantic Salmon Federation (ASF) with financial assistance from the Atlantic Canada Opportunities Agency launched this five year education and public awareness programme promoting the conservation and enhancement of recreational fish resources and habitats in Canada's Atlantic Provinces to try and cover for the lack of other funding. The ASF itself works with government and industry to eliminate harmful practices in the forestry, agriculture, aquaculture and mining industries. It also engages in habitat evaluation and enhancement, and educational programmes in Atlantic Canada, Quebec and New England

7.3 American Funding

The decline in fish stocks in America was recognised as far back as the late 1800's, but this decline continued through the early part of the 20th century and it was recognised that a more vigorous movement was needed to restore America's fisheries. In 1950 Federal legislation called the Federal Aid in Sport Fish Restoration Act was passed. It was designed to channel money from anglers towards the restoration and management of the nation's fishery resources.

Fishery license fees had traditionally formed the financial backbone of most state fishery agencies, but with fish stocks declining, angling numbers declined and thus financial resources were depleted. A new source of revenue was needed. An excise tax of 10% was added onto the purchase price of angling equipment, which would help to raise revenue solely to fund restoration projects by the US Fisheries and Wildlife Service. This Sport Fish Restoration Act has remained virtually unchanged for the past four decades and is America's most effective success stories in natural resource conservation. By 1990 (after 40 years), the Act had provided over $1 billion for fishery enhancement projects. Annual funds have increased from roughly $40 million in the 1950's, to over $200 million in 1992.

As has been mentioned, stream restoration can be a costly process, but in the US as well as federal funding, a number of other bodies provide grant-aid. Trout Unlimited (TU) is America's leading trout and salmon conservation organisation. Since its inception in 1959, TU has been dedicated to conserving, protecting and restoring coldwater fisheries and their watersheds. There are more than 420 TU chapters or areas which are active at the local level in planning and conducting habitat improvement projects, working with government to secure fish-friendly policies and teaching young people the importance of protecting wild fish and their habitat. TU provide some funding for projects in the US through their Embrace-a-Stream programme similar to the Canadian Streamkeeper programme. TU may award grants of up to $10,000 to fisheries projects with research and education projects being eligible for funding.

In addition to TU programmes, there are several other groups and foundations in the US that award grants. Some examples are:

- **Fish America Foundation** – established in 1983 by the sport fishing industry to support grassroots activities to improve fisheries resources. Thirty to forty grants of up to $10,000 are provided nation-wide each year.

- **Coors Pure Water 2000 Programme** - The Coors Brewing Company set up the Pure Water 2000 programme in 1990 to help preserve, protect and clean up America's water resources. Since then it has provided more than $1.5 million to support water resource protection and education projects.
- **Trout and Salmon Foundation** - Since 1969, the Trout and Salmon Foundation has provided more than $250,000 in grants for the preservation and enhancement of the trout and salmon resources of North America.
- **National Fish and Wildlife Foundation** - this body was established by congress in 1984 to leverage public and private funds by awarding matching grants (minimum 1:1 match) for conservation activities.

7.4 Funding in the UK

When looking at the funding situation in the UK, it must be remembered it is different for different parts of the country. For instance, fishery ownership is different in Scotland than it is in England and Wales. Also, the Environment Agency is the government body concerned with fisheries in England and Wales and they derive income from fishing licenses as well as using public money. In Scotland the Association of Salmon Fishery Boards (A.S.F.B) is a Non-Governmental Organisation (NGO) which is the umbrella body that encompasses all individual Fishery Boards. These District Fishery Boards receive income through the charging of fishery assessments on the privately owned fisheries in their jurisdiction, but no government funding is provided.

Stream habitat enhancement can be an expensive operation, and many District Fishery Boards, private and public fishery owners do not have the finances available to undertake expensive fishery development programmes, which may include instream enhancement. There are various funding opportunities available at present to fisheries organisations in the UK, but competition for these monies is great. The Millennium Fund, the Heritage Lottery Fund, Government grants and various European Union (EU) grant aid schemes such as the European Regional Development Fund (ERDF) are sources of considerable funding for habitat improvement schemes. This money will not last forever and more effort could be put into forging partnerships between landowners, fishery owners, business and encouraging project sponsorship. Also, consideration could be made as to the imposition of a surcharge on all angling permits and licenses that provides for a fund dedicated to habitat restoration.

The government should act quickly to mobilise and inject greater levels of public money into the conservation of the Atlantic salmon, not just for the freshwater phase but also the marine phase of its life cycle. Its survival is of paramount importance, as it is a vital mainstay in many communities and its demise would have a devastating effect. It is not the purpose of this report to investigate funding opportunities and deficiencies for habitat restoration projects, but it is important to acknowledge that without suitable financial backing much needed projects can not be undertaken.

Chapter 8 - Conclusion and the Future

8.1 The Present Situation and the Future

Habitat problems experienced in most rivers can be summarised into several categories.

Limiting Factors to Smolt Production	Freshwater Habitat Problem
• *lack of spawning adults*	*1 obstruction to upstream migration*
	2 lack of adult holding pools
• *limited egg deposition/ survival*	*1 lack of stable spawning substrate*
	2 high fine sediment content in gravel
• *poor fry survival rates*	*1 high substrate mobility*
	2 high fine sediment load
	3 poor food availability
• *poor parr survival rates*	*1 lack of terrestrial and aquatic food*
	2 lack of channel diversity/ microhabitat
	3 poor overwintering or flood

The proposal for this fellowship was to investigate structural techniques to alleviate some of these problems in degraded habitats in moderate to high gradient upland river systems. However, throughout the document, the importance of Integrated Catchment Management has been stressed. As has been repeatedly indicated, treating the symptoms of riverine habitat degradation with instream structural solutions provides a temporary respite to a longer term and potentially more devastating environmental problem. Structures do not address the causes of the degradation, which are usually to be found on a wider catchment scale, they ameliorate the consequences. But, structural rehabilitation is the usual inevitability, as catchment restoration is far more difficult to implement, although it is likely to produce more sustainable results. The fundamental importance of the riparian zone in influencing instream channel morphology and stability has only recently been acknowledged, although its other functions have been realised for several decades. Restoring the riparian zone should be seen as the primary stream restoration technique in any salmon habitat improvement project, as it is fundamental to the biological and physical health of a stream.

To date most restoration schemes in the UK have taken place on a local level in an ad hoc trial and error manner. Integrated Catchment Management Programmes (ICMPs) are beginning to be initiated in some areas and this can only improve the situation. ICMPs should encompass all land uses, land users and interested parties to ensure that they co-operate to secure the health of the catchment ecosystem and allow for a sustainable future. Their implementation should be encouraged establishing a network of ICMPs as soon as practicable. There should be a national Catchment Co-ordination Unit that ensures that survey techniques, data analysis, water quality measurement, weather data recording etc. are carried out to a common standard in a common format in each catchment to ensure that scientific data is comparable. The unit would be responsible for collaboration, co-operation, co-ordination and information transfer between ICMPs via an integrated catchment database such as a Geographic Information System (GIS). This concept is beginning to be implemented, for example by the Fishmongers' Company. They appointed a Salmon Fisheries Co-ordinator for Scotland in 1997. Part of the role of the co-ordinator involves assisting in the development of the Scottish Fisheries Co-ordination Centre (SFCC).

Most structural habitat restoration projects that have been undertaken to date have been in relatively lowland situations. The upland riverine environment experiences much more dynamic and inherently unstable conditions and although it has improved over the last decade, there is still a general lack of geomorphological understanding of these conditions amongst some fisheries managers. This has caused much needed habitat restoration work in upland spawning and nursery streams to be avoided, or undertaken without the appropriate expertise, leading to failure. River management should always be based on an understanding of the fluvial system and its interactions and linkages with the surrounding landscape. It is for this reason that anybody involved with river restoration or habitat improvement for fisheries should have training in fluvial geomorphology so as to understand fully the complicated morphological reasons why rivers function as they do. Having said this, one of the most important things not to be excluded is experience and observation. No amount of formal training will allow you to predict exactly the behaviour of individual rivers. Local knowledge and experience should never be overlooked.

More educational leaflets could be introduced to inform landowners, farmers and other river users how and why a river functions as it does, and what management policies and practices are needed that will allow riparian vegetation to maximise its effects upon the hydrology and channel morphology of stream systems. Effective riparian vegetation can take decades to establish, so structures can span the gap until such time as there is a good stand of riparian vegetation. The roles of streamside vegetation are diverse and complicated, and an improved understanding of the ecology of riparian vegetation and its interactions with aquatic life is a pressing research need and this information needs dissemination to fishery managers, landowners and any other interested parties.

The indications are that the effectiveness of managing stream habitat for fish will lie increasingly in habitat protection i.e. preventative management, and in restoring habitat by putting nature in a position to do most of the work by regenerative processes. "In the natural regenerative approach, managers recognise their overall task more as people management than as fish management" (White, 1996). None of the rehabilitation methods discussed in this report or in other stream habitat enhancement guidelines, can be relied upon to mitigate poor management practices. Thus the trend must be toward preventing, reducing and removing man-made causes of deterioration and letting natural interactions of vegetation re-growth, hydraulics and sediment redistribution improve and maintain habitat. But some artificial restructuring of channels which has been used in the past will remain important, especially where natural regeneration would require decades, or even centuries. The reason for structural habitat manipulation in streams is to put streams in a position to restore themselves. But, the first priority above all others in any project should be to protect all habitat that remains in a healthy natural or semi-natural condition prior to any degradation. The importance of preventing habitat degradation now, instead of being forced to rebuild habitats in the future because of today's management practices, cannot be overemphasised. Protection of habitat is by far the most effective long term management strategy.

8.5 The Cardinal Rules of Habitat Restoration for Fisheries

When undertaking a stream improvement programme there are many important points that should be considered. Most of these have been discussed in this document, but they have been simplified and summarised in a series of "cardinal rules" of stream restoration by Trout Unlimited in America, to which I have added a couple extra.

- **Look at the big picture.** Don't focus solely on instream habitat, but also look to the riparian zone and the larger watershed. The health of the riparian zone and catchment is a major determinant of the health and stability of the stream.
- **Gather pre-works information.** Accumulate and assimilate as much background (historical) information on the catchment as is possible
- **Put the problem in context.** Ensure that what you assume to be problems are actually problems for the fish by undertaking baseline biological stock assessment surveys.
- **Seek long term goals.** The goal of the project should be to restore the natural qualities of healthy streams, not a quick fix solution to solve a local problem.
- **Learn from nature.**. Learn what the natural qualities are and work to restore them to the degraded system
- **Focus on the limiting factors at work in your stream.** Focus on the causes of the problems, not just the symptoms.
- **Each stream is like an individual - treat it that way!** Carefully plan your project with an eye to your stream's particular physical, hydrological and biological characteristics. What works well in one stream may fail dismally in others.
- **Involve a wide variety of experts.**
- **Work with, not against the natural capacity of streams and watersheds to restore their own health.** Changing land use practices or protecting a stream corridor may be enough to set a stream on the road to self-recovery, so only use structures where necessary to aid the recovery process
- **Strive for a natural appearance.** Wherever possible, select materials that blend into the natural setting of your stream
- **Maintain and Monitor.** Post-works maintenance and adjustment are essential to the effectiveness and longevity of the rehabilitation. Each rehabilitation project should be assessed to establish whether it is functioning as planned and this allows improvements to be made to any future projects.
- **Disseminate and Educate.** Report on each projects successes and failures and give this information for others to learn from. Educate, inform and involve interested parties, as educating today may prevent problems tomorrow.
- **Accept and Learn from failure.** Remember, nothing is a certainty in riverine environments!

desired. Post implementation monitoring and maintenance must be undertaken and budgeted for in the project formulation stage. Some of the better designed projects in North America, which should have lasted a century or more, deteriorated severely in 25 years or less because they did not receive the small amount of annual inspection and adjustment required to maintain durability. The effective life of many types of structure will be greatly extended if periodic post-construction maintenance is done, which is frequently neglected. But, it must be remembered that due to the complex and varying nature of streams, the impacts and benefits of stream enhancement projects are never totally predictable. It is important to acknowledge that there will be failures. There is nothing certain in river restoration, and being able to accept and learn from failed techniques is valuable experience as it will allow you to develop and improve future projects.

8.3 Research

Some work has been done in laboratory flumes to determine the effects of differing structure orientations and protrusion lengths of deflectors and heights of weirs, but most research findings have not been commuted to the layman in an understandable and practical format. With the acceptance that structures will always have a role in habitat enhancement, although somewhat diminished, higher levels of laboratory analysis is an important step in the development of new stream enhancement technologies, such as tree revetments used in BC and submerged vanes used in Iowa. Undertaking tests in controlled flume conditions allows an understanding of the likely outcomes of structure placement in certain stream conditions. This includes estimations of the critical flow conditions of structures, channel geometry alterations, bed and bank shear stresses, scour hole sizes and sediment transport and deposition rates etc. These are difficult to calculate and therefore it is important to use prototypes and it is invaluable to undertake laboratory analysis under artificial conditions. More testing of model structures under laboratory conditions is required to get a better understanding of the likely morphological and hydrological consequences of installing a structure. Model testing is an important and effective means to predict results and aid in the design of structures, but having said that, monitoring the performance of structures under real conditions may prove to be more important and should be given greater consideration. The CFB in Ireland is addressing this research need by undertaking physical, hydrological and biological monitoring of the performance of a range of different structures in varying riverine conditions. Information like this should be compiled in a short, practical and easily accessible format, possibly in the form of Government Information Leaflets.

8.4 Fish Management or People Management?

As was indicated previously, relatively few new techniques for salmon habitat restoration have evolved since the 1960's. The basic principles have been understood since the beginning of the century and the techniques have only been modified or improved slightly over that time. But, still many of the techniques are incorrectly used or implemented. This was the basis for undertaking this report, as a means to convey information about some new techniques used to create habitat, but more importantly, to give an insight into the reasons **why** structural techniques work, **when** they should be used and **where** in the channel they are most appropriate.

Some general questions have arisen during the fellowship that need to be answered prior to the use of structures in habitat projects, if structures are to be used.

- Are structures going to solve a habitat problem, or are they just providing a temporary respite?
- Are dynamic streams and stable structures compatible or even possible?
- Does structural stability assure habitat improvement?
- Are habitat stability and habitat improvement the same?
- It is unrealistic to expect structures to last and remain stable forever, so how long should a structure be expected to remain stable?

It is vital to acknowledge that any engineering work that modifies the river system has the potential to cause instability and adversely affect the riverine environment. Attempts to impose an unnatural condition on a river can lead to major instability problems, unless the river is heavily engineered. Any change in the flow regime and/or the dimensions of the channel through structure installation can destabilise the river and promote erosion and deposition not only within the engineered reach, but upstream and downstream from it.

It is obvious that structures alone are unable to replicate the various functions of healthy riparian vegetation. The degraded condition of many riparian areas highlights the fact that enlightened management policies and practices are needed that will allow riparian vegetation to maximise its effects upon the hydrology and channel morphology of stream systems. Effective riparian vegetation can take decades to establish, so structures can span the gap until such time as there is a good stand of riparian vegetation. The roles of streamside vegetation are diverse and complicated, and an improved understanding of the ecology of riparian vegetation and its interactions with aquatic life is a pressing research need and this information needs dissemination to fishery managers, landowners and any other interested parties.

The indications are that the effectiveness of managing stream habitat for fish will lie increasingly in habitat protection i.e. preventative management, and in restoring habitat by putting nature in a position to do most of the work by regenerative processes. "In the natural regenerative approach, managers recognise their overall task more as people management than as fish management" (White, 1996). None of the rehabilitation methods discussed in this report or in other stream habitat enhancement guidelines, can be relied upon to mitigate poor management practices. Thus the trend must be toward preventing, reducing and removing man-made causes of deterioration and letting natural interactions of vegetation re-growth, hydraulics and sediment redistribution improve and maintain habitat. But some artificial restructuring of channels which has been used in the past will remain important, especially where natural regeneration would require decades, or even centuries. The reason for structural habitat manipulation in streams is to put streams in a position to restore themselves. But, the first priority above all others in any project should be to protect all habitat that remains in a healthy natural or semi-natural condition prior to any degradation. The importance of preventing habitat degradation now, instead of being forced to rebuild habitats in the future because of today's management practices, cannot be overemphasised. Protection of habitat is by far the most effective long term management strategy.

8.5 The Cardinal Rules of Habitat Restoration for Fisheries

When undertaking a stream improvement programme there are many important points that should be considered. Most of these have been discussed in this document, but they have been simplified and summarised in a series of "cardinal rules" of stream restoration by Trout Unlimited in America, to which I have added a couple extra.

- **Look at the big picture.** Don't focus solely on instream habitat, but also look to the riparian zone and the larger watershed. The health of the riparian zone and catchment is a major determinant of the health and stability of the stream.
- **Gather pre-works information.** Accumulate and assimilate as much background (historical) information on the catchment as is possible
- **Put the problem in context.** Ensure that what you assume to be problems are actually problems for the fish by undertaking baseline biological stock assessment surveys.
- **Seek long term goals.** The goal of the project should be to restore the natural qualities of healthy streams, not a quick fix solution to solve a local problem.
- **Learn from nature..** Learn what the natural qualities are and work to restore them to the degraded system
- **Focus on the limiting factors at work in your stream.** Focus on the causes of the problems, not just the symptoms.
- **Each stream is like an individual - treat it that way!** Carefully plan your project with an eye to your stream's particular physical, hydrological and biological characteristics. What works well in one stream may fail dismally in others.
- **Involve a wide variety of experts.**
- **Work with, not against the natural capacity of streams and watersheds to restore their own health.** Changing land use practices or protecting a stream corridor may be enough to set a stream on the road to self-recovery, so only use structures where necessary to aid the recovery process
- **Strive for a natural appearance.** Wherever possible, select materials that blend into the natural setting of your stream
- **Maintain and Monitor.** Post-works maintenance and adjustment are essential to the effectiveness and longevity of the rehabilitation. Each rehabilitation project should be assessed to establish whether it is functioning as planned and this allows improvements to be made to any future projects.
- **Disseminate and Educate.** Report on each projects successes and failures and give this information for others to learn from. Educate, inform and involve interested parties, as educating today may prevent problems tomorrow.
- **Accept and Learn from failure.** Remember, nothing is a certainty in riverine environments!

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