Restoration of Riverine Salmon Habitats
A Guidance Manual
Fisheries Technical Manual 4

R&D Technical Report   W44

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HO-11/97-B-BAHB

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Dissemination status
Internal: Released to Regions
External: Released to Public Domain

Statement of use
This Manual provides guidance on the restoration of riverine salmon habitats and presents a project management approach which should be adopted to promote the effectiveness of such work. The Manual is for use by Environment Agency Fisheries Staff and external Fishery Managers involved in promoting and implementing this area of work.

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Preface

This manual is intended as an overview of habitat restoration specifically for Atlantic Salmon (*Salmo salar*). It is concerned principally with physical factors within and immediately adjacent to stream environments which can be readily altered to enhance poor or degraded salmon habitat.

The manual is based primarily on a detailed literature review of both published and un-published information, summarising the main points and key messages. For more detail on specific issues, the Reference section provides a comprehensive list of literature sources. Examples of habitat restoration methodologies have been presented and the likely impacts on salmon population dynamics anticipated where possible.

The overall–objective is to advise on best practice as it is currently perceived. However, habitat restoration in the UK is a rapidly evolving discipline, and hence the manual has been constructed in a format to facilitate updating as new information comes to light. Therefore it is important to stress that it is presented as a working document which will evolve and become refined as the restoration techniques described herein are developed.

Further it should be remembered when reading the manual, that the restoration techniques discussed and their impacts on salmon *in situ* are presented as examples within the framework of a specifically developed project management methodology. The techniques themselves and the simple population models accompanying them are intended as illustrations and are not designed to be prescriptive. Rather, with time, robust data from UK rivers will be gathered to augment existing knowledge and provide reliable estimates of the level of impact on population numbers that a given restoration technique or strategy might be expected to attain.

The manual is aimed primarily at Fishery Staff within the Agency together with independent fisheries interests who are involved in habitat restoration and stock enhancement. However, it is hoped that it will appeal to a range of disciplines, both in the Agency in the wider professional and voluntary community, with a view to encouraging best practice to be implemented wherever the opportunity for salmon stream restoration presents itself.

GLOSSARY

Alevin	Newly hatched salmon, with yolk sack.
Allocthanous	Material derived from outside of the river channel.
Allopatric	Species not living in conjunction with another species.
Buffer Zone	A strip of riparian land that separates the river from agricultural impacts.
Epiphytic	A plant that uses another plant or non-living structure for support.
Fines	Particles less than 2 mm in diameter.
Fry	A salmon which has absorbed its yolk sack and is beginning to feed freely.
Gabion	Baskets constructed of galvanised wire or plastic polymer and filled with stones.
Groyne	Structure built into the riverbank to deflect the current.
Parr	Juvenile salmon.
Revetment	A retaining wall or facing to the river bank.
Riparian	Land immediately adjacent to the river.
Riprap	Loose boulders used to protect the bankface.
Smolt	A juvenile salmon that has developed salt water tolerance and is actively migrating to sea.
Sympatric	Species living in conjunction with another species.
Thalweg	Centre line of flow.

EXECUTIVE SUMMARY

The National Strategy for the Management of Salmon in England and Wales (NRA, 1996) recognises habitat as an integral environmental component in the management of salmon stocks within homewater fisheries. Unfortunately, at present, there is no consistent framework to use when restoring degraded habitats. This report investigates salmon habitat creation and restoration strategies and provides guidelines for future schemes.

The main points arising from an extensive review of both published and 'grey' literature are as follows:-

- Catchment processes determine the distribution, abundance and quality of salmon habitats and must be understood if a restorative programme is to be successful;
- Generalised ideal habitats for different life history stages of salmon were defined and it was recognised that habitat availability has a crucial influence on habitat use.

A number of environmental factors were identified that lead to a deterioration in salmon habitats. These include mechanical shock, unsuitable gravel composition, extreme flow conditions, riparian land use and hydraulic manipulations. These factors can result in erosion, siltation, excessive temperature fluctuations, poor water quality, lowering of dissolved oxygen levels and a reduction in habitat diversity.

Regulated rivers are especially prone to further potential environmental impacts on salmon productivity, including increased siltation, poor water quality, unnatural flow regimes, a reduction in the wetted area for juvenile rearing and insufficient flows for drawing in adults. However, due to the controlled nature of such rivers, there are opportunities to utilise or manipulate flow to maximise habitat potential.

Salmon habitat restoration techniques were divided into two main categories:-

1. Instream techniques that protect, restore or create appropriate habitats for spawning, juvenile and adult salmon. Recommended techniques include:-

    - Cleaning of gravels (manual and mechanical methods)
    - Spawning gravel addition and retention structures
    - Addition of rubble mats
    - Flow constriction structures
    - Creation of pools and overhangs

2.   Strategic riparian land management techniques that indirectly promote beneficial salmon habitat.   Recommended techniques include;

- Trimming tunnel vegetation
- Maintenance of riparian buffer zone
- Fencing and isolation of river from livestock
- Raising public awareness of sustainable land use practices

Certain areas of habitat restoration may result in a conflict of interests between different life stages of salmon, other species of fish present, conservation objectives and flood protection.   A holistic approach with adequate consultation is, therefore, required when designing and implementing habitat restoration schemes.

The manual provides Project Management Guidelines on the following key stages of habitat restoration schemes:

- Identifying problems, setting overall objectives and prioritising areas for habitat restoration;
- Undertaking pre-scheme assessments to identify limiting habitats and set specific restoration scheme objectives;
- Scheme design and estimates of additional productivity;
- Cost benefit analysis of proposed schemes;
- Consenting procedures and construction issues;
- Pre and post-scheme appraisal;
- Standardised reporting.

This project has highlighted that, with a few exceptions, habitat restoration in the UK is still in its infancy with little pre and post-scheme appraisal. It is recommended that a structured database of restoration experiences is maintained by the Agency so that future schemes can be undertaken on a more informed basis. This will enhance the value of habitat creation and restoration as an important fisheries management tool.

KEY WORDS

Salmon, *Salmo salar,* Habitat Restoration, Management Guidance

1. INTRODUCTION

1.1 Introduction

In the latter part of the 20th century, Atlantic salmon stocks have come under threat from a variety of sources. Pollution, over-exploitation, disease and drought have all conspired over the years to reduce and, in some cases, eliminate salmon stocks. Running in parallel, but not fully understood until comparatively recently, is the role of habitat in influencing salmon productivity.

Changing land practices, land drainage and flood alleviation works and insufficient consideration of fish passage requirements in engineering schemes, have frequently resulted in negative impacts upon salmon populations. The various life history stages have specific habitat requirements and are affected differentially by the range of physical anthropogenic influences on water courses.

The Agency has recognised habitat as an integral environmental component of managing salmon stocks within homewater fisheries. To this end, habitat protection and improvement have been included in the **National Strategy for the Management of Salmon in England and Wales** (NRA, 1996).

The importance of habitat and its potential for manipulation as a fisheries management tool has long been recognised in North America (Solomon, 1983). A significant pool of academic and fisheries management literature has been built up over the years, concerned primarily with west coast Pacific salmonid species but including brown trout and Atlantic salmon (White & Brynildson, 1967; Hunt, 1976; Duff & Wydoski, 1982; Hunt, 1988; Adams & Whyte, 1990; Bourgeoise *et al.*, 1993).

However, a recent review by Mann and Winfield (1992) concluded that in the UK, habitat restoration has often been undertaken in a piecemeal fashion, without structured investigation into the effectiveness of techniques in our native rivers. Hence the development of habitat restoration as an effective fisheries management tool has been constrained due to a lack of knowledge on application and effectiveness.

The effort and financial resources allocated to salmon conservation evident from the publications referred to above highlight the economic value of the species as a sport fish (Tuomi, 1987) and as a recreational and environmental resource (Harris, 1978; Kennedy, 1988; Harris, in prep.). However, perhaps the most common form of population enhancement, stocking of hatchery reared juveniles, is now widely regarded as ineffective except in specific well defined circumstances. Hatchery production of salmon has not been proven to sustain wild populations within their native range and is considered to exacerbate the problems that wild salmon face, often masking their decline (McGinnis, 1994).

Habitat can therefore be regarded as a major influence in determining salmon productivity. The manipulation, restoration and creation of habitat offers significant

opportunities for the fisheries manager to make a real and lasting contribution to the conservation and sustainability of the salmon resource.

However, the restoration of salmon habitat should not be viewed in isolation of other users and ecological components of a river system. A holistic approach recognising all the demands placed upon a particular catchment should be determined within the context of the national strategy (NRA, 1996), Agency **Local Environmental Action Plans** (LEAPs), and, if appropriate, **Salmon Action Plans** (SAPs).

SAPs are not intended to be universally applied but are designed to be used on the more significant salmon rivers throughout England and Wales. The stock enhancement methodology is based on setting egg deposition targets, subsequent monitoring of compliance with targets and identification of appropriate management actions if targets are not met. It is important to stress that management actions are not exclusive to physical habitat restoration but are much more extensive and include controls on exploitation, and improvements in water quality and resources. One or more of these actions may be appropriate in a given catchment. The current manual is therefore only relevant to one aspect of the SAP methodology.

However, it is important to stress that a multi-disciplinary approach is essential for salmon stock enhancement. Clearly, if water quality, exploitation and enforcement issues are not addressed, riparian or instream salmon habitat restoration measures will be ineffective. It is essential that there is full integration between habitat restoration schemes, SAPs, if appropriate, and Local Environment Agency Plans (LEAPs) so that management decisions are made on an informed multi-disciplinary basis.

It should also be noted at an early stage that, by definition, habitat restoration represents an attempt to rectify something that has already gone wrong. Protection of existing salmon habitat as a valuable natural resource should perhaps be higher on the environmental agenda. Strategic and effective preventative management of factors resulting in habitat deterioration should therefore be of paramount importance.

Whilst such considerations are outside the remit of this manual, it is nevertheless prudent to remember that many of the techniques discussed herein deal with the **symptoms** of habitat deterioration and not the **cause**. Often the latter can only be dealt with on a catchment scale but it is essential for the fisheries practitioner to realise the broad arena in which restoration schemes operate. Awareness of this important and fundamental concept will not only result in more effective habitat restoration but, in the long term, should reduce the necessity for it.

1.2   The manual

This manual is divided into three sections:-

Part I - is an overview of information providing essential background to aid understanding of the aims and limitations of habitat restoration. Salmon river types and influential processes are reviewed together with the life stage habitat requirements of salmon and the critical factors which lead to habitat deterioration.

Part II - is a review of habitat restoration practices focusing largely on European and North American experience together with a synthesis of practical anecdotes derived from the literature.

Part III - describes in detail the methodology for assessing and implementing habitat restoration schemes. Methods of habitat mapping are reviewed providing an overview of techniques to assess habitat quality and quantity. Project management guidelines are established to determine the nature of habitat problems and the most appropriate and cost effective techniques available to resolve them. Worked examples are provided to illustrate the process of production based assessment and review, together with methods for financial analysis. Legal framework and consent requirements together with scheme assessment and reporting are also discussed.

1.3 Sources of information

Information for the manual has been collated from a number of sources. These include;

- Published literature search.
- Grey literature search accessed via questionnaire.
- Selected site visits.

The manual represents a synthesis of the literature and experience derived from these sources. However, a considerable amount of useful information is also available within numerous publications by the Agency and external organisations. These include;

- Rivers & Wetlands - Best Practice Guidelines (Agency, 1997a),
- Understanding Riverbank Erosion - from a conservation perspective (NRA, 1995a),
- Understanding Buffer Strips (Agency, 1996),
- Silt Pollution & How to Avoid It (Agency, 1997b),
- A Guide to Bank Restoration and River Narrowing (NRA, 1992)
- Trash Dam Removal (NRA, 1995b),
- Farm Pollution and How to Avoid It (Agency, 1997c)
- Farm Waste Management Plans (Agency, 1997d)
- Code of Good Agricultural Practice for the Protection of Water (MAFF, 1991).
- The New Rivers & Wildlife Handbook (RSPB, NRA, RSNC, 1994).

PART I

SALMON RIVERS : HABITAT & DEGRADATION

2. RIVER TYPES AND INFLUENTIAL PROCESSES

2.1   Introduction

An appreciation of river types and processes is an essential first step in understanding the habitat requirements of salmon. A knowledge of the interactions between the geomorphological characteristics of a river system provides an informed basis on which to create, restore and enhance salmon habitats. This chapter describes the processes and features occurring within rivers that form the habitats utilised by the different life stages of salmon.

Rivers should be considered as dynamic open systems, receiving an input in the form of precipitation, with attendant inherent processes such as erosion, transportation and deposition of materials. Outputs occur in the form of evaporation and discharges of water into the sea. A steady state is never achieved as short-term events (such as a storm) continually cause processes to operate (e.g. channel re-shaping by bank erosion and bed deposition) and alter the channel morphology as the river attempts to attain the highest efficiency possible.

Rivers are not single discrete entities but exist in association with a multitude of other parameters. The functional unit in which a river should be considered is the **drainage basin** (see Figure 2.1). This is an area of land where any precipitation falling, will find its way to the major arterial watercourse. It is delineated by the **watershed**, a boundary defined by the highest points of the basin, precipitation falling either side of which enters adjacent basins. Physical features existing in a drainage basin will not only define it, but the characteristics of any watercourses found within.

The interactions between compartments of a drainage basin are varied and complex. Essentially, the structural, geological and erosional history will determine the topography, shape, size and relief of the basin, which in turn affect how much precipitation is captured and the subsequent rate and volume of water movement through the system. The lithology, weathering and erosional processes will influence the type, formation, transport and deposition of sediment, soils and solutes, which will then promote or limit the type of vegetation which is present.

2.2   Salmon river types

Freshwater systems are used by salmon in their reproductive and nursery phase of life. Once in a river system, the adult fish will migrate upstream at varying speeds, depending on the time of year, water temperature and stream flow, until they reach a suitable spawning site. Here redds are built, mating and fertilisation of the eggs occurs and the adults attempt to return to the sea. After a period of incubation, during which the intergravel physio-chemical environment is critical, the alevins emerge from the redd, grow into fry, then to parr, and after their nursery period is complete, will return to the sea as smolts.

During this cycle of events, the fish will have had to swim through many different reaches of river, some of which have very contrasting characteristics. These can be broadly discussed as being due to geology, relief, channel morphology, flow types, channel features and bedload. All of these factors are interrelated and, as such, the classification of river types should be undertaken with this in mind.

The interrelationships governing the characteristics of rivers and streams are highly complex. Consequently, the compartmentalisation of types of waterway is not technically accurate, but such classification is useful to facilitate the communication of ideas and to allow comparisons to be made between different rivers.

Salmon rivers will be discussed under four main levels of resolution (see Table 2.1). The largest scale identified is 'waterways defined by relief' (upland and lowland), followed by 'waterways defined by lithology' (e.g. chalk streams such as the River Test), 'channel characteristics' (morphology, flow and water type) and finally 'mesohabitats' or 'channel features' (e.g. riffles and waterfalls). The main fluvial processes operating within the channel are also considered with regard to their particular significance to salmon.

Table 2.1   Scales of resolution used to identify fluvial influences on salmon.

WATERWAYS DEFINED BY TOPOGRAPHY
Upland   Lowland
↓
WATERWAYS DEFINED BY LITHOLOGY
chalk limestone sandstone resistant rock
↓
CHANNEL CHARACTERISTICS
morphology   flow type
↓
MESOHABITATS/CHANNEL FEATURES
waterfalls rock steps rapids riffles pools meanders

2.3   Waterways defined by relief

Due to the complexity and aerial extent of drainage networks, lithological categories may overlap within a single drainage basin. Salmon will therefore encounter many different river conditions during a single migratory cycle. In order to overcome this feature of river systems, attempts have been made to classify them with reference to their hypsometric attributes, being broadly summarised as **lowland** and **upland** rivers. Obviously at some stage, even if temporary water storage occurs in a lake, there is often a gradation from one to another (Figure 2.2).

2.3.1   Upland watercourses

Upland watercourses, such as Langdale Beck in the Great Langdale valley in Cumbria, originate high up on the sides of glacially carved valleys, either from the

amalgamation of precipitation running off mountains or as springs fed by groundwater. The channels tend to be small and choked with bedload, which originates from local valley sides. They are turbulent and highly aerated as a result of water cascading over boulders but do not have a large volume of discharge due to the small area of catchment contributing water.

Typically, valley cross-sections are V-shaped if incised by water, with interlocking spurs or U-shaped if eroded by a glacier, with truncated spurs. In the latter, the watercourse is termed a misfit stream, as it is too small to have created the valley in which it flows. The dominant processes occurring here are **erosive** and **transportive**, as much kinetic energy is expended by the water breaking up the bedload into smaller, more easily transported particles, such as gravels. These waterways are highly susceptible to storm events. Flash floods occur rapidly where a high volume of precipitation reaches the channel quickly as a consequence of steep valley sides and the predominance of impermeable ground. They can also be ephemeral, drying up in the summer as the level of groundwater stored in rock fractures falls.

Where a few of these tributaries reach a confluence, the channel immediately downstream will carry the combined discharge. Due to the rapid response of these waters to climatic events, the effects discussed earlier will be reflected here but on a more energetic scale due to the greater volume of water involved. For example, where Langdale Beck flows below Elterwater, it cascades over Skelwith Force, a natural waterfall, to flow into Lake Windermere. If heavy rain falls then the lateral area of the channel in the waterfall increases dramatically due to the larger contributions of water from the catchment and drainage network. Flooding can be a real risk in this situation, small streams becoming torrents in a matter of hours. This can pose a significant threat to juvenile salmon and incubating redds, as the increased hydraulic power of the water and the concomitant transport of larger material can damage, dislodge and washout the fish and their associated structures.

A large volume of boulders and cobbles are generated by upland erosive forces, but the transportational power of the water is typically not enough to move them far downstream (unless there is a storm event). So, for much of the time, braiding of channels occurs, with the water moving in a sinuous form around accumulations of bedload. These accumulations will reduce the amount of channel available as a juvenile habitat and may present an obstruction to adult migration.

2.3.2 Lowland watercourses

Where the profile of the long-section of a river has an abrupt decrease in gradient, possibly as a result of a change in geology, the characteristics of a river will alter accordingly. The reduction in slope angle may reduce the tendency of a waterway to erode vertically and incise into the bedrock but, due to a much greater volume of discharge from the many contributing tributaries, the size and width of the channel can increase. Flood events widen the cross-section, accommodating the discharge in a more efficient channel, and increase the velocity of discharge. A lower proportion of water will be in direct contact with the bed and channel sides than in upland waters, where braids and boulders are a constant source of energy loss. Consequently,

frictional retardation of flows and associated turbulence and eddies will be reduced. As such, this is an area of deposition, especially in the more seaward regions where tidal influences become dominant and salinity variations begin to occur (estuaries).

In order to increase its storage capacity, a river may meander in a sinuous path across its floodplain, loops of which migrate with time, leaving visible scars as evidence of such movement. The floodplain itself consists of alluvial deposits originating from historic floods. The floodplains are typically nutrient rich and reflect the fluvial sediment characteristics. Flow is far less turbulent, appearing deep and smooth or as a series of shallow, fast sections. Consequently, lowland river water tends to be less well oxygenated than that in upland streams. The lowland river can be considered as a corridor through which the adult fish have to pass to reach their spawning grounds. Adult salmon travel upstream from an estuary through these lowland reaches of river to reach spawning grounds at a rate of up to 20 kilometres per day (Mills, 1989). The fish move further up the river in phases of active swimming (during spates), followed by stationary periods where they 'lie' in pools. If the oxygen content is significantly reduced, such waters may present a barrier to the migration of adults.

2.4   Waterways defined by lithology

There are distinct types of waterway which can be classified according to the underlying geology. Whilst each type of river will have distinct characteristics it must contain the different habitat features required for the completion of the salmons life cycle if a sustainable salmon population is to be maintained. The biological requirements of salmon, in broad terms, include well oxygenated water that is free of organic pollution and contains sufficient areas of gravel for spawning, juvenile nursery areas and areas of cover for migrating adults.

Rivers suitable for salmon range from waterways with a gentle gradient, such as the River Itchen in Hampshire, to those with larger variations in altitude, such as the River Dee in Scotland. As such, the proportions of the different types of habitat, required by salmon, may vary in terms of quantity and quality, which will influence the size of the salmon population.

2.4.1 Chalk streams

Typically, these originate from springs which rise below escarpments where more impermeable strata are encountered or where the water-table is sufficiently high. Above the escarpment, on the chalk plateaux, there are rarely any surface streams due to the highly permeable nature of chalk. Instead, streams tend to be found in wide valleys, exploiting weaknesses in the rock (for example the River Avon in Wiltshire).

The long profile of a chalk stream is gently graded and features such as waterfalls are typically not encountered by salmon in these waters. In their uppermost reaches the tributary streams are small and, due to the soluble nature of the chalk, the bedload will not consist of large boulders, but cobble/gravel-sized or smaller particles. Further down-stream, the river will typically occupy a wide alluvial valley, having bluffs or river cliffs at its margins and a flat floodplain. The channel itself will tend to meander

in a sinuous form, allowing the river to maintain a higher volume of water. Evidence of migration of the channel across the floodplain can be seen as scars on the bluffs.

The discharge characteristics of chalk rivers are heavily dependent on the level of the water table, and are less likely to be subjected to sudden spate conditions. During periods of prolonged low rainfall, groundwater levels will decrease, causing some streams to dry up completely (ephemeral winterbournes), thus reducing the available juvenile and nursery areas. In addition, as the flows decrease gravel bars may become exposed, trapping adults in pools forming obstructions to migration.

As chalk streams are usually spring fed the quality of the water in the rivers is generally high and typically carbonate rich. These conditions promote high invertebrate productivity, which in turn sustain juvenile salmon populations.

2.4.2   Limestone streams

Areas such as the Cotswolds, Northamptonshire Uplands and parts of the Yorkshire Pennines feature karst scenery. Here, streams flow down step-like cascades, over bedding planes and through joints and fractures. Streams will often disappear underground through swallow holes, to emerge elsewhere. Whilst historically being frequented by salmon, these features will obviously present an obstacle to the migrating fish, in some cases even prevent them reaching the upper tributaries. Thus, a significant proportion of a catchment may not be accessible to salmon and consequently will not support a sustainable salmon population.

Where gradients are not so severe, beyond the upland plateaux, the limestone will tend to become sandier or be masked by impermeable drift deposits. As a result the sediment loadings to a river may be naturally high, which will then have implications for the spawning success of salmon.

2.4.3   Sandstone streams

In sandstone country, the topography ranges from rolling fells, such as those found in the Pennines, to flat plains (e.g. the Fylde area of Lancashire). In the upland regions of these waterways, the small tributary channels will feature irregularities in their bed form due to the boulder, cobble, gravel and sand sized particles entering the channel from local slopes. As a result of the mixed sizes of substrate present within a channel, the flow is often turbulent, leading to high oxygenation of the water producing good water quality conditions for salmon.

As sandstone has moderate resistance to erosion, large amounts of material can enter the river and be transported downstream, during spates. During these spate conditions a significant re-distribution of existing material within the river channel may also occur. This leads to the formation of significant bed deposits such as gravel banks. Conversely; in some situations, the bed deposits can be washed out of the system.

As the gradient of the river decreases meander-belts can develop, resulting in good accumulation of gravels on the insides of bends. Due to the large amount of eroded

material entering the river, further upstream, these rivers tend to have a good supply of gravel suitable for spawning.

2.4.4 Resistant rock streams

This category includes waters flowing over igneous and metamorphic bedrock, typified by much of the English Lake District and most of the Scottish Uplands. In these areas, the topography frequently comprises steeply inclined, impermeable rocks, giving rise to a rapid transfer of water to waterways which occupy irregular and boulder-choked channels. These are discussed in more detail in Section 2.3.1.

2.5 Channel Characteristics of Salmon Rivers

2.5.1 River morphology

Channel patterns vary in river systems (Figure 2.3), typically being viewed as either **straight, sinuous, meandering, anatomising (or braided)**. Straight stretches of a river often occur in conjunction with or between bends, or along braided reaches. They are shallow and riffled and have a wide range of slopes and discharges. Any local disturbance of flow between the straight banks will cause deviations in patterns of flow, with asymmetrical shoals of sediment accumulating along the banks. As this increases, flow will start to erode the banks and a sinuous pattern will develop.

In a meander belt, erosion is concentrated where the threads of water flowing at a high velocity come into contact with the bank. Deposition often occurs opposite these points, leading to the formation of a point bar. Both riffle-pool sequences and meander bends are repetitive. Meander wavelength and amplitude and riffle-pool spacing are related to channel width, the pools being associated with meander bends while riffles are associated with points of current crossover. Riffle crest to riffle crest averages a distance equivalent to six channel widths, whereas the wavelength of meanders tends to average around twelve channel widths. The bends are asymmetrical in cross-section, their width increasing more rapidly than depth with increasing discharge. Riffles are more symmetrical in cross-section, with higher values of roughness, water velocity and turbulence.

The **thalweg** (centreline of flow) moves towards the outer (concave) bank in a meander, swinging downstream from the outside of one bend to the outside of the next. There is therefore a tendency for lateral and down valley migration. Rivers with meanders are typical of regular discharges, stable banks (silt and clay) and gentle stream gradients.

Where streams occur in areas where the channel banks are easily eroded (being composed of loose sands, earth or gravels) or where the discharge is highly irregular (for example a glacial meltwater stream) large quantities of bedload are present. As channel widening occurs, bedload increases to the extent that, when discharge is reduced, the coarser sediments are deposited on the channel floor as braids. The widening causes a reduction in water depth, which may present an obstacle to

migrating fish under periods of low flow. An anatomising stream is one where there are many such channels but they are more stable and retain their identities with changing discharge and time. Both these channel types are hydraulically inefficient and are characterised by steep longitudinal gradients which are needed to promote the velocity required to move the water through the numerous channel branches.

2.5.2 Flow types occurring as a result of channel features

From a bankside vantage point, it is possible to describe the appearance of a stretch of water in terms of characteristics such as surface agitation, velocity of flow or depth of water, enabling the distinction between at least three different categories. River Habitat Survey distinguishes ten key flow types to aid identification of channel features (Table 2.2). From this, it is then possible to deduce some in-channel processes and conditions encountered by salmon due to the interrelationships between bedload, channel roughness, flow parameters, erosion, transport and deposition.

Table 2.2   Different flow types as classified by River Habitat Survey (NRA, 1995)

Flow Types	Associated Channel Features
FF: Free fall	clearly separates from back-wall of vertical feature ~ associated with waterfalls.
CH: Chute	low curving fall in contact with substrate.
BW: Broken standing waves	white-water tumbling wave must be present ~ associated with *rapids*
UW: Unbroken standing waves	upstream facing wavelets which are not broken ~ associated with *riffles*.
CF: Chaotic flow	a mixture of 3 or more 'rough' flow types on no organised pattern.
RP: Rippled	no waves, but general flow direction is downstream with disturbed rippled surface ~ associated with *runs*.
UP: Upwelling	heaving water as upwellings break the surface ~ associated with *boils*.
SM:Smooth	preceptible downsteam movement is smooth (no eddies) ~ associated with *glides*.
NP: No percepttible flow	no net downstream flow ~ associated with pools, ponded reaches and marginal deadwater.
NO: No flow	dry.

The different types of water detailed above are a result of how the water behaves as it moves over and around different objects on the bed or across a change in channel morphology. The actual behaviour of the water is discussed here. The different types of flow will affect salmon in terms of their mobility, maintenance of feeding/resting position and vulnerability to sedimentation effects.

In terms of fluid mechanics, there are typically three types of water flow in a river. The first, laminar flow, exists when water flows past another fluid or solid object which acts as a fixed or moving boundary and entails momentum transfer by molecular

action only. Particles in the water tend to move in smooth definite paths, with uniform velocity and no significant transverse mixing during movement along the channel. This type of flow is very rare, only occurring near the sides of the bed in the boundary layer and in groundwater. It cannot support solid particles in suspension (such as food for salmon).

Viscosity forces dominate during laminar flow of water but, when inertia forces begin to increase, the flow becomes turbulent. Particles then move in irregular paths which are neither smooth or fixed and are often manifested as eddies. There are two types of turbulent flow; streaming flow is the ordinary turbulence found in streams, whereas, shooting flow occurs at higher velocities, such as those found in rapids and waterfalls.

Typically, flow in a lowland river in flood is dominated by streaming turbulent flow and laminar flow, whereas an upland river in the same conditions would be dominated by shooting turbulent flow. The difference is largely due to the differences in channel form, slope and nature of the bedload in the two rivers. This is reflected by the contrasting behaviour of salmon in these two types of river (migrating through lowland reaches to the upland stretches where spawning and development of the juveniles occurs) and their morphological and physiological adaptations which enable them to cope with the different flow conditions encountered.

A third type of flow, helicoidal flow, is usually found in meander bends. This is a circular current superimposed on the downstream flow of water and resembles a vertical spiral. It is a result of a compensatory return flow of water across the channel caused by the build up of a slight head of water as the main current impinges on the outer bend of the river. It is probable that this flow plays a part in the transfer of sediment from the outer banks of meanders to the inside banks where it is deposited. It may bear some relevance in the siltation of gravel beds found in such locations when outer banks collapse as a result of undercutting.

If salmon are present in a river, it may be possible to predict their location by characterising the flow type. For example, adult fish will lie in pools where there is little or no flow of water, resting before continuing their upstream migration, while parr live and feed on riffles where the flow is turbulent.

2.6   Major fluvial processes

Fluvial processes are the dynamic core of a river system. They are energetic processes that will shape and alter salmon habitat and, in many cases, even destroy it. It is imperative that these are understood in order to maintain existing salmon habitat or to enable the successful introduction of future habitat structures.

These processes can be classified as being erosive, transportive and depositional. They all involve energy transfers and the movement of sediments within the channel. The energy a stream has available for work depends initially on the potential energy available (due to its height above sea-level). This is converted to kinetic energy, with the rate of this conversion depending on the gradient of the channel. Some energy is

dissipated as heat (generated due to friction between water and other physical objects), with the energy remaining being available for work (i.e. erosion and transportation). Depending on the velocity of flow, different sized grains will be entrained by moving water and transported until the velocity cannot sustain the particles movement any longer, causing the particles to be deposited (Figure 2.4).

This becomes critical when considering salmon spawning gravels. The velocity of flow will control their accumulation and stability as well as problems encountered due to the deposition of silts and clays which fill inter-granular voids and inhibit oxygenation. A localised reduction in the velocity of flow to the settling velocity for gravel-sized particles will cause a homogenous accumulation of this material (if there is enough gravel in supply). The velocity of flow over and through the accumulation will need to be high enough to winnow out any accumulating silts and allow the movement of oxygenated water through the gravel bed. If the velocity becomes too high (e.g. in a storm), then the gravel may be transported and the bed 'washed-out'. In a similar manner, the correct velocity of flow is required for the accumulation of cobbles required in salmon nursery grounds.

2.6.1　Erosive processes

The processes shown in Table 2.3 are the methods by which channel material is weakened, removed from its current position and entrained into transport. In this manner, channels are reshaped, enlarged and made to alter their course, reshaping the nature of salmon habitats.

Table 2.3　　Major erosional processes

Cavitation	Caused by the implosion of air bubbles entrained in the water forcing rock fragments to move vigorously, impacting on other objects.
Pneumatic action	Turbulent water forcing air inside fissures and cracks, causing an increase in air pressure weakening structures.
Attrition	The action of two particles striking one another, knocking small chips from them.
Abrasion	The rubbing together of particles, in a smoothing or grinding action.
Potholing / drilling	The vertical vibration or rotation of a rock tool due to eddies, exploiting bed weaknesses such as joints.

2.6.2　Transportation processes

As mentioned in Section 2.3, a particle can enter the transportation pathway once the velocity of flow is high enough. The three methods, of transportation of macro-particles are detailed in the following table.

Table 2.4   Major transportational processes

Suspension	The entrainment and movement of particles away from the bed when water movement exceeds the critical velocity for that particle (typically silt-sized particles).
Saltation	If a particle is lifted up by water but its mass is such that it will fall again, it may bounce or knock other grains into a similar motion effecting downstream transport.
Traction	Upward velocity cannot move certain large grains, but they can still be moved horizontally along the bed. Flat grains will slide, round grains will roll.

Particles entrained and transported by a river are deposited when the velocity of flow is no longer sufficiently high to transport them and form channel features such as braids.

As these processes do not occur in isolation but instead co-exist in the same reach, they will be discussed in terms of discrete channel features, each of which is characterised by an association of processes.

2.7   Channel features/mesohabitats encountered by salmon

The lowest scale of resolution used in this section is the identification of discrete fluvial geomorphological features, such as waterfalls or pools (mesohabitats or channel features) that salmon will encounter at some stage in their migratory cycle. Although individual features will differ in appearance, the overall impact on the behaviour of salmon when they encounter such features can be generalised.

2.7.1   Rock-steps and waterfalls

Large resistant boulders or bedrock in an upland channel present an obstacle to the flow of water (Figure. 2.5). Immediately behind them, due to a separation of flow and the creation of eddies caused by the obstacles, pools are formed. These rock steps (chutes) and their associated pools tend to occur frequently in upland channels. The turbulent nature of water as it flows around and over the step will increase aeration of the water, and the implosion of the air bubbles (cavitation) can cause shockwaves to hurl rock particles against channel sides in an erosive manner. Rock steps should not present an obstacle to moving salmon, with the pools behind the steps allowing salmon to rest before making the next ascent.

Waterfalls (and cascades) are a product of differential erosion where a less resistant rock layer is vertically exploited. The hydraulic impact of the cascading water as it reaches the bottom of the waterfall causes a concave depression to form (a plunge pool). Cavitation and turbulence also occur, with strong eddies forming around the

plunge pool. Any gravel will be scoured out of the plunge pool and there will be no stable substrate for spawning. Around the edge of the pool, where the water is less turbulent, accumulations of gravel may exist. Highly aerated water will move through the voids between particles keeping them silt free and mobile.

A standing wave is required to enable the salmon to clear steep waterfalls, being used as a hydraulic ramp to clear obstacles. The distance of the standing wave from the waterfall influences the success of the leap. In shallow fall pools, or in pools below sloping cascades or weirs, the standing wave may become located too far downstream for the salmon to strike the crest of the fall on the upward arc of its trajectory. If the fish strikes the falling water on the downward arc, it is immediately swept downstream (Mills, 1989).

2.7.2   Runs and riffles

Runs are stretches of quickly flowing water associated with the steepening of the gradient along a watercourse. The cause of the rapids is usually geological (e.g. resistant bands of hard rock with intervening soft layers). Water flow is turbulent and highly aerated, the soft rock being preferentially eroded to create small pools behind the rapid. Runs are easily negotiable by salmon.

Riffles occur where a heterogeneous bedload is deposited in close proximity enabling bars of sediment to form (Figure. 2.6). This provides an area of river bed that is shallow. As a result, flow velocity increases, as does turbulence and hence oxygenation. The bedload is highly mobile, especially in storm events, where its morphology may be altered. Water will pass through the voids of gravel to cobble sized clasts, winnowing out any fine particles which are transported downstream. The removal of fine particles increases the survival rate of salmon eggs deposited in the gravels. In addition, riffles and runs provide important juvenile habitat.

Glides are slower flowing than runs and are often associated with finer substrates. They can be used as juvenile habitat but are suboptimal.

2.7.3   Pools

Pools are important resting habitats for migratory salmon, typically used as places of rest for migrating adults. They occur where major obstructions are present in the channel and include boulders, bars and large woody debris (e.g. a logjam). Flow diverges into these pools, with decreasing velocity and loss of energy. In the lee of boulders or other large debris, a separation zone can occur, where there is a slight upstream accumulation of water. Pools can also exist as a result of water scouring the bed in front of an obstacle as it flows around and over it, or where flow is diverted and focused to the side of an obstacle.

Pools are often associated with riffles in a sequential form. As described earlier, if their presence leads to an increase in sinuosity, meanders may develop. In a pool, the velocity of flow is reduced, with the accompanying deposition of variously sized particles (depending on their settling velocity). This can lead (especially where

overland flow is contributing to the channel water) to siltation of gravel beds, with a concomitant reduction in the suitability of the area for salmon spawning.

2.7.4   Meanders

As water flows around a bend, it becomes influenced by centrifugal forces. This, in effect, forces the main current to swing from the outside of the bend on one loop, where velocity of flow is fastest and erosion occurs, and cross over the channel between loops to the outside of the bend in the next loop. The outside of the bend is typically a pool and the crossover area is typically a riffle (Figure. 2.7). Helicoidal flow, described earlier, results in the transport of sediment from the outside of a bend to the inside, where it is deposited in the form of a point bar.

Undercutting of the outside edge often occurs as the bed is over-deepened, with resultant bank failure. The material entering the channel is usually fine in size and could result in siltation of spawning beds further downstream.

These different river types and features have been incorporated into the NRA River Habitat Survey (NRA, 1995c), which provides a comprehensive methodology for the characterisation of rivers. For more details refer to Section 8 of this report.
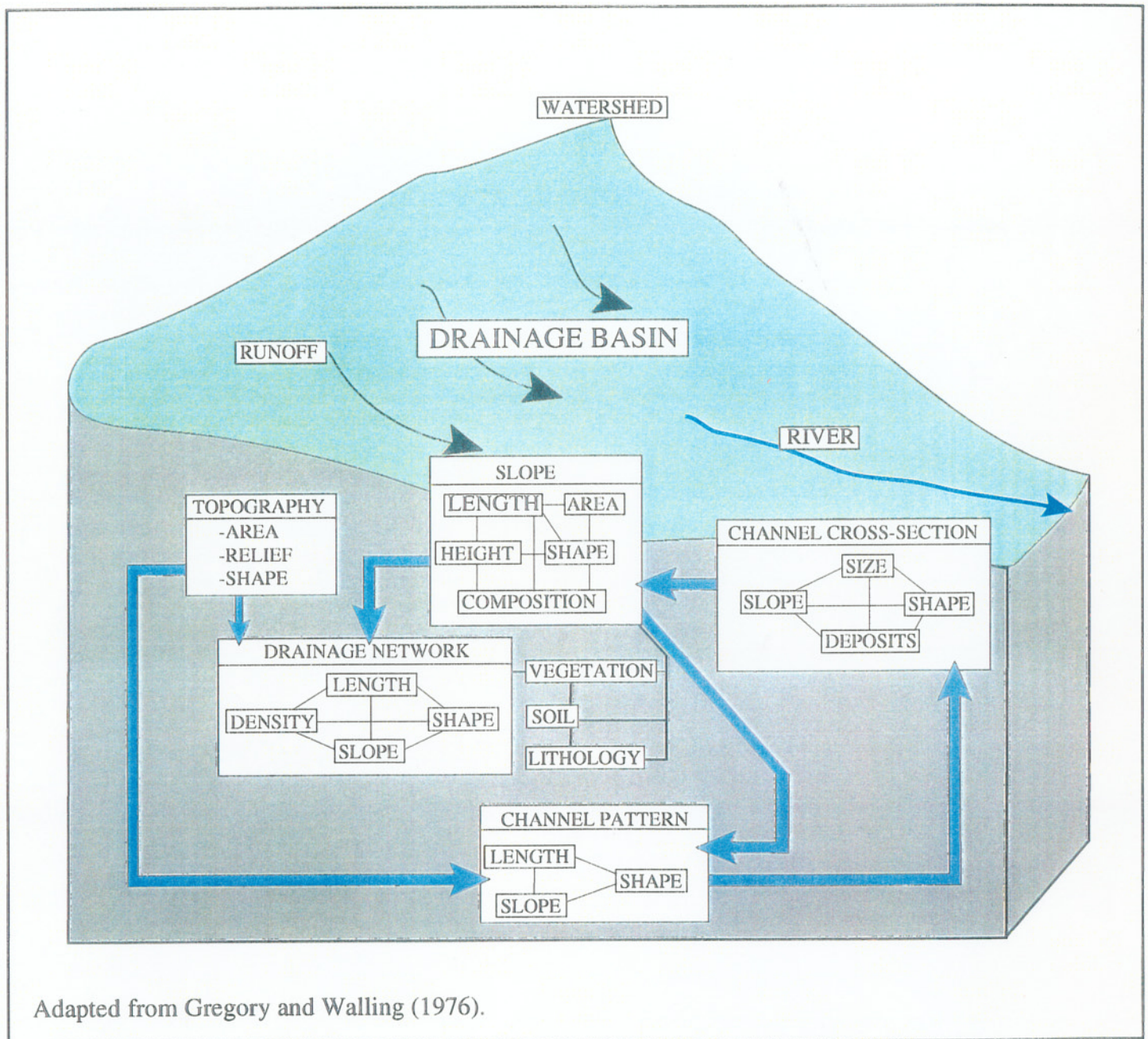
Figure 2.1 Interactions Occurring Between the Major Processes in a Drainage Basin System

The following labels appear within the figure:

WATERSHED

DRAINAGE BASIN

RUNOFF

RIVER

TOPOGRAPHY
-AREA
-RELIEF
-SHAPE

SLOPE
LENGTH — AREA
HEIGHT — SHAPE
COMPOSITION

CHANNEL CROSS-SECTION
SIZE
SLOPE — SHAPE
DEPOSITS

DRAINAGE NETWORK
LENGTH
DENSITY — SHAPE
SLOPE

VEGETATION
SOIL
LITHOLOGY

CHANNEL PATTERN
LENGTH
SHAPE
SLOPE

Adapted from Gregory and Walling (1976).

UPLANDS

Slope inputs

Bank erosion

Coarse channel sediments

Outflow onto floodplain of fine
sediment with temporary storage
of material

Meander bends migrate laterally

Flood bank situated too close to
river results in collapse

Deposit of sediment in
estuary

LOWLANDS

(After Schumm, 1977)

Figure 2.2 Variation in Channel Morphology and Processes due to
Changes in Relief in a Drainage Basin

DECREASING CHANNEL STABILITY
INCREASING SEDIMENT SUPPLY

Bed material supply dominated channels

Boulders, cobbles

Gravel

Sand

Step-pool
cascade

Gravel

Sand

Wandering channels

Meandering channels

Braided channels

Fine sand, silt

Silt

Anastomosed
channels

Wash material supply dominated channels

INCREASING CHANNEL GRADIENT
DECREASING CHANNEL STABILITY
INCREASING SEDIMENT CALIBRE

Figure 2.3 Forms of Channel Morphology
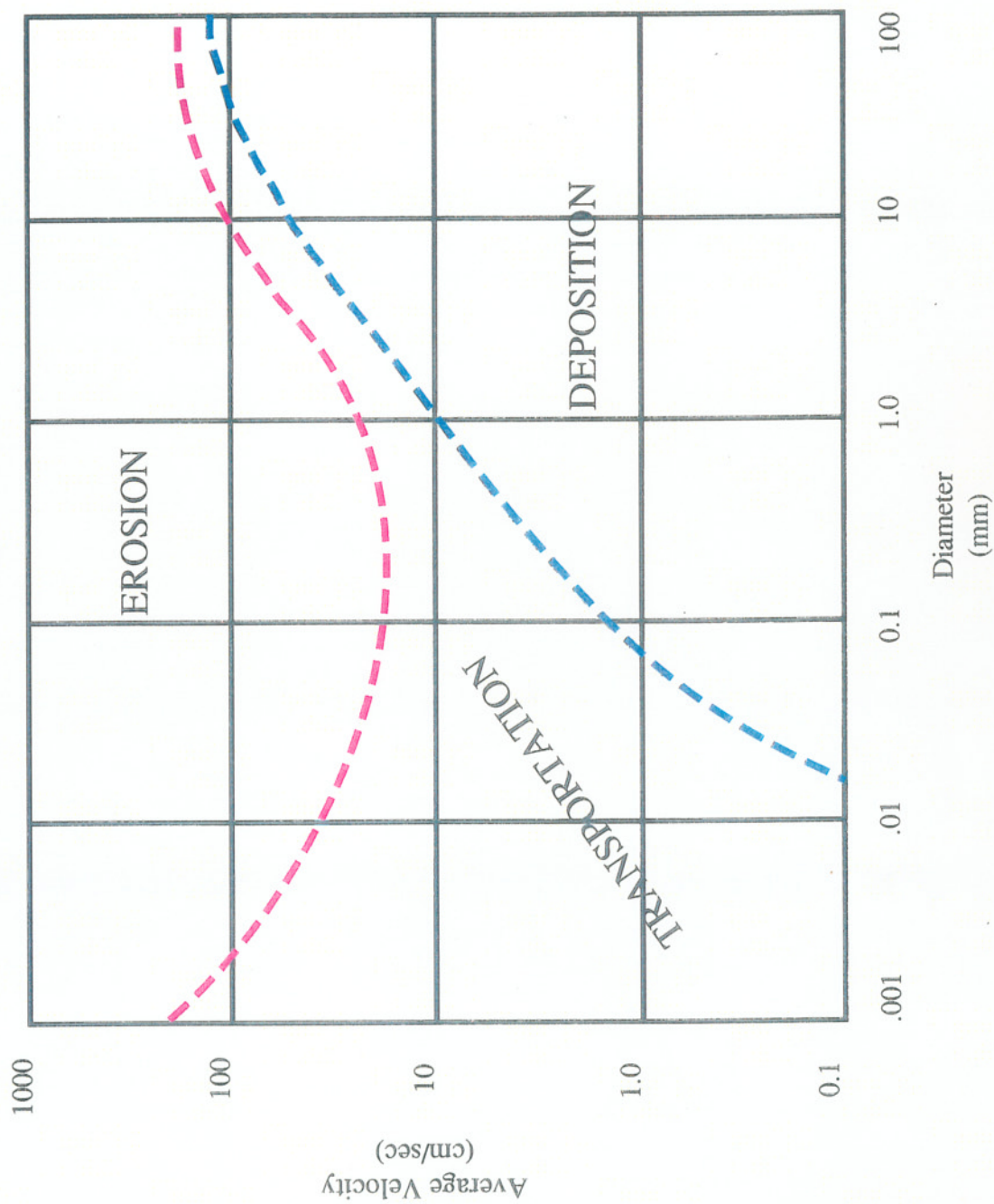
Figure 2.4 Relationship Between Erosion, Transportation, and Deposition of Sedimentary Particles
(After Hjulstrom 1939)

ROCK-STEPS

Figure 2.5

RIFFLE CHANNELS

Figure 2.6

MEANDER CHANNEL
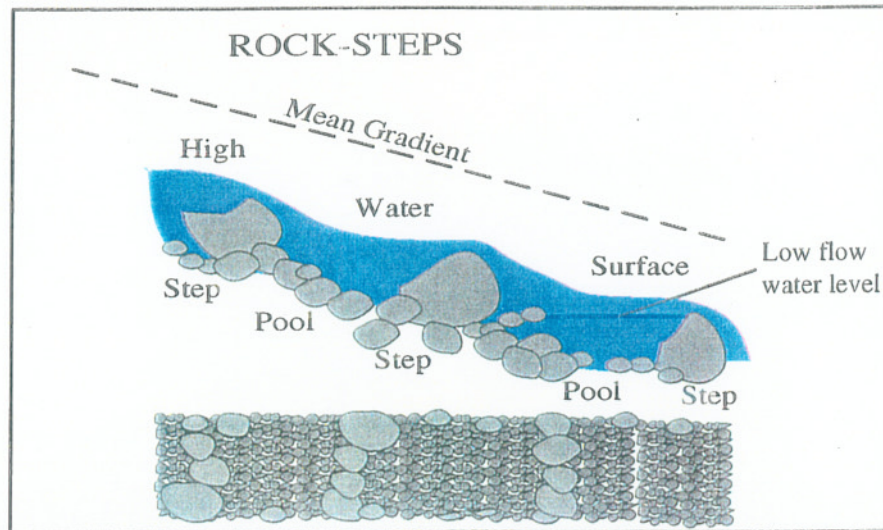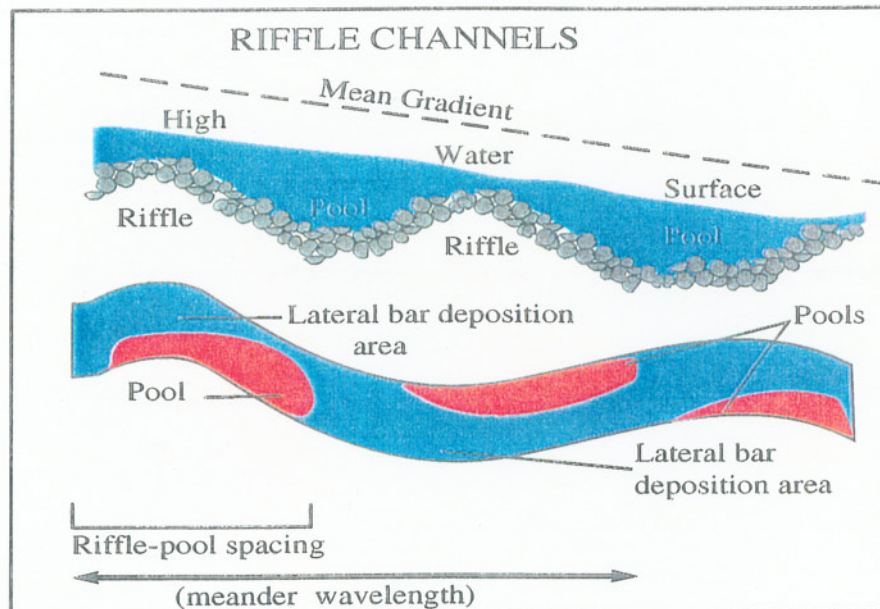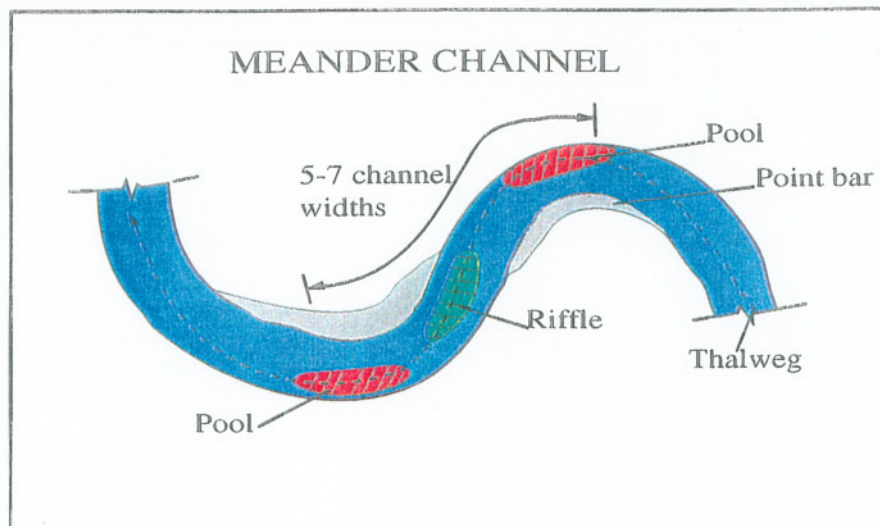
Figure 2.7

Figures 2.5 to 2.7 are adapted from Church (1992)

3.   SALMON HABITAT REQUIREMENTS

3.1   Introduction

As stated in the previous section, the physical habitat requirements of salmon vary at different stages of the life cycle. The purpose of this section is to review the literature which describes these various requirements. The freshwater phase of the life cycle has been divided into three stages for the purpose of the review, namely spawning and incubation, juvenile stages in freshwater, and the returning mature adult stage.

3.2   Spawning and successful incubation

3.2.1   Spawning locations

Mills (1989) suggests that favourable spawning locations for salmon are likely to occur where the gradient of a river is 3% or less. The preferred spawning site is the transitional area between pool and riffle where the flow is accelerating and the depth decreasing, and where gravel of suitable coarseness is present (Petersen, 1978; Bjorn and Reiser, 1991). Downwelling currents through the gravel typically occur in such locations, although areas with upwelling groundwater may also be selected as spawning sites (Bjorn and Reiser, 1991).

Wide ranges of water velocities and depths at which salmon spawn are reported. Bjorn and Reiser (1991) quote a velocity range of 25 - 90 cm/s, and depths equal to or greater than 25 cm. Beland *et al.* (1982) found that the range of velocities in which salmon were observed spawning in rivers in Maine was also 25-90 cm/s, with a mean velocity of 53 cm/s. Depths for spawning in these rivers ranged from 17 cm to 76 cm, with a mean of 38 cm. The salmon observed by Beland *et al.* (1982) were quite large, typically 4.5 kg, and the authors suggest that smaller salmon, i.e. grilse, may spawn in shallower water at lower velocities.

In an investigation into the physical characteristics of salmon spawning gravel in New Brunswick, Petersen (1978) found velocities at spawning sites ranging from 36 - 76 cm/s, typically 50 - 65 cm/s, and depths usually of 20 - 30 cm. Jones (1959) found that the most favourable water velocity for spawning salmon in an observation tank was 30 - 45 cm/s, and that salmon up to 3.2 kg in weight would spawn readily in 15 - 18 cm of water. Salmon would not spawn in the tank when the water velocity was reduced to 5 cm/s.

3.2.2   Spawning substrate

The grain size composition of gravels used by salmon for spawning varies markedly. Ottaway, Carling, Clarke and Reader (1981) investigated the structure of salmon redds in the River Wear, County Durham, and reported that the mean grain size of the lattice-work population of gravel, excluding material less than 2.0 mm, was 112.8 mm.

The percentage of material less than 2.0 mm was 8.2% by weight. At the other extreme, Kondolf and Wolman (1993) found that the median gravel sizes used by salmon in two rivers in Maine were 15 mm and 16.5 mm, with geometric means of 7.0 mm and 7.2 mm respectively. However, they also concluded, after examination of a large data set covering a range of salmonid species, that the gravel sizes actually used were determined largely by availability. This confirms an earlier observation by Jones (1959), who examined several typical salmon spawning grounds in the catchment of the Welsh Dee and found no common agreement of the various sizes of gravel.

Petersen (1978) gives a breakdown of the size composition of spawning gravels in nine New Brunswick rivers, based on the proportions of cobbles, pebbles and sand present, expressed as dry weights.

Cobble (22.2 - 256 mm)	40 - 60%
Pebble (2.2 - 22.2 mm)	40 - 50%
Coarse Sand (0.5 - 2.2 mm)	10 - 15%
Fine Sand (< 0.5 mm)	0 - 3%

Stratification was found in the gravel beds, with a higher proportion of coarse material at the top and more sand in the lower strata. Bjorn and Reiser (1991) comment that salmon have been observed spawning in areas where some substrate particles exceed 30 cm, but that typically, the majority of particles at spawning sites were less than 15 cm. For artificial spawning channels they recommend that up to 80% of the substrate should be in the range 1.3 to 3.8 cm, with the balance of sizes up to 10.2 cm.

For the successful incubation of ova and subsequent emergence of fry it is essential that there is an adequate flow of water through the gravel. For this to occur the proportion of fine material in the gravel must be relatively low. Petersen (1978) measured the permeability of gravels at salmon spawning sites in New Brunswick rivers and concluded that if the content of sand (material less than 2 mm grain size) exceeded 20% by weight, permeability was reduced to zero. He also concluded that the minimum permeability for successful emergence of fry was of the order of 1000 cm/hr, corresponding to a sand content of 12 to 15%. Roch (1994) also considers areas with a sand content greater than 20% as being unsuitable for spawning.

MacCrimmon and Gotts (1986) carried out laboratory observations on the emergence of salmon alevins relative to sediment loadings. Various proportions of a 'standard sediment' with particle sizes ranging from 0.25 to 4.0 mm were mixed with a coarser substrate known to give high alevin survival and emergence rates. At high sediment loadings (> 40%) alevins emerged prematurely when they were small and still had large yolk reserves, and were likely to be at a disadvantage compared to later emerging well-developed alevins. Other workers note that productive good quality spawning gravels have less than 5% fines (particles less than 0.8mm), unproductive gravels have >30% fines (in Nelson *et al.* 1987).

Several authors have commented that during redd construction the composition of the gravel is altered. Bjorn and Reiser (1991) noted that the spawning process dislodges fine particles from the redd, creating optimal conditions for incubation immediately after spawning. However, subsequent deposition of fine sediments can occur, which may be detrimental to both incubation and emergence of alevins as the interstitial spaces are filled with sediment. Organic matter settling into redds may reduce dissolved oxygen, as well as reducing intragravel flow of water.

Hovis *et al.* (1993) and Kondolf *et al.* (1993) make similar comments about the modification of the size distribution of gravel during redd construction, with the removal of fine sediments which are subsequently re-introduced and reduce intragravel hydraulic conductivity. Hovis *et al.* (1993) suggest that intruding particles 0.85 mm to 9.5 mm may create a seal or clogged layer within the gravel framework which may prevent deeper sediment intrusion into the redd. While adequate flow for egg survival may occur beneath the seal, fry might not be able to escape through the sealed layer. Kondolf *et al.* (1993) were able to quantify the change in the proportion of fines in the gravel as a result of spawning activity and estimated that the percentage of fines less than 1.0 mm after spawning was a factor of 0.63 of the percentage of fines before spawning. For fines less than 4.0 mm diameter, the percentage after spawning was 0.58 of the percentage of fines before spawning. The geometric mean size of particles within the redd was 1.26 times the initial geometric mean.

Although surface deposits of sediment are likely to make a substrate unsuitable for spawning, Eiler *et al.* (1992) reported that sockeye salmon may spawn in such sites where upwellings of groundwater bring enough oxygen to eggs to maintain their viability, despite heavy silt loads.

Table 3.1　　Summary of requirements for spawning and incubation

Spawning Requirements	
Flow	
i. Velocity	25-90 cm/s
ii. Depth	17-76 cm
Gravel	
i. Mean grain size	11.3 cm
ii. Percentage fines by weight	≤ 8.2
Incubation	
i. Minimum permeability	1,000 cm/hr
ii. Sand content	$\leq 20\%$

3.3　Juvenile habitat

3.3.1　Principle features determining suitable habitat for juveniles

Heggenes (1990) regarded the principal *in situ* physical habitat variables which determined suitability for juvenile salmon as water depth, water velocity, stream bed substratum and cover. Milner *et al.* (1993) used additional extensive habitat variables

such as gradient, catchment area, altitude, conductivity and channel width in their habitat model (HABSCORE) for salmonids. However, most of the studies on juvenile salmonid habitat reported in the literature have investigated one or more of the four variables identified by Heggenes.

Fry and parr densities vary considerably in natural streams, often the limiting factor being the suitability of available habitat. The National Fisheries Classification Scheme (NRA, 1994) provides a means of assessing rivers according to their fry ($<0^+$) and parr ($>0^+$) densities. The highest density category for fry is over 86 per 100 m^2 whereas that for parr is above 19 per 100 m^2, representing salmon habitat of the highest quality. Conversely, poor habitat might expect to support less than 9 fry and 3 parr per 100 m^2 respectively.

Fry and underyearling parr have been found to occupy different locations in a stream than older and larger parr, and these differences are outlined in the next section. In some areas significant differences between summer and winter microhabitats have been reported, and these are considered in Section 3.3.3 below. In addition to the seasonal changes in habitat preference, diurnal changes have also been recorded. The interactions between juvenile salmon and trout are discussed in Section 3.3.4

3.3.2   Characteristics of typical fry and parr habitat

In general, it can be said that juvenile salmon occupy shallow, fast-flowing water, with a moderately coarse substrate and with overhead cover provided by surface turbulence. Symonds and Heland (1978) found that juvenile salmon in New Brunswick streams inhabited areas with water velocities ranging from 20 - 75 cm/s, with the highest densities occurring where the velocities were 60 - 75 cm/s. Pebbly riffles without boulders (i.e. substrate particle size predominately 16 - 64 mm diameter) could be considered to be prime nursery habitat for salmon less than 7 cm long. The proportion of 0+ to 1+ age group fish decreased as depth increased between 20 cm and 40 cm, and no yearling or older parr occurred in riffles shallower than 20 cm where there were no boulders (i.e. stones > 256 mm). Experiments carried out by Symonds and Heland (1978) in artificial streams indicated that as underyearlings grew, their preference for deeper and swifter parts of riffles increased, and by the time they reached 8 - 9 cm in length, 80% - 90% chose cobble/boulder habitats (substrate size > 6.4 cm) with depths greater than 30 cm.

Bagliniere and Champigneulle (1986) found that production of juvenile salmon in the River Scorff in Brittany was concentrated in runs, riffles and rapids. Riffles, where the depth was 35 - 40 cm, the velocity greater than 40 cm/s with a turbulent surface, and where the substrate was a sand/coarse mix, were the principle habitats for underyearling fish. Rapids, which had similar depths and velocities but with a coarser substrate, were also important for underyearlings, particularly so for older parr. There was no production of salmon in pools where the depth was greater than 60 cm, the velocity less than 20 cm/s, and the substrate was sand and fine sediment. Wankowski and Thorpe (1979) also found that deep or slow moving water, particularly when associated with a sand or silt substrate, did not support resident salmonids in rivers in Central Scotland. Juvenile salmon were concentrated in riffles and fish up to 8 cm

long typically occurred where the current velocity was 20 - 30 cm/s, and 12.0 - 15.0 cm fish occurred in velocities up to 100 cm/s.

Borgstrom (1991) planted salmon fry in slow, intermediate and fast sections of a stream in south east Norway. Subsequent electric fishing surveys indicated that these fry left the slow sections, where the velocity ranged from 16.4 to 23.1 cm/s and where the mean substrate size was 0.5 - 5.0 mm. The densest populations occurred in the fast sections where the mean velocity was 39.3 - 57.0 cm/s, the depth 21.7 - 23.8 cm and the mean substrate size 90 - 143 mm. Intermediate velocity sections had densities about 50% of those of the fast sections in the first summer after planting. In the second summer there were approximately equal numbers of fish in the fast and intermediate sections, but very few in the slow sections.

Jones (1974) concluded that underyearling salmon occurred predominately in riffles less than 20 cm deep, whereas 1+ salmon occurred predominately in runs between 20 cm and 30 cm deep. Egglishaw and Shackley (1982) obtained similar results for the Shelligan Burn in Scotland, with the highest densities of 0+ and 1+ salmon occurring in stream sections where the proportion of shallow water (0 - 20 cm deep) was greatest.

Bagliniere and Arribe-Moutounet (1985) studied the micro-distribution of trout and juvenile salmon in the Upper Scorff, Brittany. Salmon density increased with water velocity, and favoured habitat was a depth less than 23 cm, a current velocity of 61 cm/s, and a stony substrate.

Although many authors quote figures for velocities which are based on surface or water column measurements, several authors stress that the critical velocity is the snout (nose) or focal velocity, i.e. the actual velocity at the precise location of the fish (Bird et al, 1994). De Graf and Bain (1986) showed that in fast-flowing rivers, both young of the year and parr selected nose velocities lower than the mean value of the available habitat, and in slow-flowing rivers, both age groups selected nose velocities greater than the average of available values. De Graf and Bain (1986) concluded that nose velocity was the principal factor determining summer habitat selection by juvenile salmon. Heggenes (1990) also considered that snout velocity is likely to be the most important factor determining location, and reported that there is apparently a close relationship between fish size and snout velocity, with underyearlings less than 7 cm selecting 5 - 20 cm/s velocity, 7 - 10 cm fish selecting 5 - 25 cm/s, and fish larger than 10 cm selecting 15 - 25 cm/s.

Shustov (1990) quotes figures obtained from studies in rivers on the Kola Peninsula. Underyearling salmon were found where the surface velocity ranged from 20 - 80 cm/s, mean 55 cm/s, but near the bed, at the fish location, velocities ranged from 0 - 45 cm/s, mean 18 cm/s. For older parr, surface velocities up to 140 cm/s were recorded, mean 64 cm/s, but at the microhabitat of individual fish, velocities ranged from 0 - 60 cm/s, mean 28 cm/s.

Morantz et al. (1987) carried out direct underwater observation on locations of individual juvenile salmon in streams in Nova Scotia and New Brunswick.

Measurements of velocity were taken at the fishes nose position and in the water column. The mean nose velocity for fry less than 65 mm long was 12.1 cm/s, and the water column velocity and depth was 31.6 cm/s and 35.1 cm respectively. For small parr 65 - 100 mm long, the measurements were nose velocity 19.0 cm/s, mean column velocity 39.9 cm/s, and depth 46.7 cm. For large parr greater than 100 mm the mean nose velocity was 21.6 cm/s, mean column velocity 34.8 cm/s and depth 46.8 cm. Fry showed a preference for gravel substrates, and parr for gravel plus cobble. Morantz *et al.* (1987) concluded that juvenile salmon can tolerate a relatively wide variety of depths and substrates, but that water velocity near the stream bed, i.e. nose velocity, is the dominant physical factor influencing selection of microhabitat by juvenile salmon. They considered that selection of habitat near the stream bed, where velocity is low, but close by faster velocities had high 'profitability'. This is because the availability of drift food is good, but the energy required to hold station is relatively low.

Rimmer *et al.* (1984) also gave values for preferred focal (i.e. nose) velocities of juvenile salmon during the summer months, with 0+ fish selecting 10 - 30 cm/s, 1+ fish 20- 40 cm/s, and 2+ fish 30 - 50 cm/s. Wankowski and Thorpe (1979) suggested that the ability of larger fish to maintain position in faster currents fulfilled to some extent their increased food requirement, as they would receive more drift food.

In-stream cover provided by varied substrate size composition is important for juvenile salmon. Mills (1989) suggested that this provides obstruction to vision between neighbouring parr and reduces territorial aggression. Large substrates also provide velocity shelter for holding station adjacent to faster drift food currents. Bjorn and Reiser (1991) and Heggenes (1990) both listed the habitat variables constituting cover as water depth, surface turbulence, loose substrate, large rocks and other submerged obstructions, undercut banks, overhanging vegetation, woody debris lodged in the channel, and aquatic vegetation. Heggenes and Traaen (1988) carried out experiments in troughs with artificial cover provided by plastic plates. Salmon fry demonstrated a pronounced preference for overhead cover which was strongest at low water temperatures. Brown trout fry also had a positive response to overhead cover, but less strong than that of salmon. Two week fed fry of both species showed lower preferences for overhead cover than swim-up fry.

Heggenes (1990) considered the substrate preferences of young salmon, and concluded that young salmon avoid areas with a substrate finer than pebble grade, i.e. less than 16 mm. A variety of substrate sizes was required, with underyearling parr preferring pebble up to cobble (16 - 64 mm) and older parr cobble up to boulder (64 - 256 mm) or even larger. Heggenes also noted that the substrate needs to be coarse enough to provide sufficient interstices for shelter in winter. Although small parr showed a strong preference for overhead cover, particularly at low temperatures, given the choice between shade and deeper water (>50 cm), larger parr preferred the latter.

Haury *et al.* (1995) found that in a tributary of the River Selune in Normandy, juvenile salmon preferred the shelter afforded by a coarse substratum, whereas older trout preferred that given by bankside vegetation. The effects of deciduous bankside vegetation on salmonid stocks in Irish rivers was studied by O'Grady (1993). He found that the mean juvenile salmon stock density in the heavily shaded areas was only

19.4% of that found in comparable open zones. For trout, stock density in heavily shaded areas averaged only 28.5% of that in unshaded areas. He attributed this reduction to the loss of aquatic floral cover such as epiphytic algae, mosses and aquatic macrophytes, as a consequence of the 'tunnelling' effect and excessive shading of the river bed by the dense bankside deciduous shrubbery. O'Grady recommended selective clearance of excess shrubbery, but leaving partial shading to prevent over-proliferation of aquatic macrophytes. Bjorn and Reiser (1991) warn against excess removal of riparian vegetarian cover, as this may result in excessive warming in summer by more exposure to the sun, particularly in small streams.

Table 3.2. Summary of typical habitat characteristics of juvenile salmon. The table is a synthesis of personal experience and data from the literature review but deliberately excludes extreme values from rivers outside the UK.

	Habitat Requirements
Fry and Underyearling Parr	
Water Depth	≤ 20 cm
Velocity	50 to 65 cm/s
Substrate Type a. Summer	Gravels and cobbles (16 to 256 mm)
b. Winter	Cobble up to boulder (64 to 256 mm)
Yearling and Older Parr	
Water Depth	20 to 40 cm
Velocity	60 to 75 cm/s
Substrate	Cobble up to boulder (64 to 256 mm)

3.3.3   Autumn and winter habitat of juvenile salmon

The majority of studies on the microhabitats of juvenile salmon have described the distribution and location of the fish during the summer months. However, several workers have noted that changes in habitat utilisation take place and that the fish are no longer visible when the water temperature falls in the autumn. Mills (1989), reporting on studies carried out by other workers on Scottish rivers, states that juvenile salmon leave the shallow riffle habitats during the colder months and that the fish move into deeper water in pools, re-appearing in the shallow water when the temperature rises to 6 - 7 °C in spring. Bjorn and Reiser (1991) also state that juvenile salmon move into deeper water and hide when the temperature drops below 10°C.

Rimmer *et al.* (1983, 1984) carried out detailed studies on the autumnal habitat shift of juvenile salmon in the Little Sevogh River, New Brunswick, using direct observation by snorkel divers. In summer, fry and parr maintained position over a 'home stone' in riffles and runs. When the temperature fell to 9 - 10°C in late September/early October almost all the fish disappeared from the stream bed surface and were found hiding in chambers beneath cobbles and boulders on the stream bed. However the overall distribution of the fish between riffles, runs and pools remained the same as in summer, with 76.8% in the runs, 19.1% in the riffles, and 4.2% in the pools. There was in fact some evidence that 1+ parr actually moved from pools to runs in autumn,

possibly because the silted nature of the pools restricted the availability of substrate chambers for hiding. The fish re-emerged and were visible on the stream bed surface when the water temperature rose to 10 °C in mid-May.

The 'home stones' with which fish were associated tended to be larger in winter than in summer, typically 20 - 30 cm, compared with 6.4 - 6.7 cm. However the focal (nose) velocities measured were typically less than 10 cm/s in winter, whereas in summer they ranged from 10 to 50 cm/s. Rimmer et al. (1984) recommend that to enhance autumn and winter suitability for salmon, the substrate should be roughened by the addition of large (>20 cm) unrounded stones where the water depth in winter is 24- 36 cm, the velocities 10 - 60 cm/s, and the substrate is not silted.

Cunjak (1988) investigated the behaviour and winter microhabitat of young Atlantic salmon in the South River, Nova Scotia, and his findings paralleled those of Rimmer et al. (1984). Observations were again carried out by snorkelling, and all the juvenile salmon seen were hiding under rocks, typically in water depths of 40 - 50 cm and with mid-column water velocities of 38 - 46 cm/s. The 'home stones' with which the fish were associated were typically 17 - 23 cm diameter, usually loose on the bottom rather than compacted, and concentrated towards mid-stream. Examination of stomach contents showed that the fish were feeding throughout the winter.

Rimmer et al. (1984) investigated the effects of temperature and season on the position holding performance of Atlantic salmon. These studies showed that yearling salmon were able to maintain much higher critical holding velocities during the April to October period, with an optimum performance when the temperature was in the range 7.5-8.5°C to 15°C. Rimmer et al. postulated that the young fish move to sheltered areas in the autumn when the temperature drops and performance ability is reduced so as to conserve energy, making only brief forays into faster water to feed.

3.3.4 Interactions between juvenile salmon and trout.

Several workers have reported that juvenile salmon and trout appear to show different habitat preferences, with the salmon typically inhabiting shallower and faster water than juvenile trout. For example, Bagliniere and Arribe-Moutounet (1985) in studies on the River Scorff in Brittany found that salmon fry typically occurred in water less than 23 cm deep, with a current velocity of 61 cm/s and were usually located in mid-stream. In contrast, 0+ trout were absent from the shallow riffles and occurred in deeper running water with mean velocity 41 cm/s, and were located along the banks. Heggenes (1990) also reported spatial segregation between 0+ salmon and 0+ trout, and found microhabitat segregation between large parr and trout, with salmon occupying the faster stream regions.

Kennedy and Strange (1981, 1986a, 1986b) have studied these distributions in detail in the River Bush system in Northern Ireland in situations where salmon were living in sympatry with trout, and where they were in allopatry. In sympatric situations, both 0+ age group salmon and trout occurred predominately in water less than 20 cm deep, but the trout fry tended to be in slightly deeper water than the salmon. Yearling salmon also tended to occur in shallower water than yearling trout. Salmon fry were

significantly more abundant in high gradient riffle areas, and older trout were significantly less abundant in shallow and high gradient areas. Under conditions of allopatry, the distribution of salmon fry changed, and they became negatively correlated with water less than 25 cm deep, and positively correlated with deeper water greater than 25 cm.

Kennedy and Strange concluded that the majority of salmon fry do not live in shallow areas by choice under sympatric conditions, but are restricted to those areas by competition from older fish. In the absence of inter-specific competition from trout and intra-specific competition from salmon parr they will live at high densities in all depth ranges, but with a preference for a mid depth range of 15 - 30 cm.

Preferences in relation to gradient mirrored those shown for depth, and in allopatry 0+ salmon avoided higher gradient faster flowing areas, compared with their distribution in sympatry with trout. However, there was no evidence that inter-specific competition from trout had a significant effect on the distribution of salmon parr. Kennedy and Strange suggest that the larger pectoral fins of juvenile salmon enable them to utilise habitat which trout cannot readily utilise.

Heggenes (1990) reported similar differences between salmon distributions in sympatric and allopatric situations to those found by Kennedy and Strange, with salmon in allopatry tending to occupy the areas dominated by trout when in sympatry.

3.4   Adult habitat requirements

There is a paucity of information in the literature relating to the habitat requirements of adult salmon. Most of the information is derived from the angling fraternity. The major requirements are that spawning and nursery areas are accessible to adult salmon, and that there are adequate holding areas to provide security for these large fish.

Bjorn and Reiser (1991) discuss the ability of salmon to negotiate barriers to upstream migration. They conclude that leaping conditions at falls are ideal when the ratio of the height of the fall to the depth of the pool below is 1:1.25. Obstacles 2 - 3 m high can be surmounted by salmon. Where obstacles are impassable because of their height or inadequate take-off depths an appropriate fish pass will be needed. Beach (1984) gives an authoritative account of the types of fish pass and their specification which are approved for use in England and Wales, see Section 6.4.1.

Bjorn and Reiser (1991) mention the role of debris jams in preventing or delaying upstream migration, but warn that their removal should be done with care to avoid sedimentation of downstream spawning and nursery areas. In addition, woody debris has been found to provide a significant amount of instream cover for salmon, increasing habitat diversity.

Cover for salmon waiting to spawn can be provided by overhanging vegetation, undercut banks, submerged vegetation, submerged objects such as logs and rocks, floating debris, deep water, turbulence and turbidity (Bjorn and Reiser, 1991). If the

holding pools and spawning areas have little cover, the fish present will be vulnerable to disturbance and predation over a long period of time. Bjorn and Reiser (1991), suggest that the proximity of cover to spawning areas may be a factor in the selection of spawning sites by some salmonid species.

The size of a redd will be dependant upon the size of the spawning fish, although an average size would be 3 m by 1 m for a 2.8 kg female salmon (Crisp and Carling, 1989). However, in order that each pair of spawning salmon do not interfere with the spawning activity of nearby fish a larger area is required. Beall and Marty (1987) discuss optimum fish densities for use in artificial spawning channels and estimated that the amount of space required by a singe pair of Atlantic salmon for spawning was 9.5 m^2.

3.5   The value of a riparian zone to salmon fisheries

The implications of riparian management for salmon fisheries are well documented (Hynes, 1970; Kerr & Schlosser, 1978). Riparian zones help to strengthen and maintain river banks and create habitat diversity not only for salmon but for adults of various invertebrates that act as a fish food source (Haury *et al.*, 1995).

Riparian areas also act as natural filters, minimising physical and chemical effects from overland runoff; the buffering capacity depending on the type and density of vegetation growing, as well as the width used as a buffer zone. Their effects are particularly beneficial in times of low flow where the dilution of runoff water will be at its lowest (RSPB *et al.*, 1994). In addition, during the summer, plant growth will reduce channel width, concentrating flow and increasing water depth, thus maintaining the viability of the habitat in times of low precipitation. In winter, the plants will die back, and will therefore not present a flood hazard during higher flows.

A degree of overhanging foliage shades the water (limiting high summer water temperatures) and provides areas of cover for salmon and invertebrates. Riparian vegetation increases juvenile salmon food availability in two ways; firstly, terrestrial invertebrates can fall directly from the vegetation into the water; secondly, they are required for the mating of adult invertebrates and thus are essential to sustain expanding invertebrate populations. The leaves and stems are also a major source of allochthanous detritus, a food source of many invertebrates and are also colonisable microhabitats for epiphytic algae (a further significant food source of invertebrates). Ormerod *et al.* (1986) reported that the type of vegetation adjacent to a stream can greatly influence the number of invertebrates falling into the stream which are available to fish as food. They concluded that bracken and heather produced the greatest number of invertebrates available to fish, followed by deciduous woodlands and finally coniferous plantations.

3.6   Summary

From the various studies reported in the literature it is possible to compile a picture of an 'ideal habitat' to optimise the production of juvenile salmon, and hence ultimately of returning adults. It should be noted that the ideal habitat quoted for each of the different life stages may vary with the different river types described in Chapter 2.

3.6.1   Spawning

The optimal condition is stable gravel with a good lattice framework of grain sizes in the pebble to cobble size range of 16 mm to 256 mm, but with the majority of particles less than 150 mm. Material of grain size less than 2.0 mm should not exceed 20% by weight, and preferably should be less than 12 - 15% to ensure adequate permeability. Water depth over the gravel should be at least 15 cm, but not greater than 75 cm. Velocities should be in the range 30 - 70 cm/s. There should be either downwelling or upwelling of water through the gravel.

3.6.2   Fry and underyearling habitat

Water depth should be around 20 cm or less, especially where trout are also present. This depth may increase in chalk streams (up to 40 cm). Although focal (nose) velocity is likely to be the key feature, this is difficult to measure. However, water column velocities in the range 20 to 75 cm/s are likely to provide suitable velocities near the stream bed. Substrate should be made up of pebbles and cobbles in the size range 6 to 64 mm, without boulders for summer habitat. However to provide suitable winter habitat there should be riffle and run areas with 20 to 46 cm diameter stones. Riparian vegetation should not be so extensive as to cause 'tunnelling' and loss of aquatic flora production, although some shading is beneficial to ameliorate temperature changes.

3.6.3   Yearling and older parr

Water depth should ideally be in the range 20 - 46 cm, with water column velocities of 25 -100 cm/s, the lower values being typical of chalk streams. The substrate should be coarse, predominately cobble and boulder in size, ranging from 64 mm to 256 mm to provide adequate cover. Riparian vegetation again should not be so extensive as to cause excessive shading.

The proportion of underyearling to older parr areas needs to be such that there is adequate space for both categories. Symonds and Heland (1978) suggest that the amount of nursery habitat required to produce sufficient underyearlings to fill the rearing habitat to capacity is unlikely to exceed 25 - 28% of the total rearing area.

3.6.4   Adults

Free access to the spawning areas is essential, and with adequate secure holding areas for adults adjacent to the spawning areas. Obstacles should not exceed a vertical height of 3 m. In order for salmon to successfully negotiate an obstacle with a vertical height

of Y m, the plunge pool directly below the obstacle, needs to have a depth of 1.25 x Y m. The area available for spawning should be a minimum of 9.5 m^2 per pair of spawners.

4.   CRITICAL FACTORS LEADING TO DETERIORATION

4.1   Introduction

Having examined the habitat requirement of the various life stages of salmon in riverine systems, this section provides details of the critical factors which lead to habitat deterioration necessitating remedial action.

Freshwater habitats may be modified as a result of natural changes in river channel and climate but by far the largest impact is human use of the river and the surrounding land. In the UK adverse effects are predominately related to construction work within channels (e.g. flow-regulation or flow-diversion schemes) forestry, land drainage, agricultural management and mining.

Environmental changes include:-

- Obstructions to Migration
- Temperature Changes.
- Chemical Changes.
- Dissolved Oxygen Variations.
- Mechanical Shock.
- Gravel Composition.
- Siltation.
- Low Flows.
- High Flows.
- Hydrological Manipulations.
- Riparian Land Use.

Many of these aspects are closely related. The treatment below is therefore divided into categories for convenience only, as the effects may be contiguous.

4.2   Temperature changes

Water temperature determines both the period of incubation of salmonid eggs and thus the time of emergence, and the subsequent development rate of alevins. However, the temperature within a spawning bed is not necessarily the same as that in the freely flowing stream water. Crisp (1990a) has shown that temperature gradients and fluctuations persist to depths of 40 cm to 50 cm in spawning gravels. These depths include the range of depths to which salmonids habitually deposit eggs in redds. Temperature within spawning beds is mediated by the porosity and the hydraulic conductivity of the gravel. Direct impacts on porosity, including compaction and long-term changes in the flow regime, are the largest cause of changes to intragravel temperature. Webb & Walling (1993) examined the temporal changes in thermal regime owing to river regulation in south-west England. They concluded that brown

trout (*Salmo trutta*) would emerge from the gravel 57 days earlier than when compared to trout from unregulated streams and, would weigh up to 67% more by the end of the year. Such temperature-mediated changes in the date of emergence and growth could be beneficial but may be deleterious if, for example, alevins emerge at a time when food is not available. Papers concerned with the effect of temperature on salmonids during low flows are reviewed by Crisp (1995), whilst Jensen (1990) and Jensen *et al.* (1989) consider the effects of temperature variations on the growth of brown trout and Atlantic salmon from hatching to initial feeding.

4.3   Water chemistry

Salmon are clearly susceptible to occasional spills of pollutants but may also be affected by chemical changes in the water owing to land-use changes. A principle effect of forestry activity is to increase the output of fertilisers such as nitrate and phosphate during initial site fertilisation and again during clear-felling operations when soils are disturbed (Binkley *et al*, 1993). The risk is enhanced if operations coincide with intense rainfall.

Upland drainage is practised both by foresters and agriculturists. The mobilisation of nutrients from peat, for example, owing to the cutting of moor-drains is well-known although the effect on salmon is less clear. Coloration and change in the smell of water may disorientate migratory salmon, but there are few data concerning effects such as increased acidity or toxicity (Omerod *et al.*, 1989). Atmospheric fluxes of numerous organic compounds have increased in recent decades and these compounds tend to accumulate in peat soils (Winkler & DeWitt, 1985), and are subsequently released when mechanically disturbed or subjected to oxidation. There is some evidence from Northern Ireland of an increase in water acidity and toxicity, owing to peat drainage, which may have impacted salmon populations (Bayfield *et al.*, 1991). A peat landslide owing to poor land management in the Pennines resulted in a large increase in suspended solids, iron, aluminium and lead whilst pH dropped in receiving waters. A salmonid fish kill resulted but this was attributed to direct choking and deoxygenation rather than toxicity (McCahon *et al.*, 1987).

More recently, concern has been expressed about the release of fulvic and humic acids and organic compounds from timber resins during forestry harvesting (Scrivener & Brownlee, 1989; Bowman & Bracken, 1993) but there is little information available for the UK (Adamson *et al.*, 1987). Concern also exists with respect to waste products from fish farms.

4.4   Dissolved oxygen

It is generally recognised that oxygen concentrations should not fall below a single-day mean of 8 mg/l of O_2 for spawning fish, although 5 to 6.5 mg/l is acceptable to adult fish (Binkley & Brown, 1995). Large quantities of organic fine sediment or woody logging-debris can reduce oxygen levels by increasing the Biochemical Oxygen Demand (BOD).

Fine sediment blanketing the surface of gravels may also impede the diffusion of oxygen down towards eggs and alevins. Laboratory and field studies have shown that the survival of salmonid eggs and alevins varies during development. There are a number of studies for North American species but few data for Atlantic salmon. Salmonid eggs appear to be able to withstand O_2 levels of 2.5 mg/l (Blaxter, 1969), although levels as low as 0.76 mg/l have been reported as having no deleterious effect during early stages of incubation. However, minimum requirements increase to 10 mg/l near to hatching. Further, the oxygen supply-rate limits the transfer of oxygen to the embryo, so that the critical threshold concentration is dependent on the intragravel flow velocity (Daykin, 1965). Studies on the supply rate are few (Daykin, 1965; Wickett, 1975; Turnpenny and Williams, 1980) and only Hayes *et al.* (1951) consider Atlantic salmon in detail. Effects of low oxygen concentrations can also be divided into lethal and sub-lethal.

4.5   Mechanical shock

Mechanical shock to salmon eggs can occur primarily by two means. Natural floods may disturb the gravels such that eggs are jiggled *in situ* or are washed-out and drift downstream (Crisp, 1990b). Disturbed eggs are subject to greater mortalities (Jensen & Alderdice, 1983), although the sensitivity of eyed eggs is not especially acute (Crisp & Robson, 1985). Eggs will also be disturbed by direct mechanical excavation or by traffic crossing the spawning beds; although nothing is known of these effects, they may be presumed to be deleterious.

4.6   Gravel composition

Consequently, changes in flood dynamics might alter both the size of gravels available for spawning and the depth to which gravels are turned-over and eggs washed-out (Milner *et al.*, 1981). The exact composition of gravel resulting from natural forces or human intervention also determines the ability of alevins to emerge from the gravel beds (Peterson & Metcalfe, 1981).

Construction of reservoirs or other structures across rivers usually limits the natural flux of gravel through the reach of river immediately downstream of the impoundment, and flow regulation also prevents periodic natural floods loosening the river bed. As a consequence, the river bed tends to degrade and to coarsen. This leads to an evacuation of much finer spawning gravel and coarsening and compaction of the residual material (Reid *et al.*, 1985), such that it is of little use for spawning. Great care needs to be taken during the commissioning and operational phases of impoundment management to avoid excessive discharges (tests on valve or turbine performance for example) have been known to damage salmonid spawning gravels downstream of UK impoundments (Hey, 1986; Neill & Hey, 1982).

4.7   Siltation

Siltation of spawning gravels is a particularly common risk owing to disturbance in the catchment by activities such as forestry, agriculture and mining (Herbert *et al.*, 1961).

Naturally, most spawning rivers in the UK would have suspended concentrations of sand, fine silt and clay of less than 5 mg/l during low flows and indeed may be essentially clear-water rivers. During high flows, concentrations may rise to *circa* 100 mg/l but rarely do natural concentrations rise above this level. High concentrations in the water may physically choke fish or, at the least, disrupt feeding behaviour (Barrett *et al.*, 1992).

Furthermore, Servizi and Martens (1991) observed that suspended particles have a deleterious effect on the health of young salmon, abrading their exterior (leaving them more susceptible to infection and parasitism) and impairing gill function and thus oxygen transfer ability. Tolerance to suspended solids is reduced when other factors such as low oxygen saturation levels and small body size are present.

Tolerance to suspended particles has been found to be temperature dependent with a 96-h LC50 mortality being greater at lower temperatures (Servizi & Martins 1991). This has implications when an increase in turbidity is found in deeper rivers or where tunnel vegetation is dominant as the reduced euphotic zone limits heat transfer in the water and thus temperatures are reduced.

Construction work in channels, such as deepening by dredging (Carling, 1995) or pipeline-crossings (Neill & Hey, 1992), can elevate concentrations to many thousand mg/l. As access is needed to the channel for machinery, construction work is nearly always scheduled for the summer when low-flows occur. This means that the flows are incapable of transporting the fine sediment which blankets the river bed close to the source. It is often thought that if the current is strong enough to suspend the sediment then it will not deposit within salmonid spawning beds. However, turbulence pulses effectively inject fine sediment into the pore-space between gravel particles. Once the fines settle below the top layer of gravel they cannot be re-suspended unless the gravel is turned-over by floods or by artificial mechanical action. The fines smother salmonid eggs by preventing intra-gravel currents (Moring, 1982; Thibodeaux & Boyle, 1987) and, by clogging the gravel pores at the surface of the riverbed, prevent alevins from emerging (Phillips *et al.*, 1975; Hausle & Coble, 1976) or effect emergence dates and the robustness of the alevins (MacCrimmon & Gotts, 1986; Olsson & Persson, 1988). Excessive organics washed into the sediment, especially those derived from peatland drainage, are also injurious, inducing deoxygenation of the intragravel environment (Olsson & Persson, 1986).

4.8   Low flows

Low flows may occur naturally, owing to drought, but adverse effects may be exacerbated by human activity. River regulation and water transfers generally reduce floods and sustain low flows over longer periods than occur naturally. However, forestry, agricultural and urbanisation practices may influence low flow levels. For example, land drainage may help sustain base-flows in rivers but generally appears to accentuate hydrograph peakedness such that flood levels are accentuated for short periods of time, in contrast to lower peaks with a longer time-base. This can mean that periods of exceptionally low flows will increase in catchments that have been artificially drained.

Low flows may result in elevated water temperatures and deoxygenation during summer periods, causing salmon kills (e.g. Brooker *et al.*, 1976), especially amongst the 0+ cohort (Cowx *et al.*, 1984). Additional effects include stranding of fish redds such that the egg pockets are dewatered and the eggs die. In winter there is the possibility that exposed shallowly, inundated or drained spawning gravels may freeze and destroy fish eggs or alevins.

Prolonged low flows caused by drought, abstraction or river regulation reduce depth and wetted areas, reducing the availability of certain habitats. For salmon, this can include loss of spawning areas which 'dry-out', loss of juvenile rearing habitat (De Graf & Bain, 1986) and loss of 'living-room' (Cowx *et al.*, 1984; Giles *et al.*, 1991). Flows may also be insufficient to draw adult fish into the river or allow unobstructed passage to headwaters.

Bohlin (1977) has suggested that as trout fry tend to inhabit shallow areas of streams, the 0+ cohort is more likely to be adversely effected by low flows which cause shallows to dry-out. Large trout have different distributions. The degree of density-dependent mortality of the 0+ class then depends on the specific competition which develops between different age cohorts. Owing to the complexity of life-stage interactions it is usually necessary to resort to models such as PHABSIM to determine acceptable minimum flows (e.g. Petts *et al.*, 1995).

4.9   High flows

The movement of gravels during natural or controlled high flows can cause the erosion of spawning beds and the downstream drift of salmon eggs and alevins, usually associated with high mortality (Crisp, 1995). As a general rule, eggs buried at depths of 5 cm will be scoured away during floods, whilst there will be variable loss at 10 cm depth and negligible loss at 15 cm depth. As larger fish bury their eggs more deeply, it is clear that small salmon in particular are vulnerable to egg wash-out from redds.

There is anecdotal evidence that spates in many UK rivers (e.g. the River Severn, River Ure, River Swale) are becoming more flashy i.e. higher peaked hydrographs with a shorter time-base. The existence and causes of such changes are disputed and have not been adequately addressed from a scientific perspective. Altered hydrograph characteristics have been attributed to changes in land-use, including an increase in field and moorland drainage, as well as changes in vegetation, which are more evident in recent decades due to the stocking density of sheep in the uplands.

Flashier spates mean that more power is exerted on the river bed, causing erosion of spawning gravels and bed-level degradation. Such changes are believed to have occurred widely, for example in the Rivers Wyre and Lune in Lancashire. Higher energies lead to the coarsening of river beds such that gravels are no longer suitable for spawning. Additionally, changes in the hydraulic regime may be disadvantageous to salmon. Indirectly, in some rivers degradation can result in lateral instability with increased frequency of riverbank erosion, with resultant inputs of undesirable fine sediment into the river course (Hey, 1986).

Sudden and unnatural discharge fluctuations mediated by flow regulation also cause problems, including the injection of fine sediment sourced from reservoir deposits (Erman & Lignon, 1988) and the displacement of the habitat use by juvenile salmon (Heggenes, 1988). The availability of some areas of coarse sediments increases the possibility that salmon can maintain station by resting in the lee of large rocks, but usually there is a net outward migration if fluctuations persist (Ottaway & Clark, 1981; Heggenes, 1988).

4.10   Hydrological manipulations

The manipulation of hydrological parameters such as water routeways (e.g. overland, base and channel flow), and channel efficiency have direct implications upon salmon populations as they will invariably alter habitat characteristics. Work of this type tends to focus upon aspects of river management, such as flood prevention, floodplain drainage, reduction of bank erosion and the maintenance of navigation systems. These objectives have largely been achieved by the use of 'hard' engineering techniques (Brandon, 1987).

The deepening of river channels aims to reduce flood periodicity, however, as a consequence, channel diversity becomes degraded, with a loss of valuable salmon habitats such as riffles and pools. Due to the rapid transition from a continually wet channel to dry banks and a localised lowering of the water table, a loss of riparian vegetation and nearby wetland areas occurs (RSPB *et al.*, 1994). The result is a greater risk of bank collapse which will increase downstream channel sediment flux.

The straightening of river channels increases channel gradient by providing a shorter path. This may result in a greater potential for the transport of sediment from the upper catchment of a river than is actually supplied to it. The consequence of this is the erosion of the channel bed, progressing upstream as a 'nick point', in order to supply more sediment (Parker and Andres 1976) with an increased deposition of material in downstream reaches. Erosion, of this type, has the potential to degrade salmon spawning habitats, as the nick point progresses upstream. In addition, downstream gravel beds will be subjected to higher sediment loads.

An alteration of channel cross-sectional shape to a trapezoid is undertaken to maximise channel efficiency, as it minimises the channels wetted perimeter. This engineering technique has been widely used to reduce the risk of flooding as it increases the velocity of discharge, removing objects likely to cause the formation of debris dams (such as marginal scrub). The practice has been widespread in Ireland with a concomitant loss of salmon habitat (O'Grady, 1991b). The result is a homogenous channel bed with a paucity of habitats suitable for salmon. Typically these are seen as deep glides which harbour little or no primary production. Salmon food resources such as invertebrate communities suffer as a result of this change, as do the salmon themselves.

A loss of riparian vegetation and an increased potential for the water to transport sediments, including spawning gravel can result from this type of channel alteration. The effects are magnified during flood events.

4.11 Obstructions to migration

Obstructions to migration can be permanent habitat features such as impassable falls, temporary natural features such as trash dams, or engineered structures such as dams, weirs, fords and culverts. The location of obstructions in relation to spawning areas available upstream is obviously an important consideration.

Natural obstructions caused by trash dams are becoming more widespread as manpower constraints have resulted in reductions in routine river maintenance. However, wholesale removal of woody debris is not now regarded as advantageous (House & Boehne, 1986), experience from North America revealing that as a consequence stream productivity can be severely diminished.

4.12 Riparian land use

4.12.1 Erosion and the collapse of river banks

The removal of riparian vegetation (e.g., flood protection works and excessive grazing see 4.12.2) can lead to river bank instability, once plant roots decay and their soil binding ability is lost. A direct result is the increased susceptibility of river banks to being undercut and their premature collapse into the channel. The slumping of banks in this way leaves a vertical face of exposed sediment behind (a 'river cliff') which is susceptible to other forms of erosion and weathering. The steep angle of the bank severely hinders the regrowth of marginal macrophytes (Richards, 1982), which would otherwise protect the bank. The lack of a well developed transitional zone and the resultant instability of the bank raises the probability of an increase in the sediment load to the channel.

An increase in sediment flux, especially at times of low flow, will increase turbidity of the water. In turn, this will reduce the primary productivity of epiphytic algae, reducing invertebrate densities and hence fish carrying capacity. In addition, an increase in sediment flux could result in the siltation of salmon spawning areas, (Kondolf and Wolman, 1993).

The widening of channels through bank collapse can reduce the velocity of flow as a consequence of the increase in cross-sectional area, reducing turbulence. In turn this will reduce the movement of water through the gravel beds and increase the siltation. In periods of low flow, the exposure of mid-channel bars can cause the migration of the channel, as the main current is deflected away from its original course. In this way, braiding of the channel can become established with the effect of exposing gravel banks and the consequential desiccation of redds and mortality of salmon eggs. In addition, the excessively shallow channels caused by braiding are of little use as juvenile nursery areas and, as such, the overall rearing capacity of the reach will be reduced.

4.12.2 Grazing and loss of riparian zones

Various authors describe the negative impact of grazing on riparian vegetation, stream cover and erosion (Duff, 1977; Platts *et al.,* 1983 and Platts & Nelson, 1985). If grazing is allowed right up to the river bank, then riparian buffer zones (see section 3.5) will be lost as they typically present a more lush and attractive pasture to the cattle than the adjacent land. As a result, the buffering capacity of the system is reduced and agricultural runoff can enter the river directly, with a subsequent and immediate impact on water quality.

Heavily grazed grasses put all their energy into above ground growth at the expense of the development of the root system. The binding and consolidation effect of root systems is therefore reduced, rendering heavily grazed riparian zones more susceptible to direct degradation by erosion and indirect effects exacerbated by trampling and bank collapse.

Grazing pressure on marginal shrubs and trees can lead to their horizontal growth over the water as this is the only direction in which successful growth can occur. Asymmetrical growth of trees may lead to their collapse into the channel as they become more and more overbalanced. This scenario is accentuated where bank erosion and undercutting also occurs, exposing and undermining tree roots.

Conversely, excessive grazing removes overhead vegetation cover, reducing protection from predators and allochthanous flood from invertebrates and leaf litter.

4.12.3 Trampling and compaction

The compaction effects of hooves or wheels moving over soft ground have wide ranging implications for salmon habitats (Platts *et al.,* 1983 and Platts & Nelson, 1985). The movement of livestock in grazing pastures will, over time, compress the upper horizons of the soil into an impermeable front through which the percolation of rainwater becomes inhibited. This can then give rise to a rapid increase in the volume of water entering drainage networks increasing the potential for bank erosion and scour of salmon habitats.

Such water will undoubtedly carry fine particulates which, when deposited, could fill inter-granular voids in gravel beds, rendering them unsuitable for spawning. As with erosion another effect is the increase in water turbidity and the subsequent decrease in the depth of the euphotic zone, leading to a reduction in epiphytic algal productivity, which provides a food source for invertebrates. In this way, young salmon may suffer a decrease in growth rate or even mortality as a result of a decreased food availability.

Further complications can arise where cattle are able to graze up to the channel edge or drink in the channel itself. The movement of heavy animals and the penetration of hooves into the bankside material will eventually cause the bank to slump into the water (especially when fluvial undercutting of the bank also occurs). This will result in

a temporary increase in the downstream sediment flux as well as reducing marginal cover.

Once in the channel itself, cattle may cause compaction of gravel beds and even destroy redds, crush eggs and alevins, as well as damage or destroy other in-stream works. If exposed by low flows, silted and compacted gravel beds will harden in the air, forming a gravel-silt concretion which is more resistant to fluvial erosion and natural restoration. Such concretions are of no use as salmon spawning habitats being unworkable by fish.

4.12.4 Tunnel vegetation

The effect of overgrown or tunnel vegetation on stream productivity can be profound. O'Grady (1993) identifies a reduction in the numbers of juvenile salmon where marginal vegetation is so dense as to have limited the extent of incidental light reaching the river bed. This appeared to be an extensive phenomenon, existing in many of the observed salmon habitats used in his study. He cites a similar trend observed in North America in Hawkins *et al.* (1982).

Juvenile salmon densities have been found to be reduced by up to 80 % in areas containing excessive tunnel vegetation (O'Grady, 1993). The mode of action was thought to be due to a decrease in the amount of light reaching the channel reducing the primary production of the river, which in turn reduces the invertebrates available for juvenile salmon.

Shading effects on juvenile salmon became more significant as the length of tunnelled channel upstream of the site increased. The same trend does not, however, apply to trout. O'Grady suggests that, if it is assumed that invertebrate drift levels reduce with an increasing length of tunnel vegetation upstream, then this bias towards salmon could be due to the heavier reliance of juvenile salmon on invertebrate drift as a method of receiving food.

The collapse of trees and large shrubs into the channel can impede the flow by increasing channel roughness, reducing the conveyance of water or, increasing the risk of flooding due to the formation of a debris dam. Silt may accumulate whilst the dam is present but after it is over-topped or washed out, the pulse of stored water may remove accumulations of gravel downstream to areas where spawning is less appropriate.

4.12.5 Urbanisation and agriculture

Differences in land use within a catchment have a marked influence on both stream hydrology and water quality. Hydrological influences can significantly impact upon salmon habitat.

Increased urbanisation dramatically increases the proportion of impermeable catchment surface presented to precipitation events. The majority of precipitation falling in these areas will enter the sewerage network and be discharged into

waterways either directly, or after passing through Sewage Treatment Works. The increase in volume of discharge after a storm is rapid, increasing the risk of flooding, bank erosion, transportation and scour of sediments from salmon spawning areas.

Urban sediments contain a cocktail of pollutants such as metals, and hydrocarbons, which present an obvious toxicity problem to salmon. In addition, the sediment discharge, especially after a period of dry weather, will increase the suspended solid load, which when settling out downstream, may blanket spawning gravels or abrade the fish themselves (White *et al.*, 1993). Runoff from roads poses a similar threat, as the quality of the water is often poor with a subsequent detrimental impact on invertebrate and fish communities.

Changes in agricultural practices resulting in the untimeliness of cultivation, are one of the major causes of increased fine sediment flux in river systems. The harvesting and sowing of crops in the late summer or early autumn leaves many fields bare and exposed to erosion. Eroded sediments are transported via efficient field drainage systems directly into rivers where they settle out when hydraulic conditions permit, degrading salmon habitats.

Livestock management practices have also changed significantly with attendant problems described earlier. Also, the tendency towards less control over grazing locations, particularly in valley bottoms, and poorly located ring feeders, result in high densities of livestock leading to accentuated local erosion.

4.13   Habitat deterioration, bottlenecks and the catchment continuum

The previous sections illustrate how critical factors may lead to deterioration in salmon habitat. However, it should be stressed that some factors will only impact on certain components of habitat which may specifically effect a single life history stage. A good example would be a lack of spawning habitat caused by siltation. Although juvenile rearing areas may be plentiful, the population will be constrained by a lack of suitable spawning gravels which will in effect act as a throttle on subsequent recruitment. Similar mechanisms operate when juvenile habitat is in poor supply, when egg deposition and survival may be plentiful but a lack of parr habitat acts as a throttle on recruitment to subsequent life stages.

Hence, habitat degradation being differentially limiting on various life stages of salmon illustrates the concept of **habitat bottlenecks**.

Further it should be recognised that the river catchment is a continuum and that habitat, and critical factors impacting upon it, do not act in isolation. Frequently limiting factors will operate on a catchment wide scale (e.g. farming practices, erosion and so on). Therefore habitat bottlenecks and the identification of the related causes of habitat degradation should be examined with this in mind.

The catchment continuum is also a critical concept when the juxtaposition of habitat types is being considered, such as the relative proximity of juvenile rearing habitat to

spawning areas. This emphasises the need to view habitat degradation in the wider context of the catchment and to be wary of focusing in on specific areas in isolation.

Identifying and alleviating habitat bottlenecks via habitat restoration is thus a fundamental theme of this manual and will be dealt with in part III. Part II will illustrate how habitat is restored with a variety of instream, bankside and catchment wide techniques.

Part II

SALMON HABITAT RESTORATION TECHNIQUES

5.   SALMON HABITAT RESTORATION TECHNIQUES

5.1   Introduction

This section provides a critical evaluation of the various techniques that have been used in salmon habitat restoration. Guidelines are provided on quantifiable best practice as well as on failure, so that conclusions can be drawn, regarding techniques that are appropriate and inappropriate. In addition, those which require further investigation can be identified.

Jones and Milner (1992) make the point that effective habitat reinstatement requires the integrated development of spawning, rearing and adult holding areas. As habitat requirements differ substantially between the various life stages, the full range must be provided so that none become limiting avoiding habitat bottlenecks as mentioned in the previous section. This emphasises the need to view the catchment as a continuum, with many different physical habitats and river types being encountered during the life cycle of salmon.

In the past, traditional engineering approaches have had a tendency to control river behaviour by using hard structures (such as groynes, weirs and revetments) and techniques such as channel straightening and cross-section re-profiling to attain a more efficient flow of water and reduce flood hazards. In recent times, however, it has been recognised that river management by force alone is impractical and ecologically damaging.

Catchment or drainage basin management schemes attempt to use geomorphological principals to control rivers (for example the use of meanders to store excess flood water) and try to take into account processes and products from other compartments in the catchment. In doing so, it is possible to reduce or enhance the interrelationships between other compartments of the drainage basin, the drainage network itself and ultimately the biota within the rivers and streams. Holistic catchment management strategies can provide long-term benefits that are more difficult to obtain by solely concentrating on in-stream works; the two approaches need to be integrated.

With this in mind, the restoration and management of salmon habitats must incorporate **catchment-wide strategies** and the personnel involved in such work must be aware of the implications these strategies have on the restoration of salmon habitats.

It is with a realisation of this and other factors that a more holistic approach to managing rivers is now actively encouraged in the Agency.

5.2   Spawning habitat

5.2.1   Spawning habitat protection

Protection of existing spawning gravels from the factors leading to deterioration discussed in Section 4, such as washout and siltation, is a frequent requirement in salmon fisheries. Gravels can be protected in two ways; by preventing washout during spates (preventing denudation of gravels or encouraging further accumulations to develop) or by preventing siltation and associated compaction.

Both objectives can theoretically be achieved by the introduction of groynes or weirs. Indeed, in the literature, the use of gabion weirs to accumulate gravels and reduce localised siltation in North America has been well documented (e.g. House & Boehne, 1985 and Klassen & Northcote, 1988). Although both these papers refer to the West Coast and hence Pacific salmonid species, the principles and objectives are still valid for Atlantic salmon.

House and Boehne (1985) undertook a detailed study on the use of 'v' shaped gabion weirs (see Figure 5.1) to accumulate gravels, reduce siltation and create plunge pools for cover use by spawning adults. The paper demonstrates that, with careful consideration of specific hydraulic conditions on site, gabion weirs can be very effective in accumulating and protecting gravels. Within the trial area (500 m of a 5.5 km reach), spawning habitat increased on average by 28% as a result of installation of 7 gabion weirs. Utilisation of the new spawning areas, which represented up to 61% of the total spawning area as measured by redd counts, was monitored over a two year period. Although no specific data are presented, gravel accumulated behind the gabions did not become clogged with surface fines, even during low summer flows, and was regarded as being of better quality than that deposited elsewhere. Gravel above and below the gabions (up to 6 m in either direction) was said to relatively free of fines down to a depth of 10 cm. Whilst this is not considered sufficiently deep for Atlantic salmon, no other data are presented to allow a before and after comparison.

Useful practical information is given by House and Boehne (1985) on construction, highlighting the need to ensure adequate bed and bank protection and anchoring of structures. In this regard they were critical of the use of logs as the accumulating structure, where they had not been effectively secured to the bed.

Klassen and Northcote (1988) also provide a good account of the success of paired gabion weirs in preventing accumulation of fines in spawning gravels. The work was undertaken to examine the use of weirs to mitigate for lost large woody debris, regarded as important natural features in streams for gravel retention and cleaning. In this case however, gravel was artificially introduced behind the gabions for the experiment. Compared with control areas (both those regarded as good and poor spawning habitat), intra-gravel conditions were found to be significantly improved in the gabion weir sites, notably with an increase in dissolved oxygen (DO) and a decrease in factors which negatively impact upon DO. It was also noted that the gabion sites attracted significantly higher numbers of spawning fish than at control sites.

In their discussion, quoting Vaux (1962), Klassen and Northcote note that the key features influencing water exchange between the water surface and gravel are water turbulence, stream surface profile, gravel bed depth, gravel permeability and irregularity of the stream bed surface. Gabion weirs significantly affect several of these factors and hence are conducive to higher surface-gravel water exchange, resulting in improved egg to emergent fry survival rates. In an earlier paper (Klassen and Northcote, 1986), the authors also noted that gabion weirs stabilised gravel, preventing washout and hence physical disruption of redds from scour.

5.2.2 Spawning habitat restoration

To a degree, natural river systems are self cleaning, with spates and freshets flushing accumulated sediment from spawning gravels. However, as identified in Section 4, changing land practices and river management (canalisation and impoundment) have led to a situation where natural flushing is often insufficient to remove silt from gravels. The fines content therefore increases and armoured layers develop, resulting in a gradual deterioration in the quality (see Section 4) and ultimately the quantity of spawning habitat available.

Gravel cleaning is a popular restoration technique for reducing silt content. For Pacific species Wilson and Sheriden (1974) claim that the normal egg to fry survival rate of typically 10% can be increased to a level in excess of 40% in if silt can be reduced or removed.

However Meehan (1972), whilst examining the environmental impacts of gravel cleaning operations in a detailed study, demonstrated that following cleaning bottom fauna populations initially decreased. After three months, however, a doubling of the invertebrate fauna was evident, although numbers returned to pre-treatment levels after one year.

Gerke (1973) and Wilson (1975) describe the successful use of tractors with forks, rakes or blades to clean spawning gravels by stirring up the bed and causing the fines to be mobilised and carried away in suspension by the flow. In both studies adult fish were observed to be spawning successfully in areas cleaned in this way, demonstrating that rigorous disturbance of gravels to remove fines does not appear to discourage fish from spawning. Finnigan *et al.* (1980) describe the use of a small bulldozer to scarify the bed during high flows to break up the natural compaction of spawning beds and remove the silt. However, they make the point that consideration ought to be given to the timing of such works, ensuring that hatching and dispersal of alevins has taken place.

Solomon and Templeton (1976) refer to the practice of ploughing the stream bed in an attempt to control weed growth having seemingly advantageous effects, overcoming problems with compaction and improving salmonid densities. Although mechanical raking and ploughing are known to be undertaken in several Agency regions, no documentary evidence to the effectiveness of the technique was available.

Semple (1987) describes the successful use of a simple water pump to wash fines out of gravel spawning areas in the eastern USA. Using a high pressure 5 cm hose attached to a conventional petrol driven water pump with a three man team, a cleaning rate of 172 m^2 per hour was achieved. The results indicated that this technique was a very effective way of enhancing the quality of Atlantic salmon spawning habitat. The average life of the operation was three years. Finnigan *et al.* (1980) also refer to the use of high pressure hoses for gravel cleaning but suggest adapting the end of the hose to take a steel pipe nozzle which will penetrate the stream bed and flush fine silts and sand to the surface.

However, as pointed out by Mih (1978), a feature common to all the gravel cleaning techniques described above is that re-suspended fines will only be momentarily mobilised and hence will settle out downstream, presumably, at least in part, in other spawning areas. This is particularly true if cleaning operations are undertaken in low to moderate flows, as will often be the case for practical reasons. Hence, gravel cleaning should proceed in a co-ordinated downstream direction, allowing adequate time for fines to be transported before commencing work on a downstream gravel bed.

Andrew (1981, in Solomon 1983) describes a 'vibrating bucket' technique used in the Fraser River, the idea being to prevent siltation of downstream areas during gravel cleaning. A hydraulic excavator (with a perforated bucket) is used to excavate gravels. By vibrating the bucket underwater, the fines are shaken out (see Figure 5.2). The cleaned gravel is then deposited back into position, effectively burying the displaced fines. As with ploughing, this technique is in use in several Agency regions (e.g. South West, N. Reader pers. comm.), although again no documentary evidence as to its effectiveness is available.

Mih (1978) goes on to discuss several rather cumbersome and technical methods of de-silting gravels in natural and artificial channels (including mechanical, water jet and flushing techniques). These include an air/water injection technique, utilising 90 gallons of water a minute in an air/water mixture which, under optimum conditions, clears fines to a depth of 30 cm. Whilst successful in artificial and uniform spawning channels, particularly where the fines had a high organic content, its use in natural riffles was limited due to bottom substrate irregularities and boulders. A 'Riffle-Sifter' is also described in detail, designed for use in natural streams, which has the advantage that the fines/water mixture is deposited on adjacent land following suction removal, cleaner water running back into the stream.

Mih and Bailey (1981) discuss the further development of a prototype which appeared to successfully clean gravels to a depth of up to 30 cm. Unfortunately, the machines involved are large and cumbersome and are fairly site specific, offering little scope for widespread use on natural rivers in the UK.

Wesche (1985) refers to the use of deflectors (groynes) as a method to reduce silt content of spawning areas and encourage accumulation of gravels. However, he warns of possible negative effects such as gravel washout, providing detailed comment on the importance of citing of the structures (see later).

5.2.3 Spawning habitat creation

The use of weirs and groynes to intercept and accumulate the naturally occurring gravel being seeded into a river reach as part of the normal dynamic river bedload transport process, has been referred to above (e.g. House & Boehne, 1985; Wesche, 1985; Klassen & Northcote, 1988). A considerable amount of work has been undertaken on this topic in North America relating primarily to Pacific salmon species and trout (Maughan, Nelson and Ney, 1978; Finnegan *et al.*, 1980; Klassen & Northcote, 1986; Reeves *et al.*, 1991).

Finnigan *et al.* (1980) describe in detail various options that are available to create weirs and stop logs, behind which gravel can either be allowed to accumulate naturally or selected gravel can be added (Figures 5.3 and 5.4). One of the simplest methods is to use block stone or boulders, the crest of the weir being level with the natural irregularities of the rock allowing fish passage. Where a substantial gradient needs to be overcome, weirs can be placed in tandem.

Alternatively, rock-filled gabion baskets can be used to create a weir and control the gradient of the channel. Finnigan *et al.* (1980) point out that, since gabion and rock weirs are not water tight, they promote good exchange of flow between stream and gravel spawning bed for a considerable distance upstream of the structure. For this reason, spawning salmon show a distinct preference for the area immediately upstream of the invert control. Logs can also be used to stabilise gravel but, as illustrated in House and Boehne (1988), care must be taken to ensure that they are properly anchored to the stream bed to avoid undercutting.

Solomon (1983) refers to Seeb *et al.* (1981) as an example of successful gravel addition. A 600 ft length of channel was planted with graded gravel together with board weirs to control shifting gravel and adjust the gradient to 0.2%. A marked reduction in stream-bed fines was recorded (23 to 11%) whilst a significant improvement in egg survival resulted (29 to 59%). Subsequently, following heavy siltation after logging in the catchment, the gravels were replaced, and the fines level decreased to 8%.

An excellent example of a **spawning gravel creation** project on the Afon Gwyrfai in North Wales is given by Jones and Milner (1992) and Bowker and Brassington (1995). Two spawning beds were created by additions of gravel held in place by block-stone stabilising weirs. In addition, nine upstream and downstream pointing stream deflectors, two excavated holding pools (1.5 m depth), scattered stone blocks and rubble were placed downstream of the spawning beds. The results were initially very encouraging, with both salmon and sea trout using the new gravel spawning beds for cutting redds. However, despite salmon fry appearing for the first time only a few years after re-instatement, significant benefits were only recorded for trout.

Jones and Milner (1992) concluded that the **spawning bed profile** is of great importance, even more so than particle size. Redds were observed in areas of up-welling or down-welling, indicating that appropriate conditions for egg incubation were localised around the upstream dome of the spawning bed. Where multiple

spawning occurred, the construction of the redds flattened the bed. In natural river systems the hydraulic river processes would maintain riffles in suitable positions within the channel with the appropriate dome shaped morphology (see Figure 5.5). In regulated streams, such as the Afon Gwyrfai, artificial maintenance will be required (manually working the gravel) to maintain the spawning gravel in the appropriate configuration.

Furthermore, they observed that the restriction of redd location to the areas of up-welling and down-welling indicated that bed profile and its associated features of surface water depth, velocity and inter-gravel movements were the principal limiting features. Hence gravel size alone will not guarantee effective spawning. Therefore, the importance of spawning bed profiles limiting the area of potential usage in gravel addition sites should be recognised. Jones and Milner (1992) recommend a length of artificial spawning bed of around 1.5 x channel width in a gradient of 0.3%.

Artificial spawning channels (specially constructed off-line channels) have been widely used in North America with some success in a number of regions, namely British Colombia, California, Oregon, Washington and Alaska (Lukas, 1960; Schroder *et al*, 1973; Pratt *et al.*, 1974). Such channels are predominately used for pink and chum salmon (which migrate to sea as fry) and sockeye (which migrate to lakes as fry). Spawning channels have also been successfully used in Tasmania and New Zealand, where artificial river systems have been constructed to propagate rainbow trout and brown trout (Sloane, 1979).

Their use has not been attempted in the UK, primarily because UK rivers are regarded as being unable to support such high production levels of young fish with a significant riverine life history (e.g. Atlantic salmon). In addition, spawning channels are major civil engineering undertakings and are therefore considered by some to be of limited value to the UK (Solomon, 1983). The use of artificial spawning channels to enhance Atlantic salmon production has, however, been attempted in Canada and France (Pratt, 1968; Pratt *et al*, 1974; Beall & Marty, 1983).

Despite a reluctance to use such structures in the UK, several authors have identified positive features. Significant natural causes of early life stage salmonid mortality can include floods which destroy redds, and heavy silt loads which inhibit egg development (Hobbs, 1937; Gangmark and Bakkala, 1960; McNeil, 1966, and Harris, 1970). Control of these factors in a spawning channel provides optimum conditions for development but avoids the artificial conditions that occur in fish farms (Childerhose and Trim, 1981). Hatchery reared fish are not as well adapted to survive in the natural riverine environment as wild fish (Mead and Woodhall, 1968; Beall and Marty, 1983 and Harris, 1995 in preparation). Thus spawning channels offer the advantages of mass production of intensively reared fish with the adaptiveness to wild riverine conditions found in natural populations. When spawning channels have been located in well chosen sites they have given excellent results and contribute greatly to maintaining and redressing the status of damaged stocks (Beall and Marty, 1983).

Snow (1986) describes the use of a previously redundant spawning channel in Newfoundland, Canada, refurbished for use with Atlantic salmon, after lying idle for

several years. Water was diverted into the channel from the North Harbour River, levels being controlled by stoplogs. Predator traps at the entrance to the channel prevent eels, trout and parr from entering the channel. The channel was gently sloped for most of its length with holding pools spaced throughout. Many tons of clean rounded gravel were added to provide riffle areas, although no structural details are given. Prior to use, the gravel was cleaned by use of a large rake dragged by a tractor and flushed with river water by removing stoplogs. The process was repeated until the gravel was adequately loosened and epiphytic algae and silt removed from the system. Once the system was cleaned, conduit fences are erected to hold the brood stock in the appropriate sections and prevent escape. Adult salmon caught in the main river were then released into appropriate sections and, after a period of acclimatisation, allowed to spawn naturally. The only further management action was to protect the brood stock from poachers and predators, otherwise no further management was necessary. Fry barriers were then erected over the conduit fences to facilitate easy collection for subsequent seeding into the river system.

Beall & Marty (1983, a & b, 1987) discuss in some detail the performance of an artificial spawning channel constructed on a tributary of the high Nivelle, Le Lapitxuri, in the Basque region of France. The channel consisted of a series of 13 sections or chambers (see Figure 5.6), each measuring 10.0 m long by 2.8 m wide. The concrete sides were inclined at 45 ° to a bitumen covered base. Each section was filled with a bed of round river pebbles (diameter range of 10 to 80 mm) to a depth of between 50 and 65 cm. This provided an available spawning area of 28 m^2 in each of the thirteen sections. The overall gradient of the structure was 2% whilst that of the surface within each section was graded and maintained at 0.5%.

The flow into the spawning channel, and to a degree between sections, was controlled by weir boards, with a possible maximum flow of up to 400 l/s. Individual sections could be isolated with metal grills, a 2 cm spacing being used for adults whilst a 2.5 mm mesh was used to prevent movement of alevins.

During its first year of operation, successful spawning was achieved. Following close observation, it appeared that spawning developed normally, in a parallel fashion to that which would be expected in a normal environment. Redd digging ceased at flows below 80 l/s, most spawning activity occurring at flows greater than 100 l/s. The latter corresponds to average velocities of 0.13 to 0.15 m/s, with flows locally at 50 cm depth more than 0.3 m/s.

Several general points were made, including the need for a **zone of refuge** near the redds and that groups of fish may contribute to aggregation of redds and hence unnecessary overcutting. McNeil (1964) notes that this can be a major source of egg mortality, severely limiting spawning success in extreme cases. In subsequent work (Beall and Marty, 1987), the optimum density for spawning success was estimated to be one female per 9.5m^2 of channel surface. Higher densities of female spawners resulted in aggressive interactions which reduced spawning success.

In Beall and Marty (1983b), egg to alevin survival was measured at between 65% and 86%, for fish which spawned naturally in the channel; where eggs were placed in man

made redds, survival rates of up to 90% were noted. In their 1987 paper, egg survival of 50 to 75% was considered typical for naturally cut redds in the channel. Typical values for egg survival from the Pacific salmon literature are, on average, 50% in spawning channels.

The authors also note a significant downstream migration by alevins following emergence. Self seeding from the spawning channel, may therefore be possible, provided suitable nursery areas are available downstream. Alternatively, downstream migration facilitates easy collection of alevins in traps. 99% of emergence and migration occurred under the cover of darkness. Beall and Marty (1983) conclude that the production of alevins in artificial channels provided a viable alternative to traditional fish farm incubation and that there is no reason to assume that juveniles produced in this way are not as environmentally fit as their wild relatives.

5.3   Juvenile habitat

5.3.1. Juvenile habitat protection

Protection of juvenile habitat is targeted at two main problems, siltation and compaction of substrates and shading.

Waters (1995) reviews the impacts of sedimentation on streams, in particular the effect of sediment transport reducing invertebrate densities with a concomitant knock on effect on food availability for salmonids. Addressing excessive sediment loading to a river system will reduce siltation of juvenile habitat, maintaining invertebrate productivity and hence salmonid production. Prevention of external point sources (such as land drains) may be considered a water quality issue and so outside the scope of this manual. However, excessive erosion due to natural or anthropogenically influenced stream processes is not.

The latter can be prevented or at least reduced by use of **bank protection** techniques. **Bank revetments** of various types can be constructed to protect banks from erosion. They can be constructed from all manner of materials, including gabion mattresses, logs or boulders (see Hunt 1988, 1992, 1993 and Hunter, 1991). Figure 5.7 provides an example. In addition, a common form of bank protection often recommended for use in conjunction with other habitat improvement structures is **boulder armouring or rip-rap**. Heavy boulders or quarried stone are carefully tipped into place, dissipating the stream's energy to protect the bank. Prior to placing of boulders, the bank should be graded with hydraulic machinery to a slope of about 45 degrees. The stone is then tipped about 1.5 m out from the base of the incline to the top of the bank, where reclaimed soil can be used to cover the surface of the rip-rap enhancing its aesthetic appearance. The rip rap can be further reinforced by securing Norwegian spruce trees (discarded Christmas trees) to the exposed surfaces. This technique is widely adopted by O'Grady in Ireland where bank revetments using logs are commonly used. In addition, the planting of willow slips in surface soil used to cover rip rap will also consolidate the revetment structure in time (O'Grady, pers. comm.).

5.3.2   Juvenile habitat restoration

Over recent years significant work has been undertaken on practical methods to restore salmon juvenile habitat, notably in Eire, where systematic experimentation and evaluation of techniques has provided a solid foundation on which to recommend best practices (O'Grady, 1991a, b; O'Grady, 1991 and O'Grady et al., 1993).

One of the most basic methods is the control of tunnel vegetation. Research has shown quite conclusively that tunnel vegetation impacts negatively upon juvenile salmon. The mechanism is thought to be that the excessive shading caused by tunnel vegetation restricts epiphytic diatom growth, which in turn limits invertebrate productivity and hence reduces fish food availability within the affected reach. The overall impact is therefore to reduce primary productivity with a consequent reduction in salmon production and carrying capacity.

Smith (1980) noted this effect in a Scottish stream subject to heavy shading by coniferous trees. Both invertebrate and salmonid numbers were reduced. In North America, Bilby & Bisson (1992) state that manipulation of the vegetative canopy by allowing increased incident light levels to streams may ultimately lead to increases in fish production. Hawkins et al. (1983) also report higher densities of salmonids in less shaded areas of streams. It is worth noting, however, that some authors notably House and Boehne (1986), maintain that the physical structure of the instream habitat is more important than shade in governing a streams capacity for production of salmonids.

However, in his study on the effects of vegetative cover on Irish streams, O'Grady (1993) reported a highly significant reduction in salmonid standing crops in heavily shaded areas, suggesting reduced invertebrate biomass as the cause. Partial opening of the canopy therefore allows increased light to reach the stream bed, stimulating diatom growth and hence providing a higher level of baseline primary productivity. This has a knock on effect of increasing invertebrate food availability for salmon and hence the holding capacity of the reach. O'Grady's research has shown that the standing crop of salmon parr in heavily tunnelled areas is only 20% of that in open areas, suggesting that selective opening of the canopy could increase standing crop by as much as 5 times (O'Grady, 1993).

Whilst O'Grady recommends that in Irish rivers selective clearance of excessive shrubbery should be regarded as a priority measure, care needs to be taken in applying the principle with due consideration to the location and nature of the riverine habitat concerned. High gradient channels with an erosive habitat dominated by mosses and algae will probably benefit from shade removal in terms of salmon production. However, in low gradient streams, opening the canopy may result in excessive macrophyte growth which will choke the channel, leading to a significantly altered hydraulic regime, particularly in summer low flow periods. Weed choked channels are often devoid of salmonids and care therefore needs to be exercised when removing excessive vegetation in these circumstances (O'Grady, 1993).

5.3.3   Juvenile habitat creation

Lynch and Murray (1992) have shown that riffles in salmonid rivers, the preferred habitat of juveniles, are characterised by high invertebrate population densities, whilst deep glides, not a favoured habitat of young salmon, are characterised by low invertebrate density. Accordingly, O'Grady et al. (1991) in Lynch and Murray (1992) confirmed that the most productive areas in the river Boyne from a fisheries perspective were shallow (0.7m), fast flowing (0.3 to 1.0 m/s), high gradient (20 to 25 cm per 100 m) areas with broken rubble or rock substrates. Hence, much of the successful rehabilitation works in Ireland for juvenile habitat have been targeted at mimicking the conditions observed in these productive riffle zones to increase salmon carrying capacity in barren reaches. Lynch and Murray (1992) confirm that riffle creation doubled the number of taxa present within 12 months of construction.

Needham (1969) showed that this type of rubble material (large cobble and small boulder) has advantages over gravel or boulders in that it can harbour a greater biomass of invertebrates than other materials. In addition, the rubble material creates a new substrate for plant colonisation, with filamentous algae often being the first colonisers (Caffrey, 1990).

O'Grady (1991) demonstrated the effectiveness of rubble mats in elevating salmon densities from 0 to 4 or 5 salmon parr per 100 m^2. Increases in fry densities were also noted but, due to conditions on site, these could not be accurately enumerated. Working on the River Boyne in Ireland, large quantities of rubble were added to the stream bed to form a substantial vertical flow constriction, increasing stream velocities. The experimental areas were up to 243 m^2 in size and used quarried rough limestone of diameter 22 to 38 cm (between 120 and 200 tonnes of rubble are needed to construct a mat). The stone was placed in deep glides (up to 2.0 m), reducing depth to within the range 0.5 to 0.7 m. Several configurations have been tried, the most successful being bands of rubble, perpendicular to the flow and 10 m wide. A 35 m stretch containing large individually placed boulders (one to three tonnes) in weight separates the rubble mats (see Figure 5.8).

An alternative design comprising 'V'-shaped rubble areas was considered only moderately successful (O'Grady et al., 1991). However, this was thought to be primarily due to low flows during the period of evaluation, indicating that in normal years the structures may well prove useful in elevating juvenile salmon densities. Nevertheless, rubble mats were considered consistently more productive because of their ability to function over a broader range of low summer water levels.

Hvidsten & Johnsen (1992), describe a similar approach to that adopted by O'Grady to restore the bed of a canalised river section dredged for agricultural purposes. On the River Soya in Norway, blasted stones of up to 40 cm in diameter were introduced onto the river bed and banks creating raised bed submerged weirs. Improvements in densities of juvenile salmon were initially recorded. However, siltation via high sediment load continued, eventually reducing the increases in density recorded earlier.

Other juvenile habitat creation techniques used in Eire, described in O'Grady (1993), include construction of loose stone flooded weirs to create a hydraulic gradient at intervals in low grade (<0.5%) channels, improving the quality of juvenile salmon habitat. The same technique is used to alter deep uniform glides in high gradient (>0.3%) zones, generating a riffle/glide/pool sequence to improve stream carrying capacity (Milner *et al.*, 1985). The thalweg has been recreated by installing an alternating sequence of deflectors (see Figure 5.9 and Plate 1), constructed to restore the natural channel base width and increase the vertical scour providing channel diversity and refuge during periods of low flow. These have been constructed with loose stone or timber. Channel constrictions have been built (i.e., 'V' shaped structures in the centre of the channel) to constrict summer low flows, increasing velocity and generally resulting in enhancement of salmonid stocks (O'Grady *et al.*, 1991).

Thorough experimental investigations into habitat restoration structures and species preferences have been undertaken on the east coast of Canada (Bourgeois *et al.*, 1993). Utilising a disused spawning channel, modified to provide contiguous conditions (0.41% gradient, 2.5 to 7.5 cm diameter gravels and 3m width), two types of habitat structure were assessed in replicated experiments under controlled flow conditions, allowing statistical evaluation of fish preference.

Each experimental treatment consisted of two structures. Treatment one consisted of a stop log weir (low head barrier) with two notches to provide two plunge pools with five large boulders (30 to 60 cm diameter) placed in the centre of the channel immediately upstream of the stop log weir. Treatment two consisted of two paired structures comprising a wing deflector and corresponding bank undercut structure located on the opposing bank (see Figure 5.10). Between each treatment was an identical sized control zone. The treatment and control zones could be isolated with barrier nets to count fish within each zone. These three areas comprised a single experimental zone which was isolated with a counting fence from the other identical experimental zones. Six such zones were accommodated in the channel giving six replicates for experimentation. The attractiveness of the structures was evaluated under controlled conditions using various densities of juvenile Atlantic salmon and brook trout captured previously from the wild and acclimatised to conditions in the channel.

The authors concluded that habitat selection by Atlantic salmon is highly dependant on competitive interactions. In areas where fish diversity is low, a wider range of habitat types will be occupied (see also Gibson *et al.*, 1993). However, salmon preferred the mid channel structures (boulders and stop log notch weir) to the stream bank treatment area. This was considered to be largely due to the **velocity spectrum** and the cover these features provided. However, the deflectors and overhangs were preferred to the open channel control areas. Considering the lack of visual isolation and overhead cover, this is perhaps not surprising. Increasing the fish density displaced fish to occupy the less preferred structures including the control area. The stream bank structures were definitely not preferred by salmon, but this was possibly because the habitat features they were intended to create, notably scour in the case of the deflectors, were not achieved. However, for juvenile fish it is suggested that overhangs are of limited value.

Raadstad *et al.* (1993) extend the idea of artificial off-line channels to rearing of salmon fry. Following introduction of two successive hydropower schemes on the River Sudalslagen, reduced densities of benthic fauna, reduced growth rates and delayed smoltification in juvenile salmon were recorded. To mitigate for the reduction in production, an artificial rearing channel was proposed where water flow and substrate could be controlled, salmon fry being stocked into the controlled water. Despite problems with disease in the stocked fish, survival rates from fry to 1^+ were more than 25%. Macrobenthos productivity was increased by a factor of three by introducing dead organic material (115 g wheat /m^2). This increase in invertebrate food is expected to increase salmon productivity, although as yet results are unavailable.

Work undertaken in Scotland by Morrison & Collen (1992) examined the use of readily available felled timber to improve the salmonid habitat in a forest stream. They created a series of small weirs and deflectors, altering the bed of the stream by creating pools and riffles, where formerly depth had been almost uniform. The results of this habitat diversification programme were spectacular for trout fry, but had no obvious effect on salmon. Hence, the use of such structures must be addressed carefully with regard to the objective if salmon alone are the target species.

Channel constrictions designed to constrain flow within a reduced channel width can create additional juvenile habitat (Hunt, 1992). This is particularly useful where braided channels are encountered, which during summer low flows are too shallow and exposed for juvenile salmon. Channel constrictions confine the flow to a reduced low flow channel, maintaining the wetted area and hence extending the juvenile habitat available (see Plate 2). In the literature no specific reference has been found to provide information on the level of enhanced productivity that might be expected. However, it would be reasonable to assume that maintaining wetted area in this manner would extend the existing productivity of a given stream by the extent of new area created. Schematic diagrams of two forms of flow constrictions are shown in Figures 5.11 and 5.12.

5.4   Adults

As highlighted in Section 3, habitat requirements for adult salmon are less well reported in the literature, information on adult habitat being predominately the preserve of the angling fraternity. Deep pools and overhangs creating lies where large fish can rest, sometimes for considerable periods, are typical reported characteristics of adult salmon habitat. This view has largely been confirmed by the scientific community, where tracking of individual fish to recognised pools and lies is commonplace (Solomon, 1982). In contrast, the literature concerning obstacles to migration and means of facilitating fish passage is well represented, with specific guidelines having been produced for construction of fish ladders and passes.

3.4.1   Obstacles to migration

There is a wealth of information on fish passage obstructions and means of overcoming obstacles (fish passes, fish ladders etc.). A full treatment is beyond the

scope of this report and so the purpose of this section is to state general guidelines and cite more detailed reports (for example Beach 1984, Carling and Dobson 1996, Reeves *et al* 1991).

There are two basic types of fish pass which are commonly used in England and Wales;

1)   Pool and Traverse passes

2)   "Roughened Channel" passes, (e.g. the Denil Pass and its variants, such as the Alaskan Steep Pass and the Larinier Pass).

According to Beach (1984), a pool and traverse pass should have the following dimensions:-

a)   The change in water level across a traverse (i.e. between adjacent pools) should not exceed 0.45m

b)   Pools should have minimum dimensions of 3 m long by 2 m wide by 1.2 m deep.

c)   Each traverse should be 0.3 m thick with a notch 0.6 m wide and at least 0.25m deep. An approximate flow of 0.13 cumecs would be required to ensure that the notch runs full.

d)   The downstream edge of both the traverse and the notch should be curved so as to reduce turbulence and provide an adherent nappe.

Current points applying to fish passes include:-

e)   The pass entrance should be located easily by fish at all flows.

f)   Resting pools 3 m long by 2 m wide by 1.2 m deep should be provided at vertical intervals of 2 m.

g)   Denil passes should not exceed a slope of 1:4.

h)   Where access past high dams is required, a fish lift or fish lock, such as the Borland Lock, may be necessary. Borland Locks have been installed in some hydro-electric dams in Scotland.

The issue of **temporary obstructions** caused by large woody debris has been subject to considerable investigation in North America. Woody debris is perceived to have an important impact on spawning and juvenile habitat for Pacific salmonids (Chapman & Knudsen, 1980; House and Boehne, 1986). The loss of large woody debris is regarded as a long lasting phenomenon that transforms streams into considerably less productive environments (House & Boehne, 1986). Consequently, the issue of trash dam removal to facilitate either fish passage and/or land drainage is heavily criticised.

Obviously this is at odds with removal of large woody debris that is considered to be an impediment to fish migration, hence a sensible approach needs to be adopted.

Large scale removal of large woody debris in order to sanitise or cleanse catchments is regarded as wholly negative with respect to stream productivity, as reported in Bustard and Narver (1975). However, evidence from studies undertaken in the UK (APEM, 1995) has shown that significant areas of spawning and nursery area can be lost to a system because of accumulations of debris rendering them impassable to adult fish. On a catchment wide scale, the number of obstructions and hence areas taken out of production can be quite significant. This highlights the need for accurate walkover surveys undertaken on a regular basis in areas prone to accumulation of trash dams, so that serious obstructions can be identified and removed. However, only obstructions which are regarded as a threat to upstream migration should be removed, thus retaining the ecological and habitat benefits of large woody debris.

5.4.2   Resting places - pools, overhangs and lies

In terms of adult habitat restoration or protection, little information is to be found in the literature specifically relating to Atlantic salmon. Much of the data collected on either trout and/or Pacific species may not be directly transferable and therefore require evaluation to assess the appropriateness of use to Atlantic salmon, (Bourgeois *et al.*, 1993).

Nevertheless, there is a considerable amount of information in the North American literature particularly concerning trout, that have some relevance to salmon (Finnigan *et al.*, 1980; Gore, 1985; Pott and Schellhaass, 1986; Hunt, 1988; Hunt, 1992 and Scot *et al.*, 1994). A brief overview of the use of groynes and gabion weirs for trout habitat creation is presented in Templeton (1995).

In his extensive review of the subject, Wesche (1985) indicates a great variety of instream structures is unnecessary and that the most commonly used in-channel structures such as current deflectors, overpour structures (dams and weirs), bank covers and boulder placement, will suffice. Other techniques applied less commonly and with variable success include digger logs, trash catchers, simple gabions, substrate manipulation, pool excavation, and channel blocks and barriers.

Finnigan *et al.* (1980) highlight the importance of stable resting habitats for adults which must hold and ripen in streams prior to spawning. Holding fish will seek out natural and man made pools and overhead cover such as overhanging banks, bridges and log jams that will provide refuge and protection from predators and interference from man. Fish which are in the river for prolonged periods are particularly susceptible to predation and injuries which can lead to **pre-spawning mortality**. In a freshwater environment, injured fish deteriorate rapidly with wounds becoming infected with fungus, leading to fish dying before spawning. Hence protected resting pools and cover are essential.

Hunt (1988 and 1992), Finnegan *et al.* (1980) and Wesche (1985) provide details of habitat structures designed to create pools. In essence, riffle/pool sequences are created

by use of either deflectors, channel constrictions of various combinations and designs, and weirs which instigate scour and erosion and therefore create pools (see Figures 5.7, and 5.11 to 5.14). The procedures are similar to those described in earlier sections regarding juvenile habitat.

Milner and Jones (1982) excavated 1.5 m deep holding pools for adults. Scour and turbulence were maintained by constructing low block-stone weirs at the upstream end of the pool, secured using railway track stakes. A gap was left in the weir to allow for flow through as well as over the weir, facilitating fish passage during low flow periods. The centre of the weir was slightly lower than the edges giving a depth of approximately 20 cm during summer low flows. The outer banks of each pool were protected from erosion by block-stone revetment.

Depth precluded direct population measurement but observation showed that the pools were used by adults at spawning time and that juveniles (mainly trout) shoaled, seemingly using the cover provided by a combination of depth, turbulence and revetment. In addition, O'Grady (pers comm.) has demonstrated that the construction of a 1 to 2 m deep thalweg together with short (2-3 m) groynes will be beneficial in providing areas of cover for adults, especially during periods of low flow.

Overhangs are another artificial structure heavily utilised in trout stream rehabilitation which may be of value for adult salmon. The overhang provides a sheltered area under which adults can hide without being exposed to predation or poaching from above. Details of the various forms of natural and artificial overhang or bankside cover are provided by Wesche (1985) and Hunt (1988 and 1992). Wesche (1985) categorises them into four types; log and board overhangs, artificial overhangs of fibreglass or metal, tree/bush retards and rip-rap. Examples of overhang structures are given in Figures 5.15 and 5.16.

5.5   Riparian and land management practices

The presence of a riparian zone alongside a channel is desired as an integral component of salmon habitat management and importantly, will facilitate several different strategic practices. Hence, riparian land management issues should be regarded as long-term strategic concerns, requiring co-ordination on a catchment wide scale. The techniques used are designed to directly influence land management practices and have subsequent, indirect benefits upon riverine salmon habitats. These include promoting channel stability and erosion control, habitat diversification by the provision of overhead cover, increased stream productivity and control of non-point source pollution via use of buffer strips.

The Tweed Foundation (pers. comm.), suggest that the protection, restoration and management of a riparian belt is a major factor central to the success of salmon habitat restoration schemes. This philosophy is reflected by the fact that a large proportion of the work undertaken by the Foundation concentrates on 'soft engineering' practises and raising awareness of land management issues with riparian owners. Unfortunately the time and expense associated with actively managing **buffer zones** discourages many agricultural landowners, particularly when the direct benefits to them do not

appear to be tangible (Campbell, pers. Comm.). Better incentives for landowners therefore need to be explored.

5.5.1   Isolation of livestock from rivers.

Uncontrolled trampling by livestock has been shown to result in a number of negative impacts on salmon habitat. Fencing to prevent bankside grazing and channel access to cattle allows redevelopment of riparian vegetation which stabilises channel banks and provides overhanging bankside cover for fish. Reduced siltation, compaction and the return of riparian vegetation offer considerable benefits to both spawning and juvenile salmonid habitat. The value of maintaining an undisturbed riparian zone both with respect to fisheries considerations and wildlife in general has been well documented (Hynes, 1970; Anderson & Ohmart, 1985).

The type of fence used will depend on whether livestock graze the adjacent land or if it is used for arable purposes. A mixture of barbed wire and wire netting is best to deter grazers from leaning on the fence. The longevity of a well constructed fence is considered to be around 25 years, after which it will have to be renewed. Resources should be set aside for this purpose.

In the majority of cases a nominal fence is still needed to prevent accidental damage to the riparian community even if grazing activity is not present as it identifies the land as being protected. In this way, people are kept from using the bankside for leisure pursuits (such as picnics or angling) which can flatten vegetation and deters other would-be riparian users from encroaching onto the managed land (Crompton, 1994).

In some cases (e.g. the River Rhiw, Wales) **hedges** can be developed by layering lines of scrub on the bankside. These can perform the same role as fences, preventing access to the bank. They also provide additional habitat by acting as a windbreak, thus protecting the more fragile riparian plants. In addition their root system helps to bind the soil together. Hedges are preferable to fences from a conservation viewpoint but require maintenance and if allowed to grow unchecked, will become inefficient barriers (Lewis and Williams, 1984). In the majority of situations fences are a more pragmatic option, especially if time and resources are limited.

One North American method is to isolate a **bankside 'paddock'** from the herd and allow vegetation to recover over a period of about five years. Once recovered, the cattle are only allowed to graze on it for short periods of time, to minimise the negative effects of unrestricted 'seasonal-on' grazing. In this manner, the grazing of bankside vegetation can be seen as a management tool, achieving an interrupted climax community and if controlled, the length of the sward and overhanging foliage can be maintained at a density where it fulfils an optimum beneficial role with regards to salmon habitat and channel stability.

A second method currently utilised in the USA is the use of **mounted cattle drivers** to prevent a herd from settling along channel margins and allows them to be directed towards a less sensitive area of pasture. In the same manner, UK shepherds historically would have fulfilled a similar role, ensuring that a flock would be kept on the move

utilising all areas of available pasture and not just the more succulent areas adjacent to rivers and streams, thus allowing the development of a well established riparian plant community. Today, an absence of control over livestock grazing allows a herd to concentrate in valley bottoms, typically alongside the channel, using it as a source of water. The provision of food such as agricultural feeds accentuates this concentration of livestock and "honey-pots" such as ring-feeders are typically located on flat tracts of land. In many situations, such as in the Tweed system (Scotland), this is invariably on flat land alongside rivers. As there is no incentive to feed elsewhere, the herd will remain within a small area, with a detrimental effect on nearby vegetation. Such feeding policies need to be reviewed and possibly include the introduction of multiple, small feeding sites in order to disperse the livestock, away from the vulnerable riparian areas.

5.5.2 Riparian vegetation management - propagation & planting

The absence of grazing from a river bank will promote the reclamation of this habitat by natural riparian plant communities. **Self-propagation** from wind-blown seeds will occur over time, but a **managed planting programme** of seeds and juvenile plants will accelerate the process dramatically and allow more control to be exerted over the structure of the community. Seeds and plants taken from elsewhere in the catchment can be 'grown on' before planting, to reduce the time period before their presence on the bank makes an effective difference. The practice of using local species, found within a specific catchment, maximises the success of any replanting and will also reduce the likelihood of problems caused by 'alien' plant competition, whilst retaining the genetic and species integrity of the riparian community.

5.5.3 Techniques used in the management of riparian trees and scrub

Undesired excessive growth of foliage, often resulting in tunnel vegetation, needs to be controlled. However, it is important to remember that good salmon habitat will require some overhanging tree cover to provide food and shade in times of elevated temperature. The density of cover needs to be balanced with open sections of well developed river banks (Tweed Foundation, pers. comm.).

When removing foliage, it is important to take into consideration other biota. For example, low hanging branches are often used by waterfowl (such as coots and moorhens) as nesting sites. A **selective thinning** of foliage is the optimum approach (patches of overhead branches are removed, but the remainder are cut back to the bank). The management of trees in this manner will diversify previously uniform shaded shallow margins, whilst retaining sufficient cover for nesting birds and invertebrates. The increase in light reaching the marginal and submerged aquatic vegetation will encourage it to thrive and hence increase the diversity of habitats (Lewis and Williams 1984).

O'Grady recommended selective clearance of excessive shrubbery, leaving some cover to prevent over-proliferation of aquatic vegetation. Bjorn and Reiser (1991) also

warn against excessive clearance, as it may result in extreme summer water temperatures, particularly in small streams.

Modern forestry practices include planting with a mixture of broadleaf and coniferous species. Afforestation with predominantly coniferous species increases the risk of acidification of waters and due to their shallow rooted nature, promotes the risk of collapse into the channel and debris dam formation. Other advances in modern forestry techniques include shorter runs of ploughing, the scarifying of ground and a reduction in the drainage network. In addition, forestry guidelines now require that planting, ploughing and drainage ditches stop some distance short of an existing watercourse, the distance being related to the width of the watercourse (Forestry Commission, 1993).

Techniques such as **pollarding and coppicing** are sometimes used to manage marginal trees. Pollarding, traditionally popular with bankside willows, requires the removal of the main branches from a tree, leaving a trunk about two metres tall. This technique produces a regenerative crown of foliage and provides a very rich wildlife habitat, the crowns producing leaf litter which accumulates below. The removed wood can be used for fencing and bank protection.

Coppicing is the removal of tree material down to the stool which remains alive. The harvesting of new stems provides material for poles and the mass of new stems if partially coppiced, can help deflect water away from mature trunks and can help to protect the river bank in high flows (e.g. the River Okement, Devon). However, these practices, once initiated, need repeating on a cycle of three to seven years in order to manage the trees successfully (Crompton, 1994).

5.5.4 Reducing agricultural runoff and sediment loss

A well vegetated riparian buffer zone will act as a trap for alluvial sediments that may be washed from the adjacent fields. If crops are harvested at a time when storms are more frequent (e.g. the early autumn), then the large surface area of exposed soil becomes very susceptible to erosion and transportation. This fact is exacerbated by the use of land drains and ditches, both of which will convey excess water and sediment to the channel very efficiently, without allowing for sedimentation before the river is reached.

In order that the impact of rapid silt transport on salmon habitat is reduced, the following recommendations should be taken into account when reviewing land management practises (Kear, pers. comm.);

- Identify the areas at risk (e.g. large fields on a slope used for arable crops).

- Return the land to permanent grass, especially where slopes are in excess of 11%.

- On gentle slopes, cultivate along the contour.

- Include a greater proportion of spring crops in the rotation system (to avoid untimely cultivation).

- Prepare coarse seed beds, refrain from rolling them in autumn (this smears the upper soil horizon and increases impermeability at a time when precipitation is frequent) and loosen compaction from wheel tracks.

- Restore hedges or leave grass strips across slopes as water and sediment retarding features.

- Integrate sedimentation pools into the arterial drainage network and control the outflow of drainage water with the use of sluices. This will have the effect of diffusing a large pulse of storm water as it enters the main channel from overland flow.

5.5.5 The importance of good public relations and raised awareness

Whilst the above will reduce the impacts of agricultural runoff, the best practice is to reduce the level of degradation of agricultural land. This will minimise effects on salmon habitats (increased siltation, turbidity, erosion etc.) and is best achieved by raising awareness within the farming community and providing financial incentives to grow different crops on erosion prone land (such as the chalk downlands of the South and East UK). Guidelines for best agricultural practice with regards to catchment management are not available at the moment but are currently being researched by the E.A. However, a Code of Good Agricultural Practice for the Protection of Soil is available for landowners to promote sound land management (MAFF 1993). In addition, Taylo, Gordon & Usher (1996) details recommendations for reducing the impacts of soil erosion.

The importance of obtaining and maintaining the support of the agricultural community in effecting catchment based salmon habitat restoration schemes has been exemplified by the Tweed Foundation. The cornerstone of their management policy is to win the support of the local landowners via an extensive programme of education and promotion, such that there is an increased awareness of the problems and processes at work.

By adopting an approach based on collaboration and consensus, problems are largely avoided and support for the long-term protection and restoration of bankside riverine habitat is widespread, with individuals becoming willing participants in the Foundation's activities. Proper communication to farmers regarding the benefits of isolating livestock from rivers, with grants offered in some cases, can result in the fencing and isolation of many miles of river rather than just a few hundred metres.

As the success of such activities depends on landowners giving up areas of land that may have belonged to their family for many years (and due to the topography of the region are often the most fertile), emphasis must be placed on changing peoples perception of a stretch of river. This must be related to the benefits landowners can gain from a habitat improvement strategy (Nicol, pers. comm.).

5.5.6 Channel modification using riparian structures

Channel modifications such as deepening and straightening (to increase flood protection) have serious implications for salmon habitats (see Section 4). An understanding of geomorphological processes allows "soft engineering" techniques to be employed (Vivash, 1994) as a means of accomplishing aims such as:-

- Channel deepening and widening
- Channel narrowing
- Channel realignments and by-passes

Fluvial erosion is a natural process which can be harnessed and manipulated by incorporating structures such as live trees, dead trunks and brushwood into the riparian zone. Woody materials will create a colonisable natural habitat, compared to the sterile homogenous environment occurring where "hard" structures are used. When combined with schemes utilising "hard" structures, woody material enhances their stability and longevity, and renders them more aesthetically pleasing.

Large tree trunks, half submerged alongside the riverbank, can help to halt erosion by directly absorbing energy from the water. Bundles of live willow withies can then be placed behind the trunks where they will develop roots and shoots, binding bank material together and trapping silts which act as a growth medium for colonising emergent macrophytes (Hemphill & Bramley 1989).

Spiling is a technique where live willow withies are weaved around freshly cut winter willow stakes. The stakes are placed into the bankside material and will protect over-steep/vertical banks or scour holes as the stakes root and produce living and long lasting protection (Hemphill and Bramley, 1989). Live willow stakes planted into a revetment structure (e.g. log structures, riprap or gabion baskets) will root and consequently bind the fill material together thus increasing its longevity and improving habitat diversity (O'Grady pers. comm.).

Hazel hurdles (constructed from coppiced materials) will not root but will protect a regraded bank from wash and scour. The natural riparian community will grow through the weave and, after approximately ten years, the wood will rot away. **Faggots** (brushwood bundles) placed in the bankside material will trap silt and sediment and hence consolidate the bank through accretion. Subsequent scour is prevented by emergent shoots (if willow is used) and the woody branches buried in the silt (Lewis & Williams 1984).

All of these techniques allow materials harvested from other tree and shrub management techniques to be utilised in an economic and beneficial fashion and can be incorporated into the range of habitat improvement techniques discussed in this Section.

5.6   Flow manipulations on regulated rivers

Despite the drawbacks of regulated river schemes for salmon habitat (see Chapter 4) they do offer opportunities to manipulate flow specifically for restoration purposes.

5.6.1   Spawning gravels

In regulated river systems water can be specifically released to mimic natural spate or freshet events facilitating removal of fines from spawning habitat. The technique is discussed in several papers (Fredriksen *et al.*, 1980; Reiser *et al.*, 1989; Nelson *et al.*, 1987; Sambrooke & Gilkes, 1994).

Resier *et al.* 1989 make the point that streams vary in both hydrological and morphological characteristics. Thus methods used to prescribe flushing flows will evolve from and be specific to a given set of stream conditions. For a specific river system they present a methodology and identify a range of flows which will initiate surficial flushing and subsequently mobilisation of gravels and, at higher flows, surficial flushing and subsequently mobilisation of cobbles. For their specific system they predicted that a flushing flow of 57 m^3s^{-1} occurring for 1 to 3 days would be sufficient to remove sediment from spawning gravels.

Fredrikson *et al.* (1980) produced a family of curves for flows necessary to disturb riffle gravel in a 16 km downstream target zone. For a given particle distribution and channel slope, the bed becomes increasingly unstable and the stability coefficient decreases as the discharge, flow velocity and depth of flow increase. By way of illustration, typical stream characteristics result in a flushing flow of 1.7 m $^3s^{-1}$ per metre of stream width. This rate of flow would produce a flushing velocity of 1.7 m $^3s^{-1}$ with a flushing flow depth of 1.0 m. Thus in a 15 m wide channel, a riffle in the target reach would require a flow of 25 m $^3s^{-1}$ to initiate silt removal.

Bjorn *et al.* (1977) make the point that where an armour layer has formed, higher flows are needed to flush fines from beneath it. This may need to be augmented by **mechanical disruption** of the armour layer (Nelson *et al.*, 1987).

Following detailed and long term investigations on the effects of a major impoundment scheme in south west England, Sambrook and Gilkes (1994) developed an **enhanced flow programme** specifically for fisheries purposes utilising a designated water bank within the reservoir (7% of capacity). The overall objective was to achieve the optimum balance between resources and fisheries production.

Rules of operation were developed to promote an **environmentally acceptable strategy** that supported hydropower generation. The approach was implemented through a process which involved identification of specific flow criteria for the various life history stages of salmon and development of appropriate installations to control flow in order to ensure the correct patterns of release. Thus adequate water would be released at the appropriate times of year for completion of all life history stages, with a view to maintaining and improving natural recruitment into the system.

In addition to simulating freshets to encourage adult fish into the river at appropriate times of year, the programme also included releases targeted at flushing silt from spawning habitat. 11.64 m ^{3}s^{-1} was proposed as a flow likely to initiate transport of spawning bed sediment in a river channel 7 m wide. Releases are made in October, to simulate and coincide with natural freshets, in order reduce the risk of compaction and consolidation of gravel spawning areas. Adequate flows are maintained from January to March, to ensure that the wetted area is sufficient to facilitate the incubation and development of eggs and alevins.

Work in Canada (Ruggles, 1988) also documents the successful use of a suitable flow release strategy to protect the salmon resource on a river system subjected to a hydropower generation scheme. Minimum summer flows were prescribed to maintain wetted area for juvenile production, based on a one in four year minimum July flow. The author refers to several other studies (Moffett, 1949; Neave, 1958; Lister and Walker, 1966 and Mundie, 1979) which have demonstrated improved conditions for anadromous fish on regulated rivers as a direct result of improved and stabilised flows.

However, it should be recognised that even in highly regulated rivers the use of artificial flushing flows may not be necessary or appropriate. Reiser et al. (1985) highlight the need to establish the problem and hence a requirement for flushing, stating that unsubstantiated blind recommendations and releases can be severely detrimental to the aquatic system. Nelson et al. (1987) reviewed the potential use of flushing flows in a severely environmentally damaged regulated river, and concluded that anthropogenic considerations, such as floodplain damage and hydropower generation, were more important.

5.6.2   Juveniles

Provided that the basic requirements for velocity and depth are met, regulated rivers can provide very productive habitats for juvenile salmon, and reduce the possibility of scouring spates during the spring and summer months. Conversely, flows can be maintained during dry weather periods which can in turn enhance overall biological productivity.

In order to minimise density dependant mortality of juvenile salmon, sufficient wetted habitat must be maintained throughout the year. This is commensurate with providing enough suitable habitat for the sustained production of benthic invertebrates, which in turn will provide food for resident juvenile salmon.

To optimise juvenile productivity in riffles, the water depth should be in the region of 20-30 cm. Water velocity in riffles should be maintained at a minimum of 20 cm/sec. Stewart (1973) suggested that a guideline flow of 2.5 Ml/d per metre width of channel should provide such a survival flow. Where possible, an optimum velocity of 50-65 cm/sec should be maintained.

Smolt migration can be assisted by appropriate releases of water during the months of April, May and June. As smolt migration takes place mainly at night, enhanced releases during the hours of darkness are likely to be the most effective. There is

evidence to suggest that smolts are unwilling to maintain station at velocities greater than 2 body lengths per second (Thorpe and Morgan, 1978), and are therefore likely to be displaced downstream by velocities exceeding 25-30 cm/sec. Releases of sufficient water to generate velocities of this magnitude should therefore be effective.

5.6.3   Adults

In order to ensure that harmful temperature and dissolved oxygen conditions do not develop, a sufficient baseline flow is required. The survival flow suggested by Stewart (1973) of 2.5 Ml/d per metre width of channel can be used as a guideline value.

Releases of water also need to be made to encourage the upstream migration of adult salmon. The actual timing of such releases may vary from river to river, depending upon the seasonality of salmon runs into the river. However, releases during the autumn months are essential in order to encourage the movement of fish onto the spawning areas. Such releases are likely to be most effective if they coincide with periods of rainfall and increased natural run-off, from other parts of the catchment (Sambrook and Gilkes, 1994).

In particular, releases of water should be used to prolong the recession of naturally occurring spates, preferably for a period of 48 hours, as radio telemetry studies have shown that the majority of salmonid migration occurs on the receding limb of a spate (Sambrook and Gilkes, 1994). Stewart (1973) concluded that upstream migration of salmon commences at flows equivalent to 7.5 Ml/d (0.087 cumecs) per metre width of river channel, and that the mean flow for salmon migration is approximately 18 Ml/d per metre width.

5.7   Water quality issues

Whilst strictly speaking water quality issues are outside the scope of this manual, certain types of habitat management and restoration have beneficial effects on water quality. Most notable are the land management practices such as buffer strips refferred to above used in farming and forrestry.

The vegetation alongside a river has the potential to reduce the impact of non-point source pollution such as agricultural runoff from a variety of origins (for example: slurries from livestock, nitrates and phosphates from fertilisers, heavy metals from mine pollution, suspended solids from land erosion etc.). Mainstone *et al.* (1994) provide a detailed review of land management techniques for the prevention of diffuse pollution within controlled waters.

Pollutants present in water moving through the riparian zone can be immobilised and degraded by the physical and biological processes operating in this strip ecosystem. The recommended width is 10 m for upland streams and 100 m for lowland rivers (Large & Petts 1992). Effective treatment is achieved by management of the riparian corridor so that environmental conditions (such as slow rates of under drainage) favour these processes (Reddy and DeBusk, 1987; Reddy and Smith, 1987).

Buffer plants such as *Phragmites communis* and *Typha latifola* can be used to create a riparian reedbed system which will act as an effective **substrate-plant biofilter**. These species are capable of high rates of growth associated with elevated levels of nutrient uptake and demand (particularly nitrogen and phosphorous). The presence of a wider land based riparian plant community will also act as a physical barrier to pollutants, retarding their translocation from soil to water as well as having a role as a biofilter. As water passes through the rhizosphere, microbial activity results in the decomposition of organic matter and the denitrification of nitrogen sources. Depending on the rooting medium, much of the phosphorous component may become fixed within the soil media (Brix, 1987).

In order to maximise the removal of nitrogen and phosphorous via direct uptake into the plant tissue, high growth rates and levels of standing biomass must be achieved. Hence frequent harvesting may be required to remove the accumulated nutrients, encourage new growth, preventing any release of pollutants from senescent plant material (McEldowney 1993). However, the harvesting of plant material will reduce the beneficial impacts that riparian vegetation imparts to salmon habitats (shade, inputs of allocthanous material, diversity of habitat etc.) and therefore frequent removal of riparian vegetation may compromise the overall validity of using this as a specific habitat management technique.

Other land based habitat management schemes which may influence water quality and fish habitat indirectly include ESA, nitrate sensitive areas, set-aside, MAFF Habitat Scheme for Water Fringe Areas and many others. Hence, the significance of these schemes in facilitating or aiding habitat restoration should be recognised

Finally, a significant amount of research is currently being undertaken on land use and upland management including a major research programme examining the influence of sheep grazing upon soil erosion and run-off rates. This may have wide ranging implications for habitat, impacting upon all functions of the Agency including fisheries, conservation, water quality and flood defence (Johns, 1997).

Table 5.1 Summary of instream salmon habitat restoration techniques.

	EFFECT	EGGS	FRY	PARR	ADULTS
1. Weirs, Stop-logs, Groynes	i) Protect gravels from washout	✔ ✔			
	ii) Protect gravels from siltation	✔ ✔			
	iii) Accumulate gravels	✔ ✔			
	iv) Create plunge pools				✔ ✔
2. Gravel Cleaning (ploughing, high pressure hose, vibrating bucket)	Reduce fines & increase mean particle size	✔ ✔			
3. Gravel Additions	Additional spawning area	✔ ✔			
4. Artificial Spawning Channel	Additional protected spawning area	✔ ✔			✔
5. Bank protection (bank revetments, rip rap)	Erosion prevention reducing siltation & compaction	✔ ✔	✔ ✔	✔ ✔	
6. Rubble Mats & Loose Stone Flooded Weirs	Reduce depth, increase velocity & hydraulic roughness		✔ ✔	✔ ✔	
7. Channel Deflectors	Increase hydraulic diversity, create a thalweg		✔ ✔	✔ ✔	✔
8. Channel Constrictions	Increase depth to eliminate braiding & create juvenile habitat		✔ ✔	✔ ✔	✔
9. Two Stage Channels	Concentrate and maintain wetted area, maintaining depth as above		✔ ✔	✔ ✔	✔
10. Obstruction Removal	Eliminate impediments to migration				✔ ✔
11 Fish Passes	Overcome impediments to migration				✔ ✔
12 Holding Pools	Provide depth as sanctuary for adults				✔ ✔
13 Overhangs	Provide cover as sanctuary for adults				✔ ✔

Table 5.2. Summary of land based salmon habitat restoration techniques.

TECHNIQUE	EFFECT	EGGS	FRY	PARR	ADULTS
14. Control Tunnel Vegetation	Increase primary productivity & consequently juvenile fish food		✔ ✔	✔ ✔	
15. Fencing	Isolation of livestock to protect banks from de-vegetation & erosion and the bed from trampling & compaction	✔ ✔	✔ ✔	✔ ✔	
16. Land Management (buffer strips, grazing control)	Reduced agricultural runoff, reduction in non point source pollution, reduction in silt transport and siltation	✔ ✔	✔ ✔	✔ ✔	✔
17. Channel Modification (riparian vegetation - trees etc.)	creation of thalweg, channel narrowing, meander creation	✔	✔ ✔	✔ ✔	✔ ✔

Table 5.3. Summary of flow manipulations as a technique for use on regulated rivers appropriate in habitat restoration.

TECHNIQUE	EFFECT	EGGS	FRY	PARR	ADULTS
18. Flushing Flows	Mimic natural spates to mobilise gravels and flush out sediments	✔ ✔	✔	✔	
19. Maintain High Summer Flows	Increase and maintain wetted area for juvenile habitat		✔ ✔	✔ ✔	
20. Simulate and Prolong Natural Spates	Encourage upstream migration of adults and downstream migration of smolts			✔	✔ ✔

5.8 Current limitations

In considering habitat improvements as a means to elevate salmon stocks, the current limitations of the techniques need to be borne in mind. These encompass a number of areas but are fundamentally influenced by a lack of coherent research and reporting of techniques used in the UK. One of the objectives of this manual is to redress this situation such that experience can be built upon to further habitat restoration as a valuable and effective tool for the fisheries manager. Notable current limitations to application of restoration techniques are as follows.

5.8.1   Habitat requirements

The habitat requirements for the different life stages of salmon discussed in Section 3 are a synthesis from a variety of literature sources. This can be used as a framework to optimise the production of juvenile salmon, and hence ultimately returning adults. However, it should be noted that these requirements have been generalised to represent a "typical" watercourse and may not address variations in different river types. For example, the habitat requirements of yearling parr in a chalk stream may differ slightly from those in an upland river.

In time, habitat suitability criteria from research studies will be available for a wider variety of river conditions allowing more specific guidance in designing schemes. In addition, information from previous habitat restoration schemes will be available if the appraisal and reporting guidelines in Section 12 are followed. The latter approach, particularly if controls are used, will be useful in assessing relative quantities and distributions of habitat for different life stages. This information is vital if limiting habitats are to be accurately identified.

i)   River types

As mentioned previously, river type is fundamentally important when considering habitat improvements. Techniques known to be effective in chalk streams may not be effective in terms of increasing productivity in highly erosive upland rivers. Hence when utilising this manual due regard should be given to the origins of referenced work and the river type in which structures have been evaluated. Much of the work undertaken in Ireland, for example, has been on lowland rivers and hence extrapolating from techniques known to be successful here should be undertaken with this in mind. This is not to say that a technique such as rubble mat addition will not be effective but that it should be applied, monitored and evaluated to establish its comparative effectiveness over a range of river types. In addition to the productivity increases associated with structures in different river types, the longevity and maintenance requirements of these structures should also be established.

ii)   Species

Much of the work reported in the manual will be appropriate to both Atlantic Salmon and Brown Trout, although potential areas of conflict have been highlighted (see Section 5.8). When planning specific schemes this factor must be taken into account. In addition, great caution should be exercised when examining literature emanating from North American Pacific coast species such as *Onchorynchus* and *Salvelinus*. Different life history stage requirements mean that much of the literature is not directly appropriate for Atlantic Salmon. However, selective consideration, particularly after consulting the habitat requirements literature review (Section 3), will enable an informed understanding of the effectiveness of various techniques based on the habitat conditions they are likely to generate.

5.8.2   Habitat assessment

The majority of the techniques used in assessing the different types of habitat present within a length of river or catchment have historically been applied to smaller riverine systems, with the notable exception of the Tweed. If a restoration scheme is proposed for a large scale system (several thousand kilometres of river), it is possible that the methods used for quantifying the extent of the different habitat types may introduce significant experimental error, leading to a miss-representation of the different habitat types present. Reference to the forthcoming Agency R&D Project on River Habitat Inventories will provide guidance to improve the use of habitat assessments at catchment level.

5.8.3   Multidisciplinary approach

The need to consider catchment wide processes when designing habitat restoration schemes has been a recurring theme in this manual. Many schemes are doomed to failure because only fisheries personnel are involved in the project management and wider based risk assessments are not undertaken.

Problems can be created both by conflicts of interest between fisheries needs and other uses (see below) but also because critical causes of habitat degradation are not addressed by fisheries schemes. An obvious example of the latter situation is the imposition of gravel cleaning schemes in silted reached when no or little attempt has been made to stem the source of sediment input from arable land.

These problems should be addressed by approaching habitat restoration from a catchment perspective using the different skills and experiences of professionals such as geomorphologists, engineers, conservationists, hydrologists, and water quality officers. **Multi-disciplinary habitat restoration groups** could be set up within the Agency and tighter links forged with appropriate outside bodies.

Instream habitat restoration schemes should be implemented with caution and respect for site specific circumstances. Indiscriminate use is more likely to result in negative impacts. It should always be borne in mind that watershed conditions and processes may rule out the use of instream schemes. Under these circumstances, restoration of natural watershed and riparian processes is often the best long term strategy.

5.8.4   Appraisal and reporting

Habitat restoration as a discipline has been held back by a lack of pre- and post-scheme monitoring and appraisal of objectives. In addition, where satisfactory appraisal methodologies have been applied, the results have not been adequately disseminated to other fishery managers. In order to overcome this lack of information, it is suggested that a regional or national contact point and database are implemented in conjunction with the appraisal methodologies and reporting requirements detailed in Section 12.

5.9   Habitat improvement – conflicts of interest

Certain areas of habitat restoration and creation may result in **intra and inter specific competition**. Habitat improvements targeted at improving stream habitat for trout (both adults and juveniles) may not necessarily benefit juvenile salmon. This was well demonstrated by Morris and Collen (1992), who used large scale habitat improvements using the traditional North American approach of log weirs to create habitat diversity (pools and riffles) in an otherwise characterless channel. The habitat improvements were seen to be highly beneficial to juvenile trout but not to salmon, which did not respond at all to the **habitat diversification**.

O'Grady (1993) points out that the effects of shading, particularly with respect to long reaches, are not so severe on trout as they are on salmon. Hence, when assessing the benefits of removal of bankside tunnel vegetation, the variable effect on different species will need to be recognised when evaluating the cost effectiveness of the strategy. In addition, the promotion of fencing as a restoration measure should be carefully considered. Whilst fencing is undoubtedly beneficial in certain circumstances, complete removal of bankside grazing can allow unchecked riparian vegetative growth (O'Grady, 1993). In these circumstances, productivity may then be lost via excessive shading.

With respect to the use of weirs to provide adult lies, it should be recognised that creation of pools via weirs, deflectors and other methods, whilst providing holding stations for adults, may contradict the habitat requirements of juvenile salmon. Bourgeois *et al.* (1993) pointed out that juvenile salmon showed a definite lack of preference for bank overhang structures. Whilst these may be of benefit to adults, little advantage to juveniles may be expected. If juvenile habitat is to be lost whilst creating these structures then clearly the results will be detrimental to salmon stocks overall via reduced juvenile productivity.

The relative requirements for different types of habitat need to be evaluated at the habitat assessment stage of a project and possible conflict arising from habitat improvements avoided if possible. This is a potentially contentious area, particularly where angling interests are involved and needs to be given careful consideration. However, it should be remembered that in many if not most salmon river systems salmon and trout co-exist in a naturally defined varied riverine habitat. Hence, if the broad aim of habitat restoration is to diversify anthropogenically influenced homogenous habitat, this can only be to the benefit of salmonids in general. Therefore, engineering schemes designed specifically for one species may not be either desirable or achievable (O'Grady, pers. comm.).

The issue of large woody debris is also contentious. Trash dams, particularly in remote tributaries, can prevent fish access to spawning grounds. Taken collectively on a catchment wide basis, such impediment to upstream migration may have a significant effect on juvenile salmon productivity (APEM, 1995). However, the value of woody debris in providing habitat diversification and promoting accumulation and retention of spawning gravels is well documented (House & Boehne, 1986). Hence large woody

debris removal is best undertaken in an objective manner and should not be regarded as a requirement for wholesale catchment cleaning.

Debris also provides ecological diversity within river systems and hence has an influence over conservation value. Other notable potential conflicts with conservation include earth cliffs for sand martins and silt banks for lampreys. In both cases, salmon management strategies such as bank revetments to stabilise erosion and sediment removal to reduce siltation, may be in direct conflict with conservation interests. This emphasises the need for an holistic and co-ordinated approach to salmon habitat restoration such that the benefits to the specific salmon population under consideration can be gauged against local, regional and national conservation interests.

Finally potential conflicts with flood defence must always be borne in mind. Considerable effort has been expended on land drainage and flood alleviation schemes throughout the country over the post war period with a view to improving agricultural production and reducing flooding risks. In many cases such schemes have had a major impact on salmon rivers. However, the primary goal has always been to protect livelihoods and property. Therefore due consideration needs to be given to the impact of any salmon restoration scheme on flood defence, emphasising the need to discuss proposed projects with the appropriate Agency staff at an early stage. Clearly schemes which exacerbate flooding risk will stand little chance of approval.

5.10   Failures - a word of warning

Despite the advantages of the use of artificial structures to improve salmon habitat and hence productivity, the potential disadvantages should also be recognised. Hall and Baker (1982) and Hamilton (1989), in summarising both published and unpublished evaluations of the effectiveness of habitat modification schemes, suggested that studies with neutral or negative biological effects are seldom published. Similarly, Hilborn (1992) is critical of the process of evaluation of artificial channels and the ability of fisheries agencies to either learn from past experiences or to disseminate information. It appears that only spectacular successes or failures are adequately reported. He concludes that experience from habitat restoration techniques is best gained when goals are well defined, experiments can be conducted and evaluated rapidly and there is close organisational connection between decision makers, evaluators and operators.

Frissel and Nawa (1992), in their detailed analysis of the incidence and cause of physical failure of artificial habitat structures in the USA, quote many authors who plead for careful scientific evaluation of schemes (Hall and Baker, 1982; Reeves and Roelofs 1982; Everset and Sendell, 1984; Hall, 1984; Klingeman 1984 and Platts and Rinne, 1985). However, large and costly schemes are still being planned and implemented with little or no analysis as to their effectiveness.

Frissel and Nawa's (1992) results suggest that restoration is frequently inappropriate or counterproductive in streams with high or elevated sediment loads, high peak flows or highly erodable bank materials. In these cases they conclude that re-establishment of the natural watershed and riparian processes is the best form of amelioration in the

long term and would be more effective in enhancing salmon productivity than stream restorative techniques.

Babcock (in Frissel and Nawa, 1992) refers to a Colorado project where 75% of the structures had failed or were rendered ineffective during the first two years post construction following floods, whilst those that remained were invariably an impediment to migration of adults. In addition, negative or neutral effects were noted arising from placement of boulder beams and log structures.

Frissel and Nawa (1992) found that in two study areas half the structures had failed in less than 10 and 15 years respectively, when the design life was between 20 and 25 years. Clearly this has severe implications for biological productivity and economic evaluation. Obviously where mitigation for lost or reduced production due to anthropogenic disturbance is the driving force behind restoration schemes, the ramifications of these results warrant thorough consideration.

Ehlers (1956) reported that in the Kaweah River, USA only 10 of a total of 41 habitat improvement structures installed by the US Forest Service in 1935 were still in operation after a period of 18 years. He concluded that most failures resulted from the end-cutting and under-cutting action of water on the loose bottom and bank materials. Whilst rock, masonry and earth filled dams are highly susceptible to flood damage, log structures, provided they were well anchored, held very well. Of particular note was his assertion that maintenance work will be necessary wherever stream improvements of these types are built.

Frissel and Nawa (1992) conclude that geological physical elements of the channel influence hydrology and hence exert the primary influence over channel morphology and control the location of pool riffle sequences, meanders and other formations. Small scale structures such as log weirs, can only work effectively within the limits imposed by these powerful, larger scale patterns and processes. In consequence, new artificial structures, in their experience, are more likely to result in local destabilisation of the channel than stabilisation of, for example, spawning gravels. In conclusion, they state that, complex multiscale interactions between watershed condition, fluvial processes and structure design will determine the success or failure of individual structures and habitat restoration projects.

Everest and Sedell (1984) suggest that in order for artificial structures to function successfully they must meet carefully defined objectives specific to target species, life history stage and prevailing physical factors. Hence the design must be closely tailored to geomorphic and hydraulic conditions (Klingeman, 1984).

Practical engineering experience (Whelan, pers. comm.) has shown that successful use of gabion weirs and groynes for gravel protection cannot be predicted with any great certainty. The use of groynes, in particular, to achieve a desired objective is often "hit and miss". Installing groynes to protect gravel should be regarded at best as an imprecise science, the outcome of which cannot necessarily be guaranteed, and should be viewed in a specific local context.

The installation of weirs to accumulate gravels can fail for three reasons. Firstly, the prediction that gravel will accumulate is uncertain. Secondly, the likelihood of significant damage to the stream bed and banks may be significant, particularly under large flows. Thirdly, under the latter conditions, particularly in flashy rivers, the consensus is that accumulated gravels and the associated structure could be washed away.

Experience of poorly planned gravel additions has also revealed that merely tipping quarry gravel into a likely looking stream area in the hope of enhancing spawning habitat is likely to be unsuccessful. In several instances during research for this manual it was revealed that *ad hoc* gravel additions were merely washed away in the next spate. Accumulation of the washed out material, elsewhere downstream, could also have serious consequences.

In addition, Finnigan *et al.* (1980) state that gravel restoration can have adverse effects especially when use of heavy machinery is involved. They concur with the above on gravel additions, pointing out that as spawning gravels are inherently unstable by definition, addition of fresh (artificial) gravel to natural uncontrolled streams is often unsuccessful.

Further, Zeh and Donni (1994), when reporting on a project to reintroduce salmonids to the Rhine, described heavy siltation of gravel addition sites rendering them unsuitable for spawning. This highlights the problems of habitat alterations to hydraulically altered channels where flow regimes are no longer natural and silt loads are heavy. They concluded that without regular and costly gravel cleaning operations, gravel additions alone would not be successful. Hermansen and Krog (1985) conclude that stream deflectors do not work in lowland rivers with a large sediment load and a slope of less than 0.05%, stating that gravels were prone to covering with a thick layer of sand.

In conclusion, the use of instream protection devices, such as groynes, and the addition of gravel to create spawning habitat should be undertaken with caution and respect for site specific circumstances. Indiscriminate use is more likely to result in negative impacts. This point is well illustrated by Maughan *et al.* (1978) who cite examples of large scale failures of habitat restoration schemes which attempted to transfer North American west coast restoration techniques to the east coast fisheries. Clearly this emphasises the need for a thorough evaluation of habitat restoration techniques transferred from elsewhere before implementation.

Jones and Milner (1992) point out that installation of such instream structures reduces channel capacity and may cause conflict with flood defence objectives that could prejudice the success of the schemes. Therefore, the potential impacts on land drainage must always be considered. Bearing this in mind, in his overview of riverine habitat improvement techniques, Templeton (1995) emphasises the necessity of consulting the land drainage authorities and securing the appropriate permissions before undertaking any instream works which could be construed as having a negative influence on the ability of the channel to carry flood waters.

Splash
aprons

Spawning
gravel

FLOW

Gabion
basket

Plunge
pool

Figure 5.1 Gabion Weirs

Excavator

Perforated bucket

FLOW

Clean gravel replaced over silt

Silt
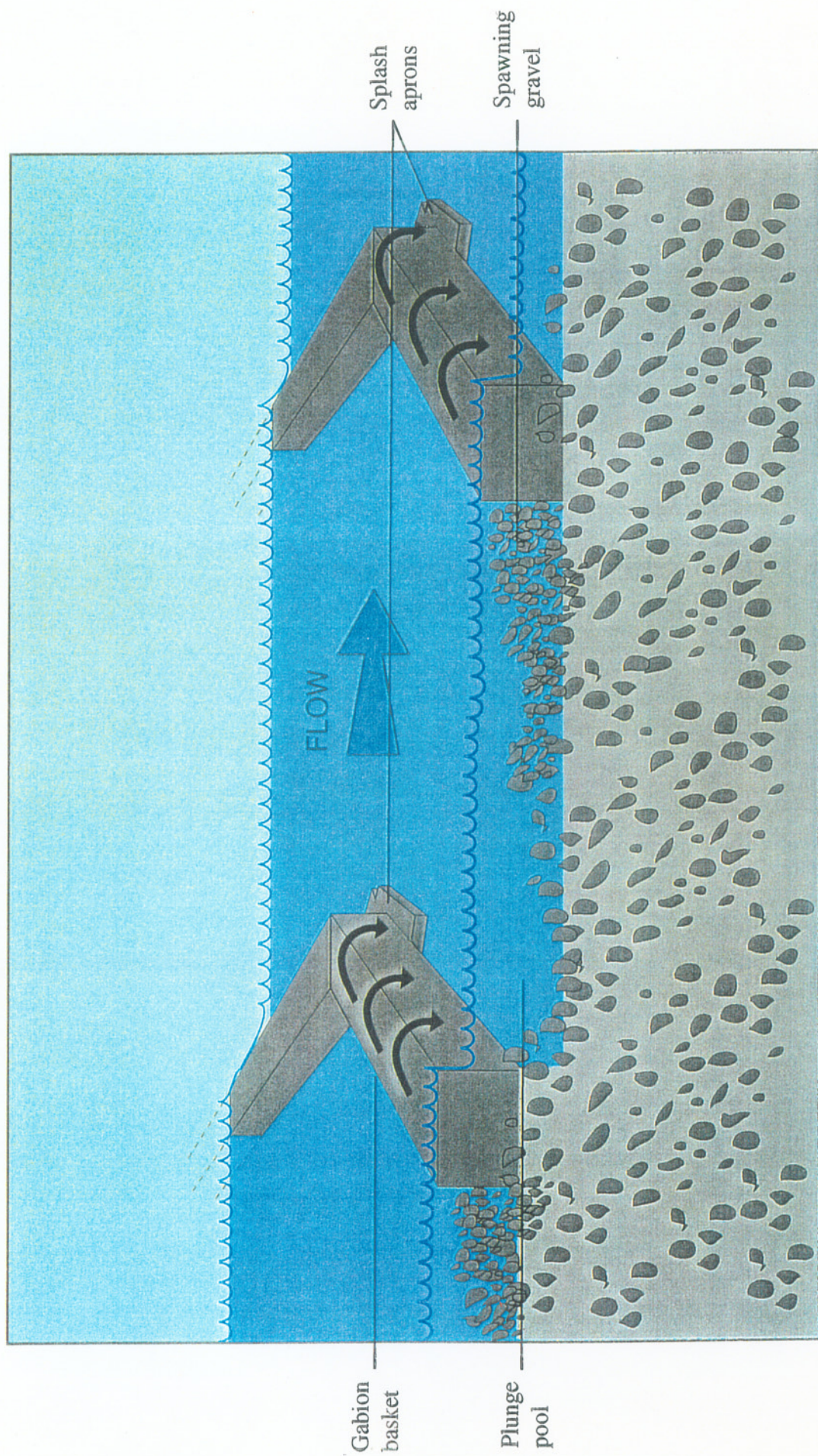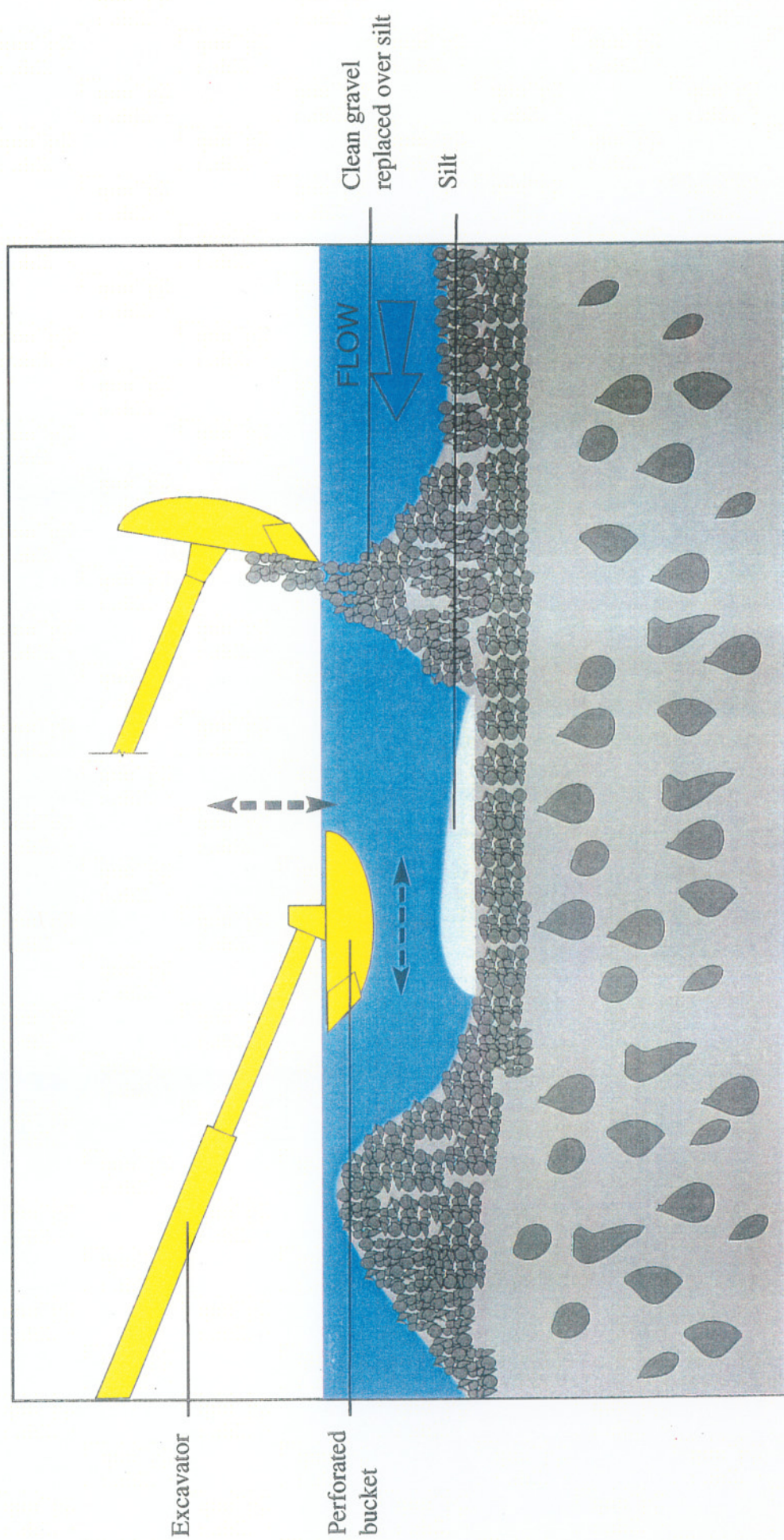
Figure 5.2 Andrew's "Vibrated Bucket".

FLOW

Area to be
excavated
(10m)

Bank protection

Fixing pins

Log
(30cm in diameter)

Cross brace

1.0m
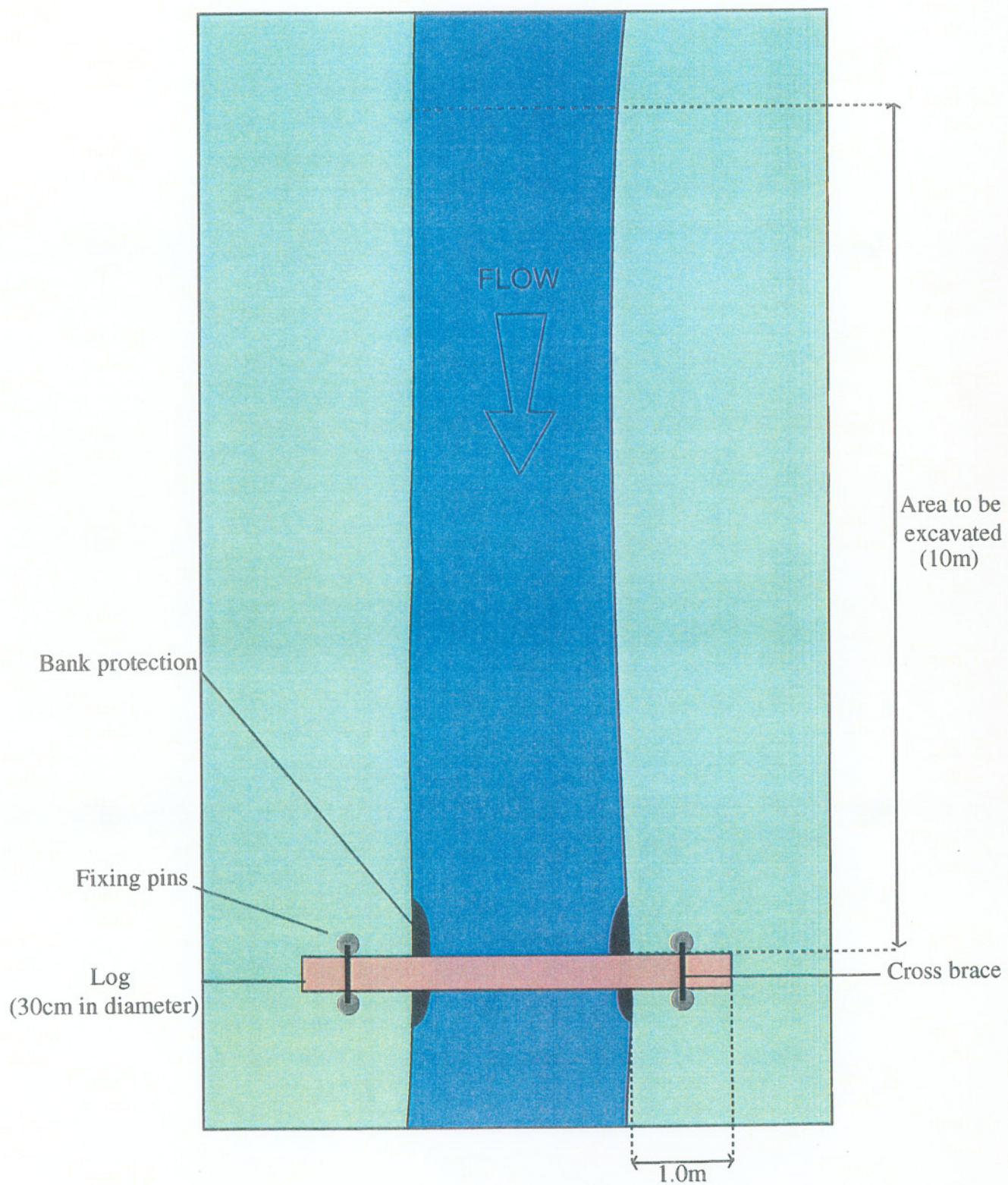
Figure 5.3   Plan of a Gravel Addition Site
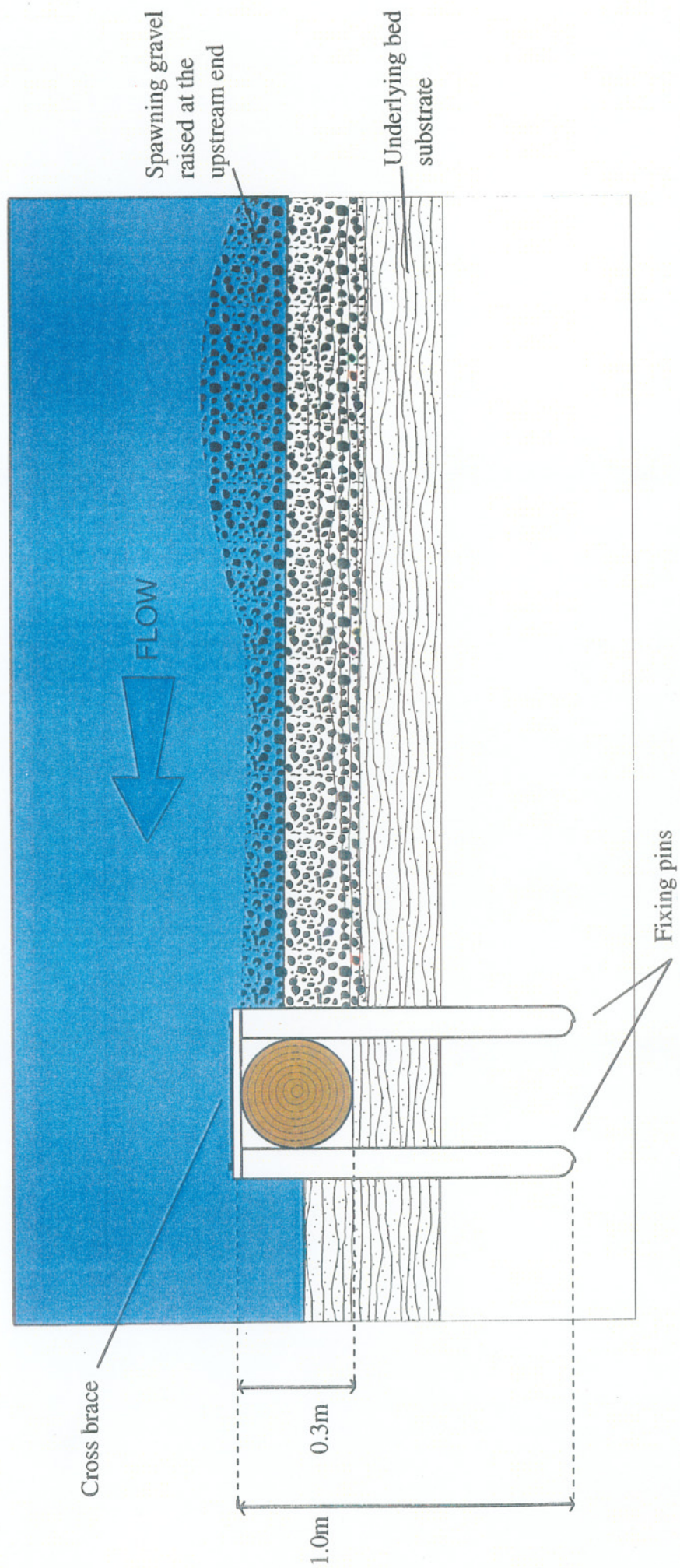
Figure 5.4   Cross Section of Gravel Addition Site.

River bed

FLOW

Eggs
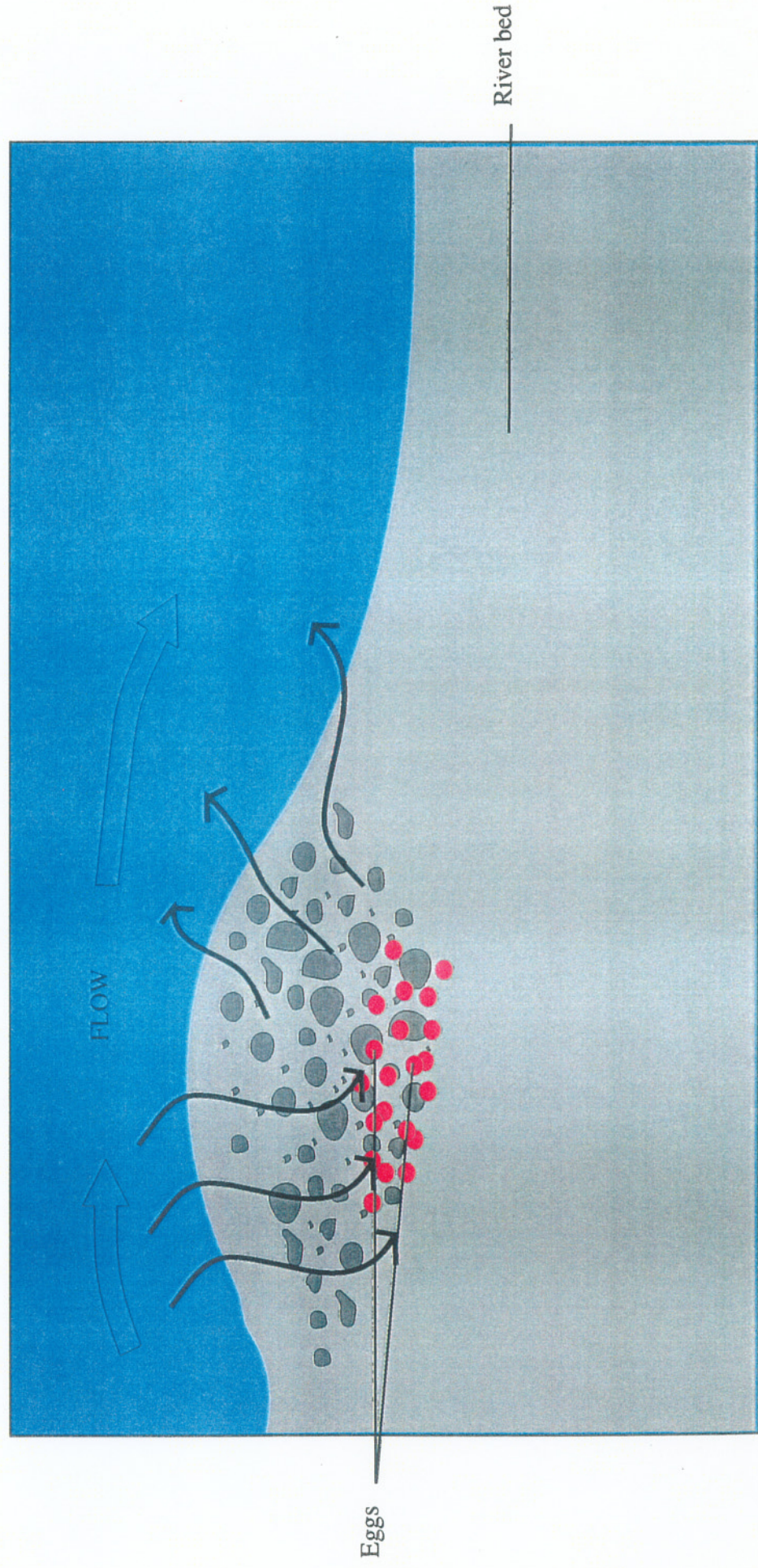
Figure 5.5   Spawning Gravel Structure

Downstream flow
controlled by weir
boards

Individual chambers
with pebbles to a
depth of 50-65 cm

Feeder stream

Access road

Intake screens

Upstream flow
controlled by
weir boards

Dam
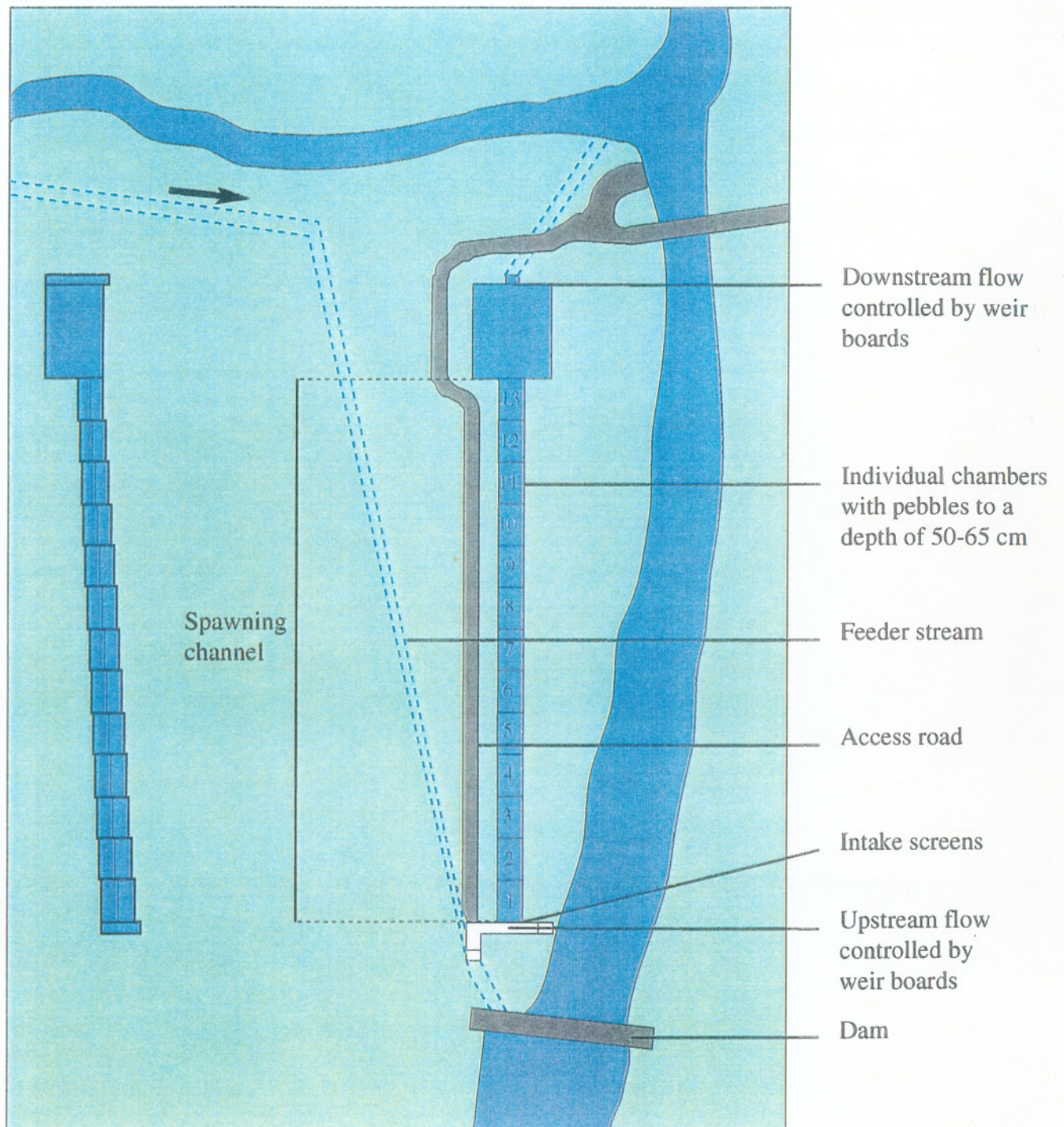
Spawning
channel

Figure 5.6   Plan of Artificial Spawning Channel
(Beall & Marty, 1983, a & b, 1987)

Plan View

Attach roadbase filter fabric to
the cross channel log & extend
upstream for 2m. Cover with
natural substrate to the bed
level of the stream.

Position cross channel log at
30-40° angle to flow & extend
into the stream bank to a
length of 60-90cm.

Fixing pins

Position revetment logs on the
outside corner of the bend and
stabilise with boulders

FLOW

View In Cross Section

Revetment log
Water level
Fixing pin and wooden spacer

Bank
Cross channel log lower on the
outside bend
River bed

Figure 5.7   Cross Channel Log & Bank Revetment

Plan View

FLOW

Rubble (200-300mm)

10m

Boulders (up to 700mm)

35m

View In Cross Section

Bank

Water level

0.5-0.7m

Rubble (200-300mm)

River bed

Figure 5.8   Rubble Mats

Plan View

FLOW
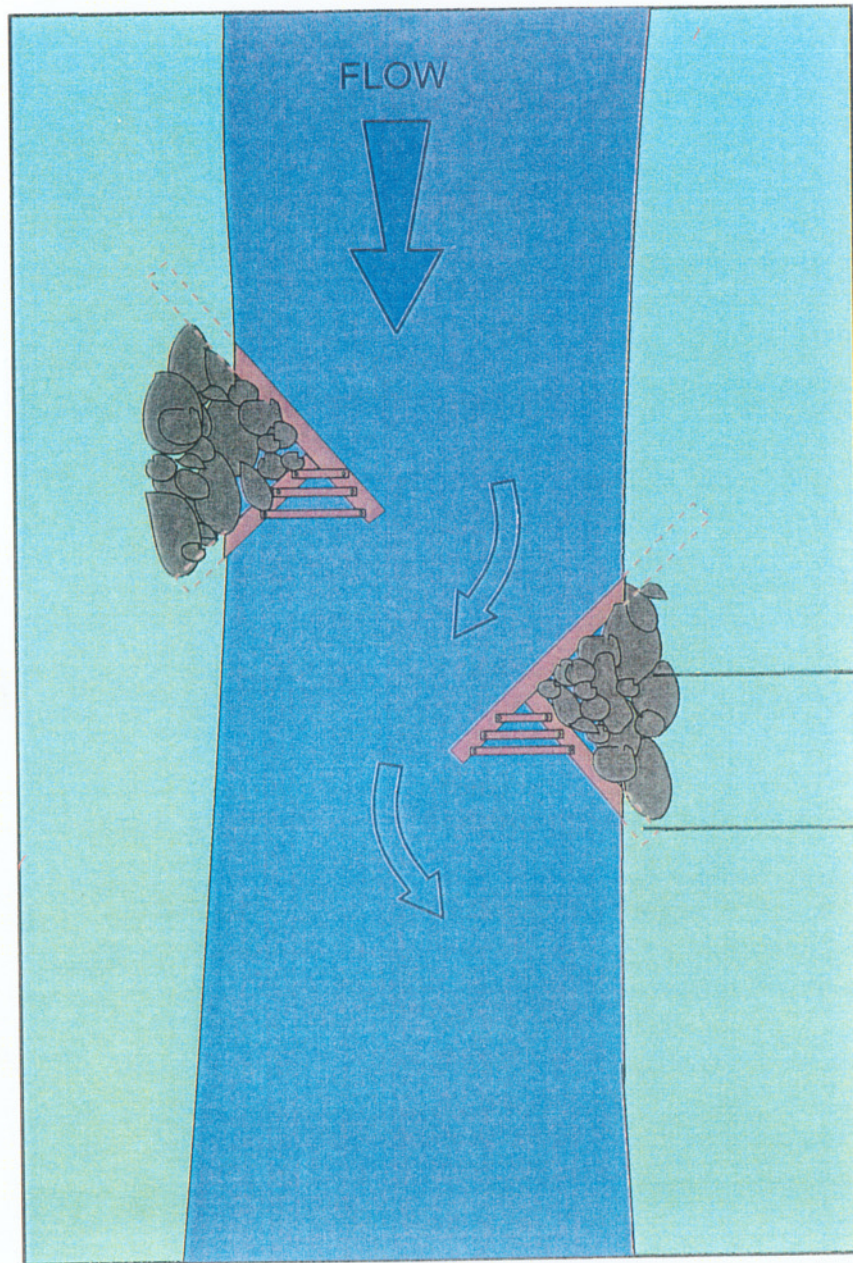
Banks stabilised with
large rip-rap.

Butt ends of logs
extended into stream
banks.

View In Cross Section
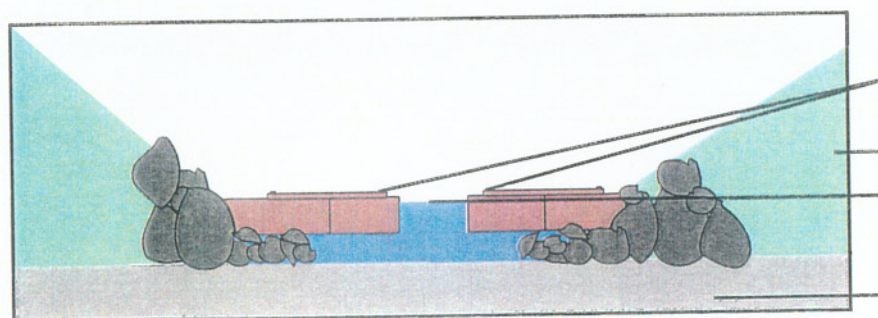
Fixing pins

Bank
Water level

River bed

Figure 5.9   Tip Deflector (paired)
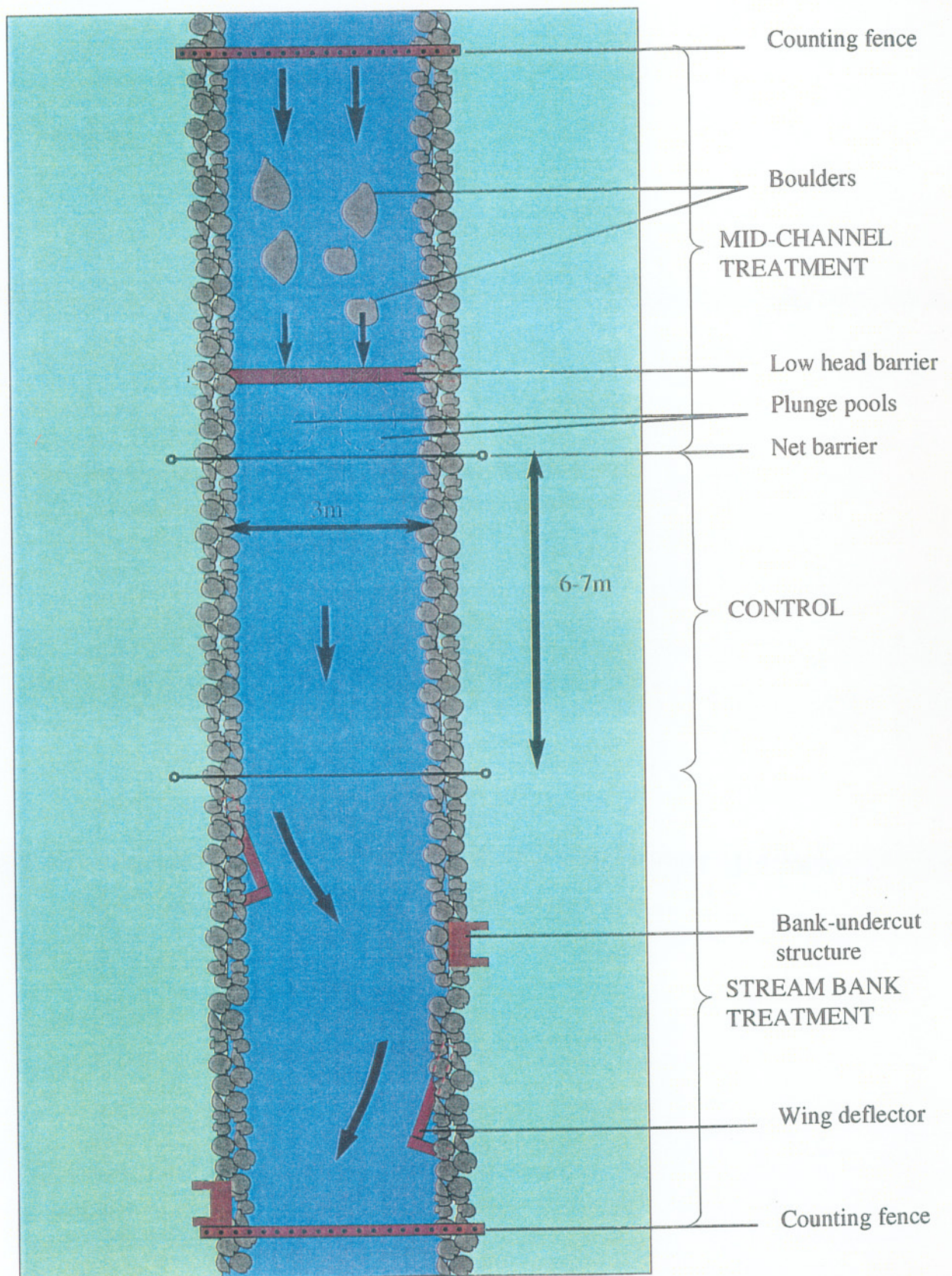
Figure 5.10 Schematic Representation of an Experimental Replicate Stream

FLOW
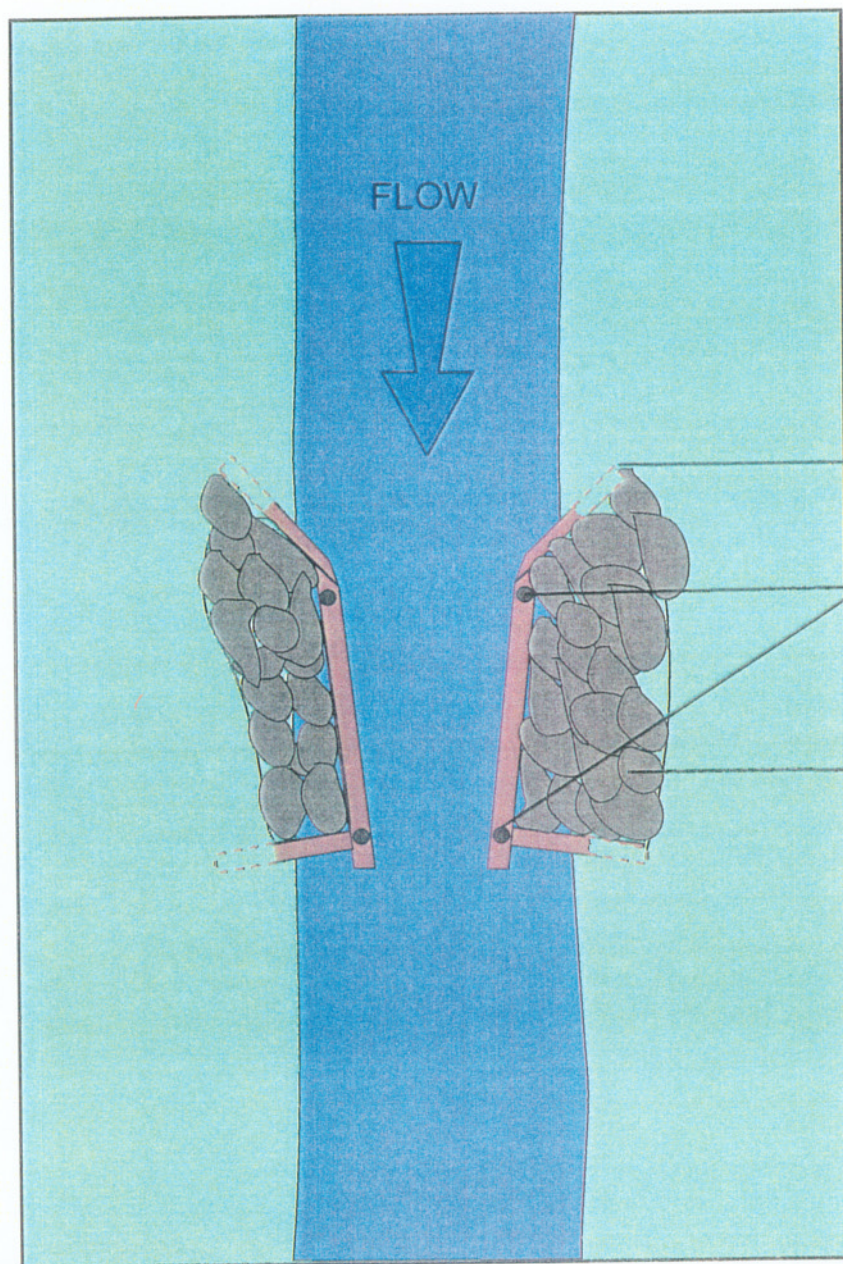
All logs used have a
minimum diameter
of 50cm

Upstream brace logs are angled at
45° to the face logs & extend into
the stream bank to a length of
60-90cm

Facing logs are pinned at
either end

Facing logs and brace logs are
stabilized by placing boulders
behind them, on a Geoweb base.

View In Cross Section

Bank

Fixing pin

Water level

River bed
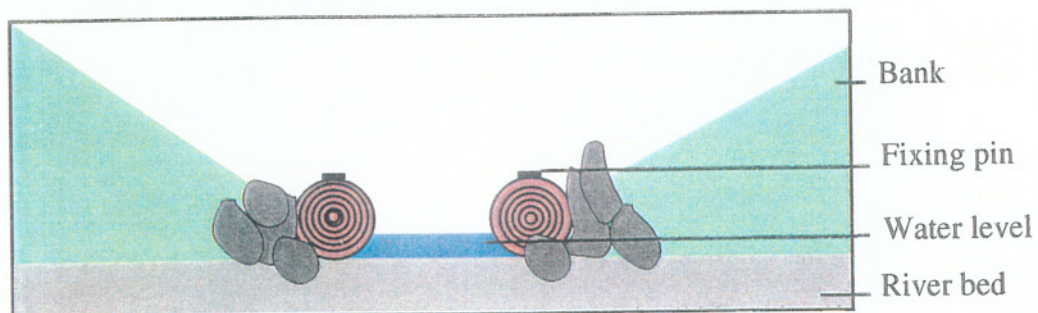
Figure 5.11   Channel Constrictor Plan View

FLOW

All logs used have a
minimum diameter
of 50cm

Raised bed

Upstream brace logs are angled at
45° to the face logs & extend into
the stream bank to a length of
60-90cm

Facing logs are pinned at
either end

Facing logs and brace logs are
stabilized by placing boulders
behind them, on a Geoweb base.

View In Cross Section

Bank

Fixing pins

High water level

Low water level

Raised bed
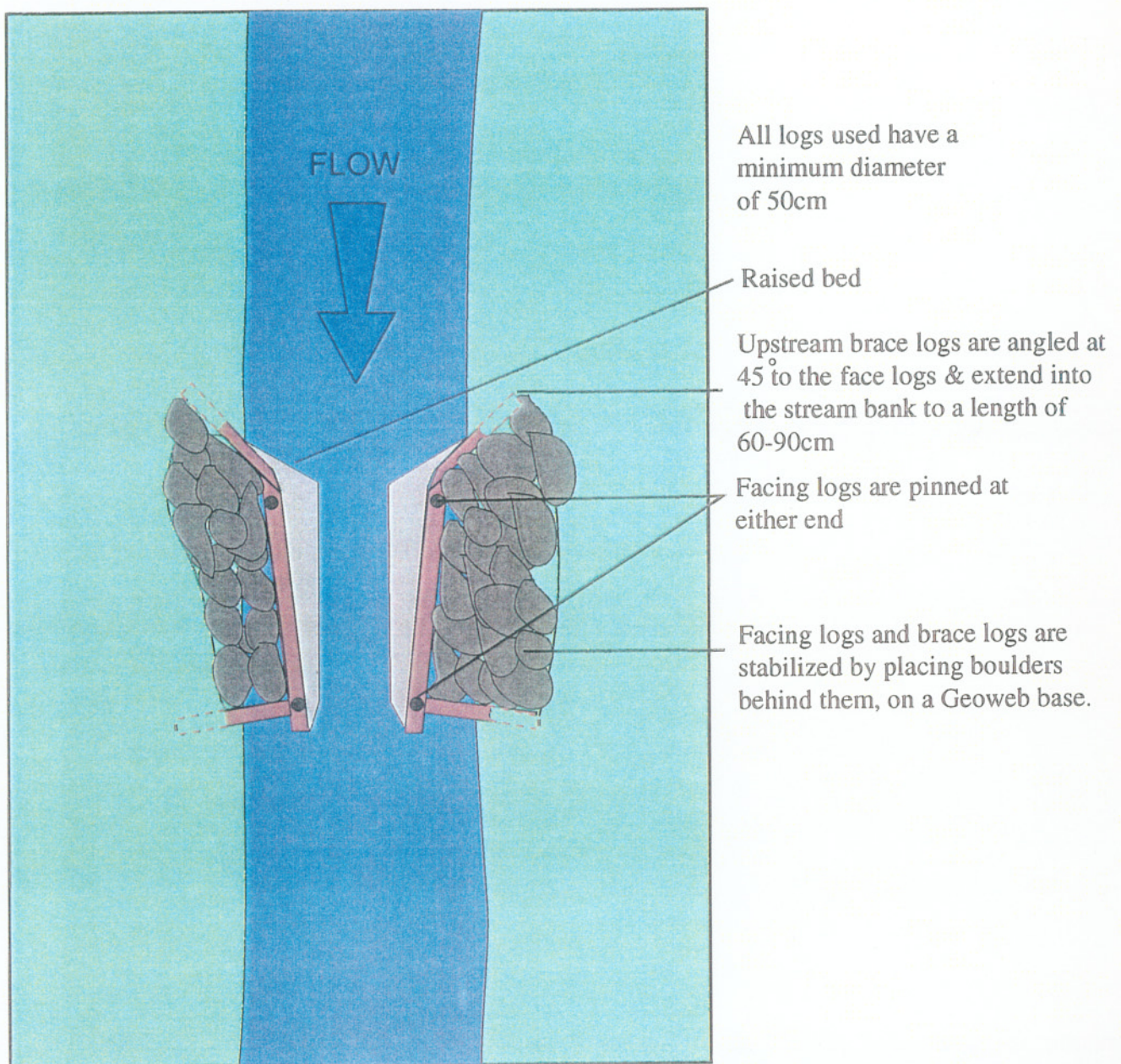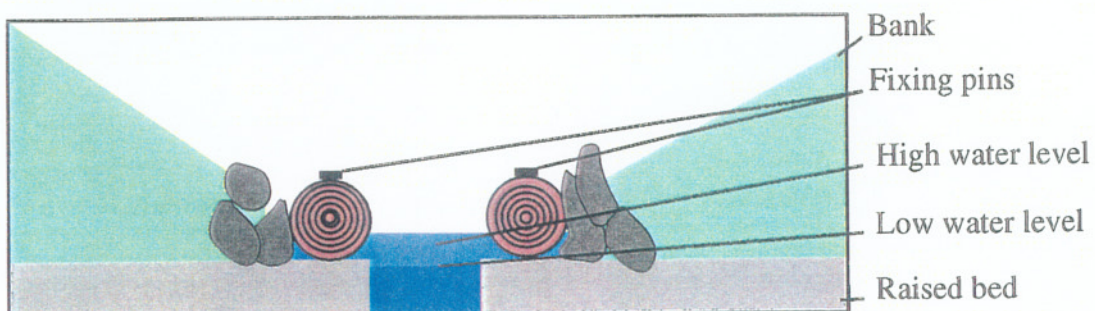
Figure 5.12   Low Level Channel Constrictor Plan View

FLOW

Upstream brace logs are angled at 45 to the cross -channel log.

Scour pool

Fixing pins

View In Cross Section

Bank

Fixing pins

Water level

River bed
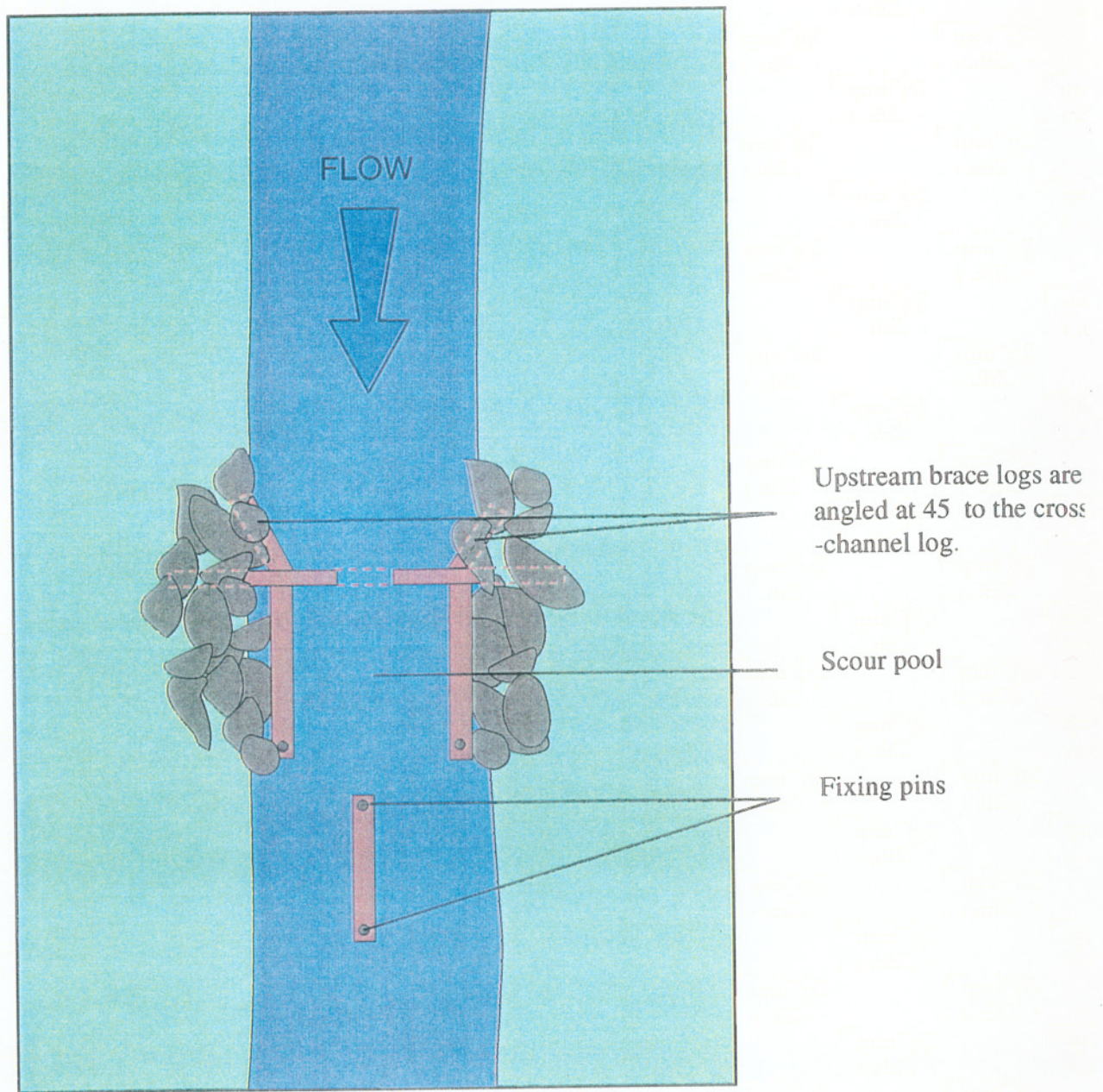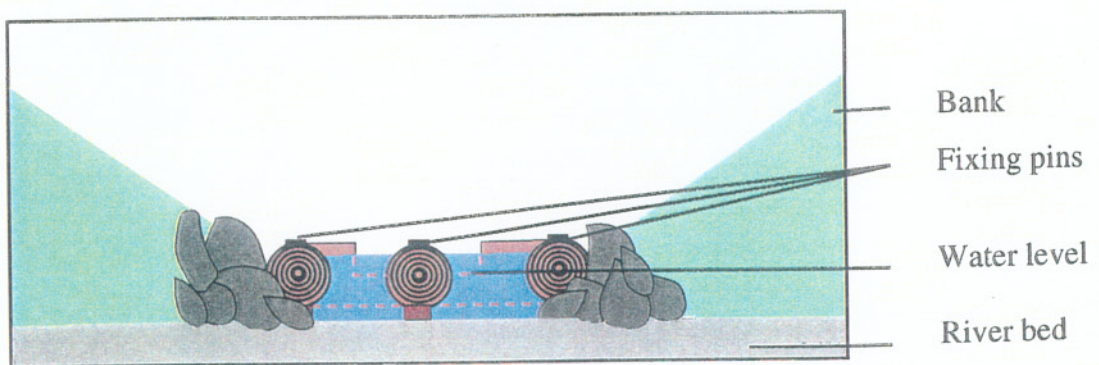
Figure 5.13 K Dam Plan View

FLOW

Hardware cloth, fiber cloth, or small mesh wire overlaid on hog wire

Brace logs face downstream ends 1-2m into bank

Stone fill

Rebar

Main logs face upstream, ends 1-2m into bank

Figure 5.14   Wedge Dam

Bundle of logs protect bank from erosion and form cover

Cantilevered Log set well back into bank

Large boulders help support log and stabilise the bank

Bank

Water level
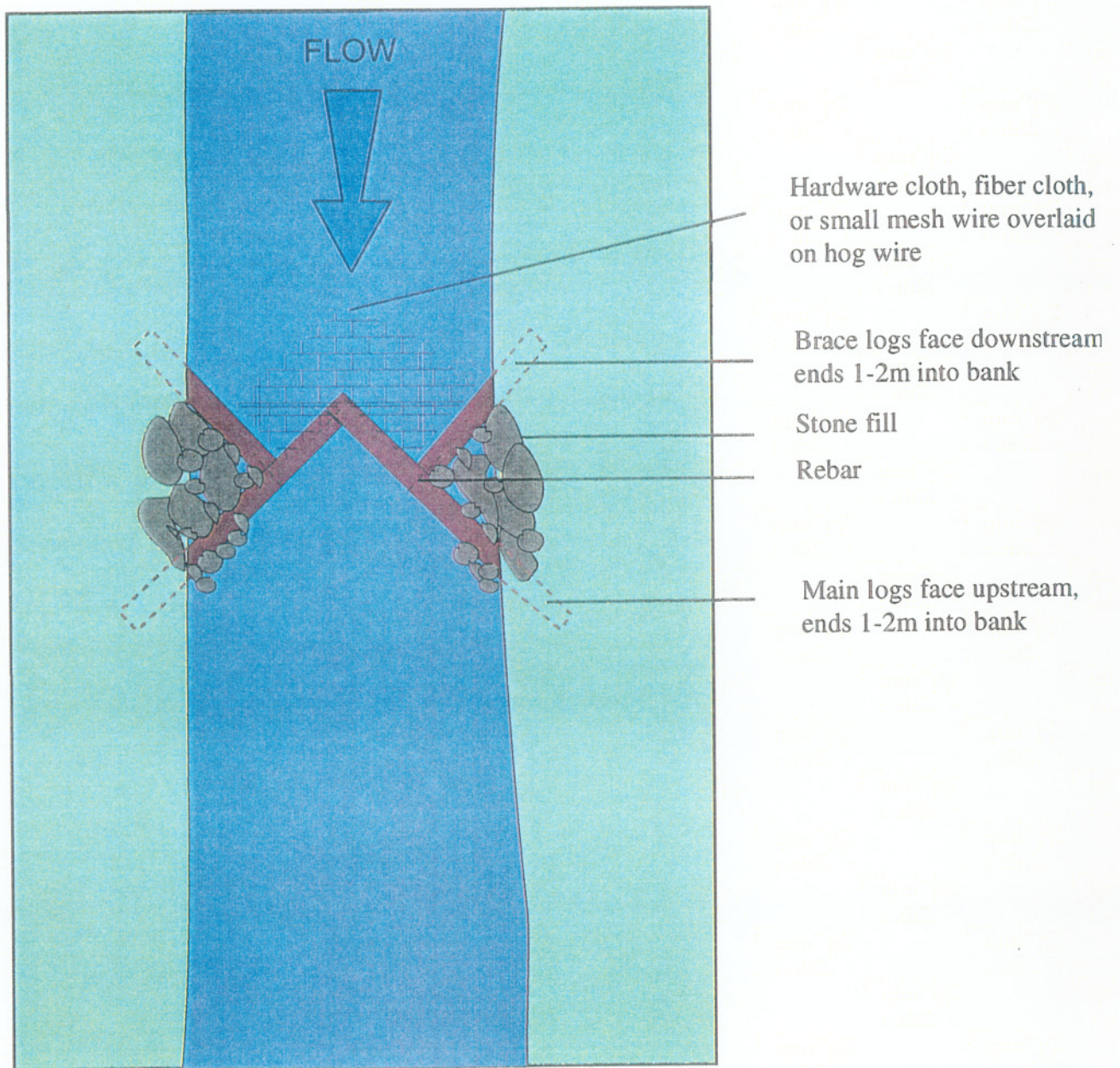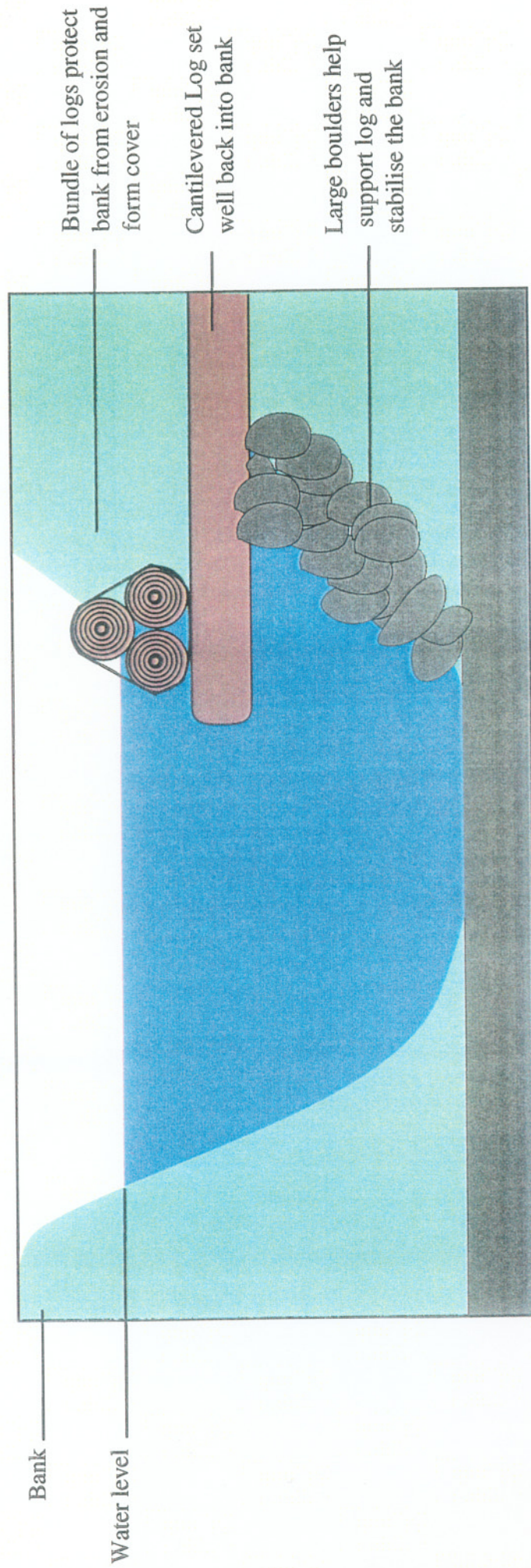
Figure 5.15   Cross Sectional View of Overhanging Bank Cover

Riprap can be used to reinforce the bank, which can be supplemented by attaching old Christmas trees to the face of the riprap

Cantilevered Log set well back into bank

Wooden planks are used to help support the log and reinforce the channel bank.

Bank

Water level

Figure 5.16   Cross Sectional View of Overhanging Bank Cover (Alternative Design)

6. PRACTICAL CONSIDERATIONS

During the course of the literature review, several authors offered practical advice based on their own experience in river habitat restoration and creation. This section represents an abridged synthesis of the experience reported in a quick access format. Of particular worth is the work of O'Grady *et al.* (1991) on rubble mats for juvenile habitat creation and Wesche (1985), who conducted a thorough practical review of in-stream structures such as weirs and overhangs. Although the latter are mainly targeted towards trout habitat improvement, the work does have some relevance to salmon, particularly with regard to spawning habitat and the creation of adult holding pools and bank cover for lies. Jones and Milner (1992) provide useful practical details specific to the UK for salmon habitat improvements undertaken on an experimental basis. The following presents an abridged synthesis of the practical points considered to be most applicable to salmon habitat restoration and creation.

6.1 Gradient

In general, there was overall agreement that gradient was one of the most important features influencing the success of habitat improvements. Klassen and Northcote (1988) and House and Boehne (1985) quote gradients in the range of 1 to 4% as being suitable for salmonid habitat restoration projects. However, Finnigan *et al.* (1980)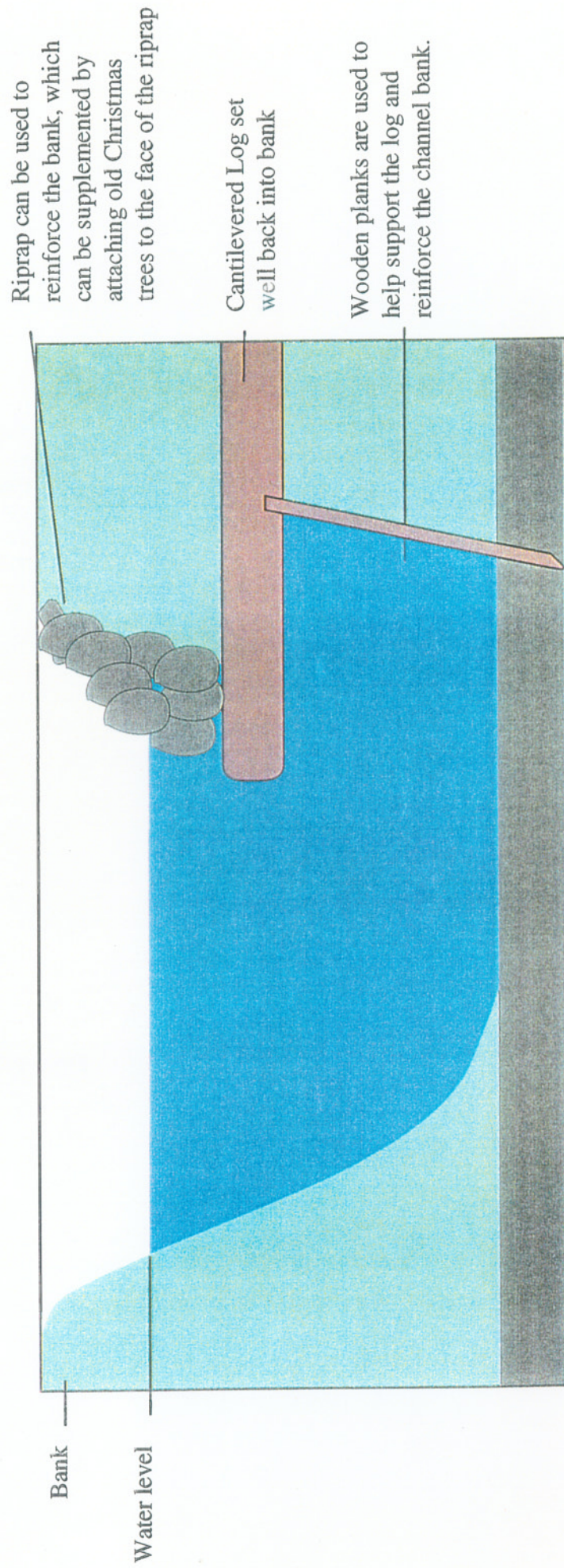 state that small streams (with a maximum width of 10 to 14 m) are prone to movement of spawning gravels by velocities achieved during freshets when gradients are as low as 0.3%. This is particularly the case if gravels have been destabilised by spawning salmonids during the process of redd cutting. In conclusion, they state it is important to improve stream habitat only in areas which have relatively stable flows and, if possible, to duplicate the existing gradient of the stream. In this context, regulated rivers offer good opportunities for habitat enhancement using artificial habitat structures.

6.2 Location of structures

Location of structures is vital to avoid problems of washout, erosion and undesirable habitat features such as sand bars developing. Table 6.1 details general points that apply to all habitat improvement structures.

Table 6.1   General principles for consideration with habitat improvement schemes

1. Consider principles of stream hydraulics during installation and placement of structures.
2. Only consider stream sections with stable banks and channels.
3. Select stream sections which are naturally armoured, if possible.
4. Select sites which are easily accessible for machinery and materials transport.
5. Select sites where natural features such as tree roots or large boulders can be used for anchorage.
6. Planning and consultation with engineers should occur at the earliest stages of design to incorporate habitat features with channel works as appropriate.

Table 6.2 details the specific requirements for optimising the location of each restoration scheme.

Table 6.2   Specific requirements for the placement of individual schemes.

Weirs & Stoplogs
1. Select sites which are straight and narrow, preferably at the end of a steep gradient.
2. Successive structures should be placed no nearer than 5 to 7 channel widths apart.
3. Low weirs are most successful in narrow (1 to 9m wide) headwater streams which are not susceptible to excessive flood flows (i.e. peaks from 2.8 to 5.7 cumecs).
4. It should be possible to anchor both ends of the dam/weir well into the banks (1 to 2m).

Boulder Placements
1. Do not locate near banks to avoid erosion.
2. Installation should be undertaken during low flows to ensure correct placement and allow for use of heavy machinery.

Deflectors
1. Deflectors can be successful on streams of various sizes and are hence not limited to small rivers.
2. Deflectors should be located to guide the direction of flow without forcing it.
3. Typical placement is in wider shallow sections, where flow constriction producing increased velocities and scour is desirable.
4. Avoid constricted channels having a high transport capability.
5. Areas with large flow fluctuations should be avoided or, alternatively low profile structures designed for low flow situations should be used.
6. Do not build at the head of riffles as this may cause severe erosion and possibly damming of the stream.
7. The bank opposite the deflector must be stable otherwise significant erosion should be anticipated.
8. In straight reaches, alternating deflectors spaced 5 to 7 channel widths apart can produce a natural sinuous pattern of flow.
9. Avoid steep high eroded banks.
10. Bank conditions should allow for anchorage of structure at least 1.2 to 2.0 m into the bank.
11. If the outside bank is stable, a deflector placed on the inside of a bend can enhance a marginal pool.
12. In rivers of low gradient (<0.03%), deflectors should be constructed so that the surface of the weir is at mean river level.

Bank Cover/Overhang
1. Often located on eroding banks on the outside of bends. In addition, they are often used in conjunction with other habitat features such as deflectors. A deflector will direct flow onto the opposite bank, an ideal location for a bank cover structure or overhang.

6.3   Structure materials

The materials used in many habitat restoration schemes are similar for the different structures identified. Table 6.3 suggests materials common to the different types of restoration schemes.

Table 6.3   Specification of commonly used materials

Weirs & Stoplogs
1. Logs - no smaller than 0.25 to 0.3 m diameter in small streams, 0.35 to 0.4 m in larger streams.
2. Hardwoods will last longer than softwoods. If hardwoods are not available larch is the preferred softwood alternative.
3. Angular rocks - up to 0.3 m diameter or larger if they can be man handled (0.6 m used in some cases). Laterally flattened rocks are considered more stable. It should be noted that rock weirs are more prone to failure via washout.
4. Gabion baskets - various sizes available although low profile longitudinal designs are obviously better for weirs etc. A typical preferred size is 3.5 m long, 1.0 m wide and 0.3 m deep.
5. Plastic coated gabions are preferred as galvanised material readily oxidises.
6. Gabion cells should be wired together to form desired height and width of structure.
7. Gabion baskets should be filled with clean cobble (10 to 20 cm diameter). Smaller materials will be washed out of the basket, eventually causing settling of the contents and rupturing.

Gravel Additions
1. If natural gravels are unavailable, bed materials should be chosen so as to reproduce the particle size of the natural sediments.
2. Mean particle size should be 11.3 mm.
3. The overall mix of gravel should be in the range of 12 to 120 mm.
4. Fines content should be less than 8.2% .

Bank Cover/Bank Protection
1. Log Overhangs - Constructed from simple logs (0.3 m diameter), two forming abutments well anchored into the bank and a third pinned to the abutments. More elaborate structures involving vertical pilings, boards and soil covering can also be considered.
2. Artificial Overhangs - Constructed from artificial materials such as galvanised corrugated iron or fibre glass attached to vertical supports driven into the bed. The material used should be covered, so that it is not visually obtrusive.
3. Tree Retards - Trees placed adjacent to and anchored to the bank. Generally trees of trunk size greater than 0.25 to 0.4 m in diameter and 9 to 18 m long are recommended.

Table 6.3 continued. specification of commonly used materials

4. Riprap - A range of non-erodable stone sizes from 0.1 to 0.8 m diameter is recommended. However, at least 50% of the material should be in the range of 0.15 to 0.6 m diameter.
5. Willow Slip - Planting of Willow in the surface soil of bank protection devices will consolidate the structure in time, promoting long-term bank stability.

Rubble Mats
1. Quarried rough limestone.
2. 22 to 38 cm diameter.
3. 10 m wide bands, perpendicular to flow.
4. 120 to 200 tonnes of rubble required for a 10m deep band in a 13 to 17 m wide stream.

Boulder Additions
1. Individual Boulders 1-3 tonnes.
2. The boulder material and size should reflect the ecological river type in order that they are not aesthetically obtrusive.
3. Boulder size is dependant on the size of stream, flow characteristics and bed stability. Various authors suggest 0.6 to 1.5 m diameter rocks, the limiting factor being the availability of equipment to lift them into position.
4. Hard, non-erodable rock is preferable.
5. Boulders with angular surfaces are preferred as overhangs and slack-water areas can be created.

6.4   Structure anchorage

Anchorage is vitally important to maintain the integrity of habitat enhancement structures and prevent damage and/or washout during spate flows. The following applies to all structures where abutments are involved, including stone, log and gabion structures.

Table 6.4   Anchorage requirements

Weirs & Dams
1. Make good use of any natural bracing present; trees, large boulders etc.
2. Bury the abutment into the bank to a depth of at least 1m, up to 2 m if possible.

Gabions
1. Wire gabion baskets together in situ to consolidate the structure.
2. Bottom gabion mattresses should be recessed into the bed to a depth of 0.3 m.
3. 20 mm iron pins (1 to 2m) length should be driven through the structure (gabion or log) into the bed for anchorage. 2 pins per mattress recommended.
4. A wire hawser threaded through the entire gabion structure greatly aids stability.

Bank Revetments
1. In clay substrates log revetments can be anchored with poles driven vertically into mud/clay, with additional pins driven horizontally into the bank.
2. Rip rap can be reinforced by overlaying with secured Christmas trees

Boulders
1. Boulders should be embedded into the stream bed for stability

6.5   Structure protection

Table 6.5 details the structural considerations that should be employed in order to prevent the failure of the structure.

Table 6.5   Structure protection requirements

1. If splash pools are to be created by scour, protect the base of the pool with 150 to 200 mm diameter cobbles.
2. On weirs, protect the area immediately upstream from progressive undercutting (i.e. working back upstream by the splash pool) by protecting with layers of chicken wire or geotextile fibres stapled or wound around the weir and held in place with layers of flat rock. Protection should extend 1 to 2 m upstream.
3. Protect the abutment with rip rap (0.1 to 0.8 m diameter) non-erodable stone to a height of 0.6 m above maximum water level.
4. Protect the abutment with rip rap, upstream and downstream
5. The profile of deflector logs should be kept low in order to prevent scour.
6. Branches of cut willow can be inserted into earth covering rip rap. Willow slips will root and help to consolidate the bank.

6.6   Structure design considerations

In order to gain the maximum benefit from the different habitat restoration structures, a number of different design considerations should be employed, as detailed in Table 6.6.

Table 6.6   Design considerations

Weirs & Dams
1. Allow for a gap, or natural incline (slope of 1% towards centre of the structure) to allow   fish passage during low flows.
2. Maximum spawning bed width in a channel 7m wide should be 10 to 12 m (i.e. 1.5   X channel width in a gradient of 0.03%).
3. Bed profile of the spawning area should be convex in order to maximise water velocities   and intragravel flows.

Rubble Mats
1. 35 m stretch recommended between 10 m wide rubble mats.
2. Target depth for low summer flows 0.5 to 0.7 m.

Boulders
1. Placed at a depth to be kept submerged under surface during summer low flows.

Riprap
1. Use a hydraulic machine to alter the bank slope to 30-45° profile.
2. Truckloads of rock should be dumped to form a base about 1.5 to 1.8 m out from   the bank edge.
3. Additional rip rap should be added on top of the base, maintaining the slope to a   level of 0.6 m above the high water mark.
4. Cover the surface with earth etc. to consolidate the bank top and improve the   aesthetic appearance.

Tree Retards
1. Tree retards should be secured with strong wire to a stable bank anchorage point   located at least 1.5 m back from the bank edge.
2. The anchors can be heavy posts sunk deep into the bank or 'dead man' cables tied   around large surface area buried objects.
3. An overlap of a half tree length is suggested.

6.7   Construction advice

The following general points regarding construction advice are suggested based on practical experience.

Table 6.7   Construction advice

General
1. Rubber tyres should be used on heavy equipment, if possible, to avoid damage to the stream bed.
2. Iron pins can be driven into place using a hydraulic hammer attached to a hydraulic machine, or a pneumatic hammer driven from a bankside compressor.
3. Vertical pilings can be driven into place with a hydraulic machine, or holes excavated using a high pressure hose to wash out gravel and bed material from a constricted area.
Gabions
1. When filling gabion mattresses, a sequential process of fill, pack and fill is recommended, minimising open space - merely tipping rock in from a hydraulic machine will result in settlement and eventual rupturing.
2. It is also recommended to overfill, giving a domed appearance to the gabion, packing it down gently using the bucket of a hydraulic machine if available, before securing the lid in place with wire.
3. Secure the lid partially along one side prior to filling to speed up the process.

6.8   Structure maintenance

General points with regard to maintenance of habitat structures are identified below.

Table 6.8   Maintenance of instream structures

1. Maintaining logs wet at all times will greatly aid longevity of the structure and, as such, requires accurate positioning. Structure lifetimes of up to 40 years are not uncommon where the component logs have been kept wet.
2. Gabions require maintenance every 4 to 5 years to repair ruptures etc.
3. Rip rap may need replacing on a 4 to 5 year cycle to maintain protection of structures.
4. Rock fill in channel constrictions may need to be replaced on a 5 yearly basis.

6.9   Manpower requirements

Various authors reported manpower needed for a variety of habitat enhancement structure.

Table 6.9   Manpower requirements.

Gravel Cleaning
High pressure 5 cm hose - with a three man team a cleaning rate of 172 m² per hour can be achieved.

Weirs & Dams
Two to three structures can be constructed in a day with a three man crew and hydraulic machine, provided materials are to hand and site conditions are reasonable.
Literature values for construction time of log weirs (man hours per structure) vary from 4.5 to 16 hours.

Deflectors
2 to 3 log or boulder deflectors can be built a day with a 4 to 6 man crew.
Construction time for gabion deflectors depends on their size and can range from less than a day for a small structure for a four man team to five days for a 50 m structure.

6.10   Structure costs

Structure costs are also reported by various authors and so the following are presented as a rough budget guide. Costs are given as unit costs per structure and as costs per 10m, where relevant. Figures have been adjusted to 1997 values.

Table 6.10   Typical costs associated with each structure

Structure	Cost
Gabion Structures	Between £800 and £2,000 per structure depending on experience of the crew.
Rock & Log Weirs	£150 to £440 per structure.
Rubble Mats	£2.20 per m² of channel.
Boulders	£23 per boulder
Fences	£45-£50 per linear 10m, one river bank only

Part III

PROJECT MANAGEMENT GUIDELINES

7.   INTRODUCTION TO PROJECT MANAGMENT GUIDELINES

7.1   Objectives

The purpose of Part III of this manual is to provide detailed guidelines on how to identify habitat related problems and to demonstrate how to implement and manage salmon habitat improvement schemes. Specifically this section of the manual will attempt to provide project management guidelines on the following:-

- Establishing the nature and extent of a perceived salmon stock problem,

- Assessing the need and appropriateness of habitat improvements to resolve the perceived problem,

- Identifying the suitability of various habitat improvement techniques to achieve defined stock enhancement targets,

- Scheme design to achieve defined stock enhancement targets,

- Cost benefit analysis of scheme design,

- Pre and post scheme monitoring requirements,

- Standardised reporting and the need for quality feedback information to assess the effectiveness of the scheme.

7.2   Scale of operation

The scale of salmon habitat restoration scheme has a fundamental bearing on the nature and extent of the level of project management required. Different approaches are obviously appropriate when considering opposite ends of the spectrum. A good example would be the project management input required for the creation of an adult holding pool in a 300 m angler's beat, compared to that for improving spawning habitat in the 3,200 km of the River Tweed catchment.

7.3   Project stage definition

Successful project management is dependent upon a logical and consistent approach to all elements involved in the process of basic problem solving, with a specific achievable objective in mind. The need for habitat restoration in salmon fisheries is often measured in terms of consistently low or reducing adult catches by rods and/or nets. The overall objective of a restoration scheme is often either to elevate catches to historic levels, or more realistically, to maximise catches in a sustainable manner. In the case of a SAP, the specific objective would be to achieve defined egg deposition

targets. Progressing logically and efficiently from a **defined problem** to an **achievable objective** is the art of project management.

Attainment of the project objective is more likely to be achieved if clearly defined project stages are identified and milestones labelled within a structured timetable. These stages are often concurrent and interdependent. Clearly the degree of sophistication required will depend on the spatial scale encountered and this will have implications for resource expenditure. However, a basic project management model may be proposed covering all levels of rehabilitation work from the individual beat to the whole catchment, which is illustrated in Figure 7.1.

For short stretches of river (<1.0 km), significant resources (manpower and cost) may not be needed or appropriate. However, proceeding through the various stages of the project management model will allow logical conclusions to be drawn with respect to the requirement for habitat restoration, appropriate techniques, likely effectiveness and cost. Subsequently, monitoring at even the most basic level (rod returns, redd counts, qualitative juvenile surveys) would allow some form of evaluation of the techniques employed and a better understanding of the value of the work to the local fishery.

At higher levels of spatial scale, the resources required to adequately assess, design and implement restoration projects will need to be significant. For very large catchment based projects this will require long term commitment of manpower and resources if the role of restoration is to be truly understood and made to be effective on a catchment wide basis.

The findings should always be documented in a defined reporting structure so that lessons from the rehabilitation scheme, whether success or failure, can be accessible to others. The objective of advancing knowledge in this important and rapidly expanding area of fisheries management cannot be overemphasised. The basic information output requirements in all cases should be as follows:-

1.   Has the restoration project been effective in achieving its objectives?
2.   If so, how much has it cost?
3.   If not, why has it failed?

7.4   Problem identification methodology

7.4.1 Introduction

Habitat restoration will only be appropriate if there is a perceived problem or deficiency with salmon stocks. Problems can operate at all levels of resolution from the beat to the catchment. Invariably, this will manifest itself as some level of concern with regard to either adult rod/net catches or juvenile fish survey data. It will, however, be necessary to have a firm understanding of the nature of the problem, its

causative factors, limitations and influences, before proceeding with habitat modification.

Only after this stage has been completed and the problem identified can remedial action be considered. It would be wholly inappropriate to proceed with habitat modifications if water quality or over exploitation of adults was the factor limiting salmon productivity. Therefore, at whatever level of resolution is being considered, it is essential that problems limiting salmon production are correctly identified. The following methodology is proposed to provide a logical basis for problem identification.

7.4.2 Information gathering

As a first principle, data relevant to the river system under consideration should be systematically collated, beginning with basic information and moving towards more scientifically based data. Although the general principles apply to all levels of resolution, clearly it is unlikely that detailed information will be available on small river reaches. However, the following data inventory would be appropriate if available;

- Historic rod/net catch data
- Redd count data - number and location
- Juvenile fish survey data
- Adult fish count data from counters or traps
- Invertebrate data
- Water quality data
- Habitat mapping data
- Location of fish migration obstructions - local knowledge
- Relevant studies (e.g. pollution reports, siltation studies, HABSCORE, PHABSIM, land practices, hydrology, riparian vegetation).

By utilising the above sources of information, an overall picture of the current status and historical trends in fish numbers can be built up. This applies to both adults and juveniles. However, in many cases, rod and net catch data may be all that is available, possibly supplemented by rolling programme electric fishing data. At this stage, the objective should be to confirm the supposition that a decrease in adult numbers is actually occurring and to try and establish the magnitude of the perceived problem.

Assuming that status of the stock can be established[1], a logical process of elimination should be followed to progressively remove various potential impacts from the investigation. Figure 7.2 represents the procedure graphically. It should be noted that although the different factors are eliminated in a progressive fashion the data collection process for each of the potential impacts can take place simultaneously.

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1 If insufficient information is available for an assessment of the status of the stock then clearly a programme of monitoring is required. On a small scale this may mean simply recording rod catch data; for larger programmes sophisticated monitoring and investigative studies may be required.

i)   Exploitation

The first area to be examined should be exploitation of the stock i.e. is there any evidence for an increase in exploitation from any sector - rods, nets, high seas fisheries, poaching etc. The influence of predators, particularly with regard to the current debate over cormorants, should also be borne in mind. Once exploitation has been eliminated, the investigation can proceed to the next obvious area, obstructions to migration.

ii) Obstructions

Although this is, strictly speaking, a habitat issue, obvious impacts arising from obstructions can be easily identified at an early stage. Built features like reservoirs or weirs may be obvious obstructions to both upstream and downstream migrating fish under certain circumstances and much time and effort can therefore be saved by addressing the impact of these obstructions early on in the problem identification process. Whilst the use of habitat mapping data (possibly including River Habitat Surveys) is desirable, often informal discussions with bailiffs will allow local knowledge to be utilised in an informed and objective manner. Such individuals may also be able to provide initial information on issues such as debris dams and river clearance programmes.

iii) Water Quality

Once exploitation rates and obstructions have been eliminated from the investigations, the next obvious issue to examine is water quality and the possibility of both point and diffuse pollution with regard to intermittent and long term events. Examination of water quality archive data together with basic invertebrate data will allow a rapid assessment of water quality within the system under consideration and the nature and extent of potential impacts.

If the above issues have been eliminated from the investigation, there are good grounds for suspecting that habitat is the factor limiting the salmon stock. Only at this stage are detailed habitat investigations appropriate. Failure to consider this fundamental process of problem identification could lead to a considerable waste of resources with no guarantee of effecting a positive outcome as a result of habitat improvements.
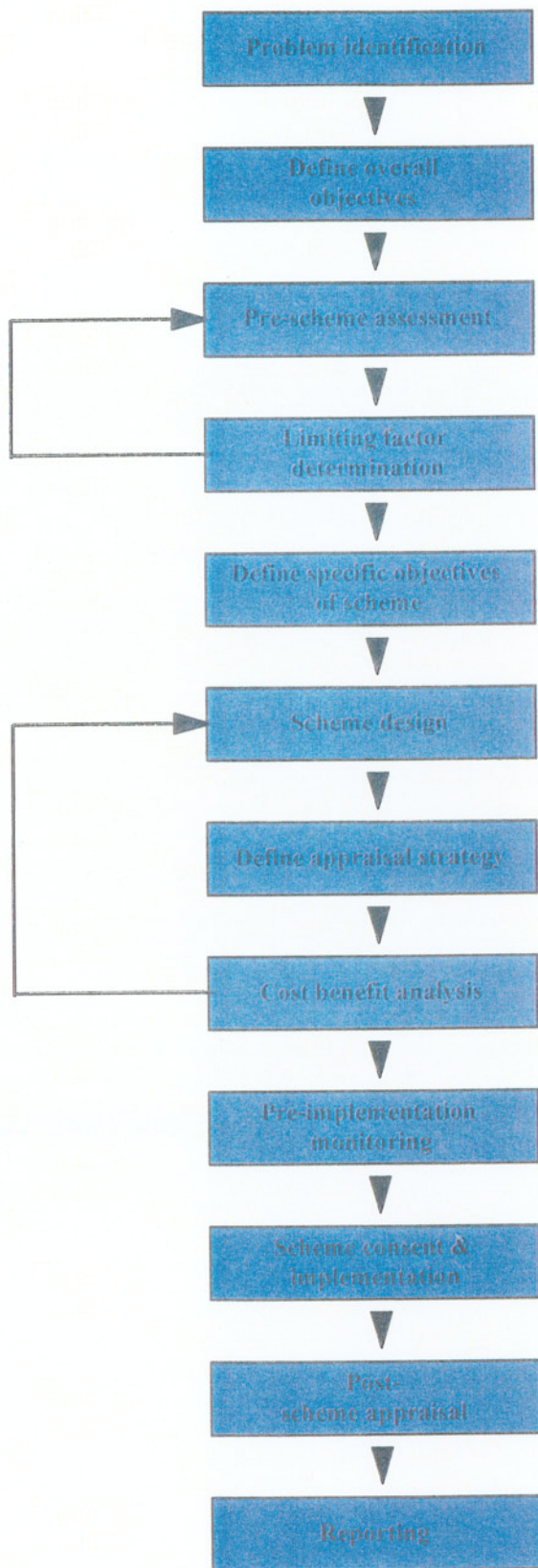
Figure 7.1 Project Management Model
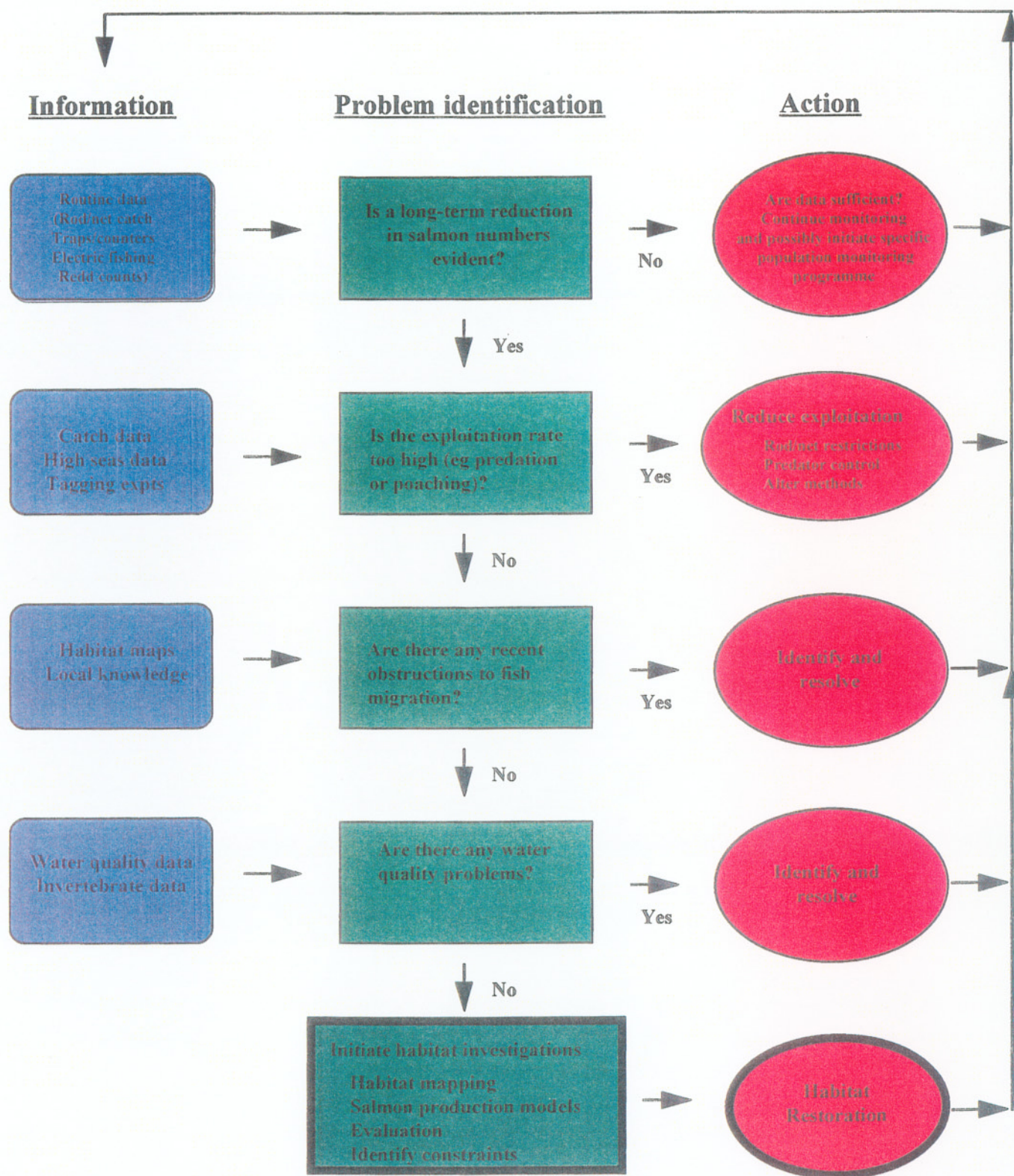
Figure 7.2. Problem Identification Methodology

8. HABITAT ASSESSMENT - MAPPING TECHNIQUES

8.1 Introduction

Once habitat has been identified as the most likely constraint on salmon production, the extent of habitat degredation must be assessed. This is important in both quantitative and qualitative terms and necessitates some form of physical habitat mapping, analysis and assessment. Following habitat assessment, limiting factors can be identified and addressed with appropriate habitat restoration techniques.

The objective for a given habitat mapping exercise, irrespective of the size of the system under investigation, is to produce a clear and quantifiable assessment of habitat types both visually, in a graphic form, and also numerically for subsequent analysis if necessary. The features and habitat types that should be quantified are defined and classified in Table 8.1 and include;

- Spawning habitat
- Fry Habitat
- 0^+ and $>1^+$ Nursery Habitat/Parr Habitat
- Glides
- Pools
- Bankside Vegetation
- Instream Macrophyte beds
- Obstructions to Migration

Table 8.1   Habitat type classification system.

HABITAT TYPE	DESCRIPTION
Spawning Habitat & Silted Spawning Habitat	Ideally stable but not compacted, easily workable with a boot without generating excessive silt release, a mean grain size of up to 80 mm for salmon. 'Fines' (< 2 mm grain size) to be less than 20% by weight.
Fry Habitat	Shallow, = or < 20 cm deep, fast-flowing (50 - 65 cm/s), with surface turbulence and a gravel (size range 16 - 64 mm) and cobble (size range 64 - 256 mm) substrate.
Parr Habitat	20 - 40 cm deep, fast-flowing (60 - 75 cm/s), surface turbulent, with gravel/cobble/boulder (size > 256 mm) substrate.
Glides —	= or > 30 cm deep, moderate velocity in range 10 - 30 cm/sec, surface smooth and unbroken, relatively even substrate of cobbles with finer material.
Pools	= or > 40 cm deep, no visible flow, surface unbroken, substrate with a high proportion of sand and silt.
Bankside/Tunnel Vegetation	Riparian vegetation ideally providing a mixture of open and closed canopy throughout the reach. Tunnel vegetation forms a complete closed canopy for extensive lengths.
Macrophyte Beds	Submerged and emergent macrophytes providing localised hydraulic diversity.
Flow Constrictions	Physical features providing a narrowing of the channel resulting in increased velocity and depth.
Obstructions to Migration	Impassable falls, weirs, bridge sills etc., shallow braided river sections preventing upstream migration during low flows

Fundamentally, habitat issues operate at a very localised level. In order to assess and classify habitat characteristics to permit an understanding of limiting factors, it is necessary to map the habitat at the same level as that at which habitat constraints operate. However, the degree of resolution will be influenced by the practicalities of performing the mapping exercise, taking account of the size and location of the system to be evaluated and also the financial resources available. For example, the approach used to map and evaluate a reach of less than 1 km in length will differ to that used for a whole catchment consisting of several hundred kilometres of river.

The following section presents information on a wide variety of techniques to assess and map habitat. However, the issue of scale should be borne in mind when determining which habitat mapping tools to employ for a given scheme. Whilst the techniques described below can be broadly defined as being appropriate for large (catchment level) or small (minor tributary) scale surveys, obviously individual manpower and financial resources will often dictate which are used.

However, an attempt has been made to indicate the relevance of techniques appropriate for various scales of investigation based on the following arbitrary divisions;

- Short stretch (<1 km)

- River reach (1-10 km)

- Subcatchment (>10 km)

It should be noted that single small sections of a river should not be viewed in complete isolation, as the factor limiting the productivity of a particular reach may be outside its immediate geographical location. As such, it is often necessary to examine an area immediately upstream and downstream.

Further, for larger surveys, practicality dictates that the amount and type of information collected will often need to be reduced per unit length of river in order to render a survey achievable within defined timescales. This can be achieved by either;

-     Reducing the level of resolution.
-     Reducing number of classes of data collected.
-     Reducing the length of river surveyed.
-     Stratifying the survey.

Hence it is important to understand that the techniques described below are not intended to be prescriptive but should be tailored and combined where appropriate to satisfy the requirements of individual restoration schemes.

8.2   Habitat mapping methodologies

8.2.1   Walk-over surveys

The objective of the walk-over survey is to provide a detailed representation of the precise location and extent of the various habitat features present along and immediately surrounding a section of river.

The field mapping technique for a small stretch is based upon a hand drawn map at a scale of 1:10,000. The habitat features noted along the stretch of the river (see Table 8.1) are drawn directly onto the map, with the boundaries of the different habitat classifications being drawn to represent their actual position within the river. This allows exact representation of the areas of individual habitat types encountered. In this manner, a mosaic of the different habitat types can be drawn along the whole section of the river. The data generated by the walk-over survey for a small stretch can be displayed graphically through the utilisation of a simple graphics package such as Adobe Illustrator. The use of more sophisticated computer packages such as a geographic information system (GIS) for the analysis is not considered appropriate, as

the data collected only relate to a small linear area. The true value of GIS is seen in the wider catchment context, discussed later.

In addition to the in channel habitat features identified in Table 8.1, a number of further parameters can also be noted and quantified, as described below.

i)   Riparian vegetation

The nature of the riparian vegetation should be recorded, as this may have a profound affect on either the productivity of a small reach or the suitability of a reach for enhancement. The American Fisheries Society (1991) recommended that the position and extent of the root systems of large riparian trees should be recorded as they have the beneficial effects of stabilising the bank and providing cover for fish. The position of large trees will also influence the location of any enhancement schemes (e.g. as anchorage for structures).

ii)   Channel dimensions

If the walk-over survey is the sole form of habitat evaluation, channel widths, particularly channel constrictions, should be recorded at regular intervals so that the dimensions of particular habitat features can be quantified and their contribution in real terms to the productivity of a water course can be accurately assessed.

iii)   Access

During the walk-over survey, the routes and ease of access into a river should be noted, as they will have practical implications for citing potential enhancement structures.

The walk-over survey may be sufficient to elucidate the features of specific habitat types that are limiting to the salmon productivity of a stream. However, more detailed habitat evaluating and hydrological techniques are available, such as River Habitat Survey (RHS), River Fisheries Habitat Inventory, HABSCORE and PHABSIM, which can be implemented if required.

8.2.2   River habitat survey

River Habitat Survey (RHS) has been developed as a classification system to describe the physical features which occur in different river types (NRA, 1995c; Raven *et al.*,1996) and provides a standard multifunctional habitat assessment technique for rivers. Although RHS was not designed to be a specialist salmon habitat assessment technique, it is, however, useful in the planning of a walk-over survey, and can provide an indication as to the type of habitat that may be found at a particular location. In particular, it facilitates an overview of large areas of a catchment identifying reaches that need to be surveyed using a more specific walk-over survey or dedicated analysis technique. The definitions used to describe individual habitat

features (e.g. riffle) have been standardised in RHS and are therefore used throughout this manual (see Table 8.1).

Each site surveyed consists of a 500 m section of river for which information is collected from two main sources, map-based catchment data and field survey data. In addition, water quality data are included using the General Quality Assessment Scheme (GQA). The data requirements shown below are taken from Raven *et al.* (1996).

i)   Field survey data

        Features that broadly characterise the site, for example valley form and adjacent land use, are used to set the scene. More detailed information is collected along the 500 m site at 10 equidistant sampling points including:

        - Channel substrate type
        - Presence of habitat features such as waterfalls, riffles, pools and point bars.
        - Bank profile, substrate and vegetation structure
        - Channel vegetation
        - Riparian land use
        - Channel dimensions
        - Artificial features
        - Evidence of recent management
        - Features of special interest

        In addition to the ten sampling points, a checklist of all the relevant features occurring within the 500m reach is made to ensure that no characteristics of the river have been overlooked. The average time component for the field survey work is less than one hour per site.

ii)   Catchment data

        Background information for each 500 m site includes altitude, slope, solid and drift geology, mean annual flow and distance from source. This information can be derived from Ordnance Survey Maps, British Geological Survey Maps and from NRA River Water Quality Maps.

A national network of reference sites is currently being developed in order that rivers can be categorised on the basis of river type and features present, river habitat surveys having been undertaken at 2 sites within each 10 km^2 block of England and Wales. Subsequently, sites external to the network can then be compared on a national or regional basis.

8.2.3 River fisheries habitat inventory

The Agency has initiated a specific R&D project aimed at classifying habitat in relation to fisheries. A two tier system is proposed, the first tier classifying a river network into broad river types, the second involving an assessment of habitat quality for fish within each river type. Links to both the National Fisheries Classification Scheme and HABSCORE data bases are being investigated and it is hoped to link the system with River Habitat Survey. Although at the initial design phase, the proposed River Habitat Inventory may develop into a significant tool to aid assessment of habitat quality for salmon in the near future.

8.2.4 HABSCORE

HABSCORE is a system of measuring and evaluating stream salmonid features over a short stretch of river, typically less than 100m in length. The methodology incorporates three main types of information:

- Site specific habitat data
- Catchment data
- Fisheries data.

The data requirements shown below are taken from Barnard and Wyatt (1995).

i)　　**Site specific habitat data**

Each site is split into a number of 10 m length cells, with the following data being collected for each of the different cells:

- Riparian shading of the reach
- Substrate embeddedness
- Wetted river width
- Boundary depth profiles
- Substrate composition
- Flow type
- Sources of bed cover
- Percentage occurrence of deep water

ii)　　**Catchment data**

The catchment data are principally derived from Ordnance Survey Maps (1:50,000 scale) and also NRA River Water Quality Maps (1:25,000 scale) and included:

- Distance from principal source
- Distance from tidal limit
- Link number (number of first order streams upstream of the site)
- Downstream link number
- Site altitude

- River flow range
- Mean conductivity
- Catchment gradient

iii)   Fisheries data

Quantitative fisheries survey data are required for the same area covered by the site specific habitat data. These data are normally obtained via quantitative electric fishing surveys. In addition, the ease of access with which migratory fish can reach the site needs to be evaluated.

By combining the three forms of data HABSCORE can be used to identify sites where habitat is constraining the population (Wyatt *et al.,* 1995). This is particularly useful when little historic data are available for a specific reach. However, it should be noted that HABSCORE should not be employed to determine the exact feature of habitat which is limiting, but to assess whether habitat is generally limiting. In addition, whilst it is evident that HABSCORE has a role in pre and post scheme assessment, it may not pick out habitat limiting factors if the effect in a particular model comes from a catchment feature.

HABSCORE may be put to best use in prioritising sites for enhancement schemes. Specific reaches that will benefit most through the instigation of habitat restoration/creation schemes can be identified at an early stage, allowing for the optimum targeting of resources. This can be achieved through the calculation of the **Habitat Quality Score** (HQS) which represents the long term average density of fish that would be expected at a particular site if water quality and recruitment were not limiting.

An additional and important application of HABSCORE is to determine the benefits derived from the opening up of previously inaccessible migratory salmonid habitat through the removal of obstructions. The HQS for a stretch of river upstream of an obstruction can be calculated to determine the maximum theoretical increase in salmon productivity from the removal of the obstacle.

The main limitation of HABSCORE is that the technique is very labour intensive and is applied over a short stretch of river, usually only 50 to 100 m Assuming that existing fisheries data are available, 30 minutes should be allowed to gather field information for a particular site. However, it should be stated that HABSCORE was never intended as a catchment scale survey tool. Its principal disadvantage is that it is an empirical model and does not reveal the functional relationships between particular habitat features and abundance. Conceptual process based models are required to fulfil that requirement, e.g. PHABSIM.

8.2.5 PHABSIM

The Physical Habitat Simulation Model (PHABSIM) is a predictive hydraulic model that provides an estimate of the amount of habitat loss or gain resulting from a change in river discharge. The model operates at the microhabitat level for a short section of a

particular reach at a high level of resolution. Reaches where the model is used usually represent a much larger stretch of river, where flows are of concern. Hence, to provide the necessary data, 5 to 10 km of the river surrounding the area of interest can be mapped using a walk-over survey.

It is a specific tool for predicting the impacts of flow changes on the available habitat, such as in regulated rivers or streams affected by abstraction schemes. For example, Johnson *et al.* (1995) have employed PHABSIM in the modelling of the impact of water abstraction upon trout and salmon populations in the River Allen, Dorset.

It should be noted that the implementation of PHABSIM is labour intensive and still at an early stage of development in the UK. Consequently, this technique may not be applicable to the majority of habitat enhancement schemes unless low flow has a major impact upon the availability of habitat and sufficient survey resources are available.

8.2.6   SAPs Habitat assessment methodology

A habitat assessment methodology has been proposed for catchments where SAPs are in place, enabling specific assessment techniques to be applied. The methodology specific to SAPs, which is applied on a catchment basis, is currently under review and is likely to be integrated into the River Fisheries Habitat Inventories R&D project. Therefore specific details are not included here but it should be borne in mind that new developments in this area are imminent.

8.2.7   Aerial photography

Aerial photography has been used on an experimental basis to assess the availability of salmonid spawning gravels (Acornley *et al,* 1995). Maps of spawning gravel distribution produced by aerial photography showed agreement with ground survey data of brown trout redds and knowledge of traditional salmon spawning sites. The authors noted that this technique would be limited where spawning sites were either located in shaded areas of the river or if the water was turbid. In addition, the results from an aerial survey only show the location of gravels and do not provide an indication of either the quality or suitability of the gravels for salmon spawning.

8.3   Modifying survey methodologies for large scale schemes

As has been identified above, in large scale schemes operating on main river, subcatchment or catchment levels, much of the survey methodology outlined above may represent an onerous commitment of manpower and resources. Hence methods of refining survey methodologies must be explored to maximise efficiency and ensure data collected is targeted specifically at the particular requirements of the individual scheme. Examples of habitat survey methodologies for large systems have been developed on several Scottish rivers including the Tweed (Tweed Foundation, 1995), the Nith (Nith Habitat Enhancement Committee, 1995) and the Dee (Webb and Bacon, 1995), the latter involving the development of a GIS integrated data-base. The

following sections provide details of how data collection can be tailored for larger habitat restoration schemes based on the Scottish experience.

8.3.1   Reducing the length of river to be surveyed

The first approach is to reduce the length of the river to be surveyed by focusing on specific areas or issues. This can be accomplished through a combination of analysing existing data sets and identifying areas thought to be of concern. Areas that have historically shown a decline in habitat quality or quantity can be highlighted as a priority for a walk-over survey, in order to assess the specific habitat characteristics that are considered limiting. Conversely, areas that are known to be of "higher quality" and subsequently high productivity can be ignored for restoration schemes. In addition, areas located upstream of an obstruction to salmonid migration can be removed from a walk-over survey if the obstruction cannot be overcome or ease of access improved.

8.3.2   Reducing the amount of information collected

A second approach is to reduce the amount of data collected during a walk-over survey. This approach can be sub-divided into the two methods described below.

i)   Reducing categories of information

This method will be applicable if the specific aim of the survey is to identify where work to improve fish habitat can be practically carried out. This approach was instigated by the West Galloway Fisheries Trust (Crossland, 1994). The three habitat improvements deemed necessary were the fencing of banks, removal of tunnel vegetation and the removal of obstructions to fish migration. Subsequently the walk-over survey noted the location and nature of obstructions, bank erosion, bank repairs, braiding of the river channel, vegetation debris in the river and effective and ineffective fencing. This approach allowed the walk-over survey to be conducted over a much shorter time than if a full survey had been conducted. It should be noted that the survey had clear objectives for the proposed enhancement schemes before it was conducted and was consequently designed to locate the areas where habitat improvements would have the most beneficial impact. As such, this technique may not be applicable to systems where the limiting factor of habitat is not known prior to the habitat survey.

ii)   Reducing the resolution of information collected

The resolution of a habitat survey can be further reduced by simply mapping the predominant habitat features along individual stretches of river. For a given length of river (50 metres) the habitat can be summarised for the main features. The methodology depends upon the ability of the person carrying out the survey to make decisions as to whether a habitat characteristic is important and therefore requires further examination. The technique has been successfully applied on the River Wyre in Lancashire. However, the resolution can only be

reduced to a certain extent, as habitat characteristics that effect salmon may vary over a short length of river. Therefore, caution must be exercised when using this approach.

8.3.3   Prioritising areas for evaluation

If resources dictate that a full walk-over survey cannot be accomplished, then a combination of the approaches discussed above can be employed to objectively assess the habitat found within the system. In the absence of river habitat survey data, a **geographical information system** (GIS) such as MapInfo can be used for prioritising areas in need of investigation. Using a combination of historical data and catchment details from an Ordnance Survey map (scale 1:25,000), the following details can be illustrated:

- Obstructions to migration
- Areas utilised by salmon for spawning (redd count data)
- Observed fish population data (electric fishing surveys)
- Riparian land use
- Access to the river

This analysis should highlight three main areas for use in prioritising sections of the catchment for walk-over surveys;

- Areas of known salmon productivity for individual life stages
- Areas where enhancement schemes are not practical
- Areas where there is a lack of knowledge and /or which require a walk-over survey

This stratified approach should indicate which areas are potentially limiting in terms of habitat. Sections of the catchment should then be ranked according to their apparent need for habitat improvement. Resources can then be allocated to areas where habitat is thought to be most limiting via the instigation of a walk-over survey. In addition to surveying areas of a poor quality, it is advisable to survey a stretch of habitat within the catchment that is regarded as not being limiting in terms of habitat i.e. "good habitat." This will allow comparisons to be made between poor and good habitat which may only be relevant for a particular catchment and river type.

8.4   Analysis of collected data

A walk-over survey will produce a large amount of data. This data set needs to be summarised into a format that allows areas of concern to be highlighted. GIS packages such as MapInfo can be used to efficiently analyse the data collected once it has been entered as identifiable habitat characteristics. The habitat features can then be either displayed visually or numerically.

i)   Visual display of data in GIS packages.

A visual display of the different features of habitat can be applied at different levels of resolution. For example, at a low level of resolution the predominant areas for salmon spawning can be displayed for a whole catchment. Alternatively, the precise location and extent of individual gravel spawning beds can illustrated for a particular reach. This facility has two main benefits. Firstly, sites that potentially require habitat improvements can be quickly identified, and secondly, the location of habitat features such as spawning gravels and nursery areas relative to one another can be determined. In addition to data derived from the walk-over survey, historic data (e.g., redd count data) can be added to determine whether changes have occurred over time.

ii)   Quantification of data using GIS packages.

The database function of GIS systems allows the extent of a particular habitat feature over a given stretch of river to be quantified. This can be achieved at a number of levels of resolution, from individual beats on a river to whole catchments. A comparison of the quality of different habitat types present along a reach can be then used as an aid in determining the factors limiting salmon productivity.

8.5.   Habitat mapping - examples

This section provides practical examples of habitat surveys undertaken at varying levels of resolution and is intended as a practical guide from the author's personal experience. Habitat mapping is best undertaken on pre-prepared proforma sheets derived from OS Maps or equivalents. A black and white photocopy of the relevant stream section is taken and scanned into a digitised format compatible with the software package to be used. The authors use 'Adobe Illustrator' software on a Pentium 75 computer. The scanned image can subsequently be 'cleaned up', with landscape features being retained or omitted as required to aid field location. This forms the **computerised base map.** The final image, including single banks for large catchment scale surveys and both banks for smaller river reach and tributary surveys, is then printed on 'aquatrace' for field use.

8.5.1   Field mapping

By overlaying the aquatrace on the original colour base OS map on a clipboard, field location is made considerably easier than if working from the aquatrace map alone. Obviously, habitat mapping relies on accuracy and hence good locational sense and basic map reading skills are essential, particularly in featureless or heavily wooded stretches. A working knowledge of the speed of movement and ground distance covered is particularly useful in this regard. However, recent developments in portable satellite based position fixing equipment has made determining exact locations somewhat easier in featureless terrain.

Habitat types are noted directly onto the aquatrace maps using a series of labelled symbols or lettered 'lollipops'. The symbol is linked by a single pencil stroke to a line

parallel with the river bank delineating the linear extent of that particular habitat feature. Substrate features are noted on the left bank and vegetation (aquatic and terrestrial) on the right-hand side. Other prominent features (e.g. log jams, macrophyte beds, bridges etc.) are noted together with trees, electricity pylons and bridges which may aid accurate location and thus confirm position.

An example of a field map is presented in Figure 8.1.

8.5.2   Computer mapping

Back in the laboratory, the field maps are transferred to the original computer base maps and colour coded using the appropriate key system. A whole range of possibilities are available with the software used and the map can be amended as considered appropriate. Figure 8.2 shows an example of a completed habitat map.

8.6   Habitat quantification

Habitat types can be quantified quite simply either manually, by direct measurement with a set of dividers, or digitally by using the appropriate software measuring tool. In either case a table of linear lengths of each habitat type can be constructed which, when combined with measured or estimated width data from the walk-over survey, can be used to produce area measurements. An example is presented in Table 8.2 .

Table 8.2   Habitat type and features corresponding to Figures 8.1 and 8.2.

Feature	Total Length (m)	Total Area[2] (m^2)	Percentage of River Length on which feature can be found
Spawning Gravels	60	420	9
Pool	147	1,029	23
Glide	47	329	7
0[+] Juvenile Habitat	77	539	12
0[+] / 1[+] Juvenile Habitat	119	833	18
Tunnel Vegetation	147	-	23
Macrophyte Beds	40	280	6
Flow Constriction	10	70	2

Figures 8.2 to 8.4 provide examples of habitat maps constructed using the technique outlined above. Three levels of resolution are illustrated; Figure 8.3 represents a short stretch (<1 km), Figure 8.2 a river reach (1 to 10 km), Figure 8.4 the sub-catchment (>10 to 100 km). Larger spatial scales, (e.g. >100 km), are probably best illustrated using a Geographic Information System (GIS).

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2 Assumes an average river width of 7m.

The objective is to produce a clear and quantifiable assessment of habitat types both visually, in graphic form, and numerically for subsequent analysis. Use of computer technology to produce digitised maps which can be quantified is a significant advantage in habitat mapping, allowing excellent presentation together with flexibility in use. The data produced for each map can be combined to produce an overall assessment for either a catchment or sub-catchment.

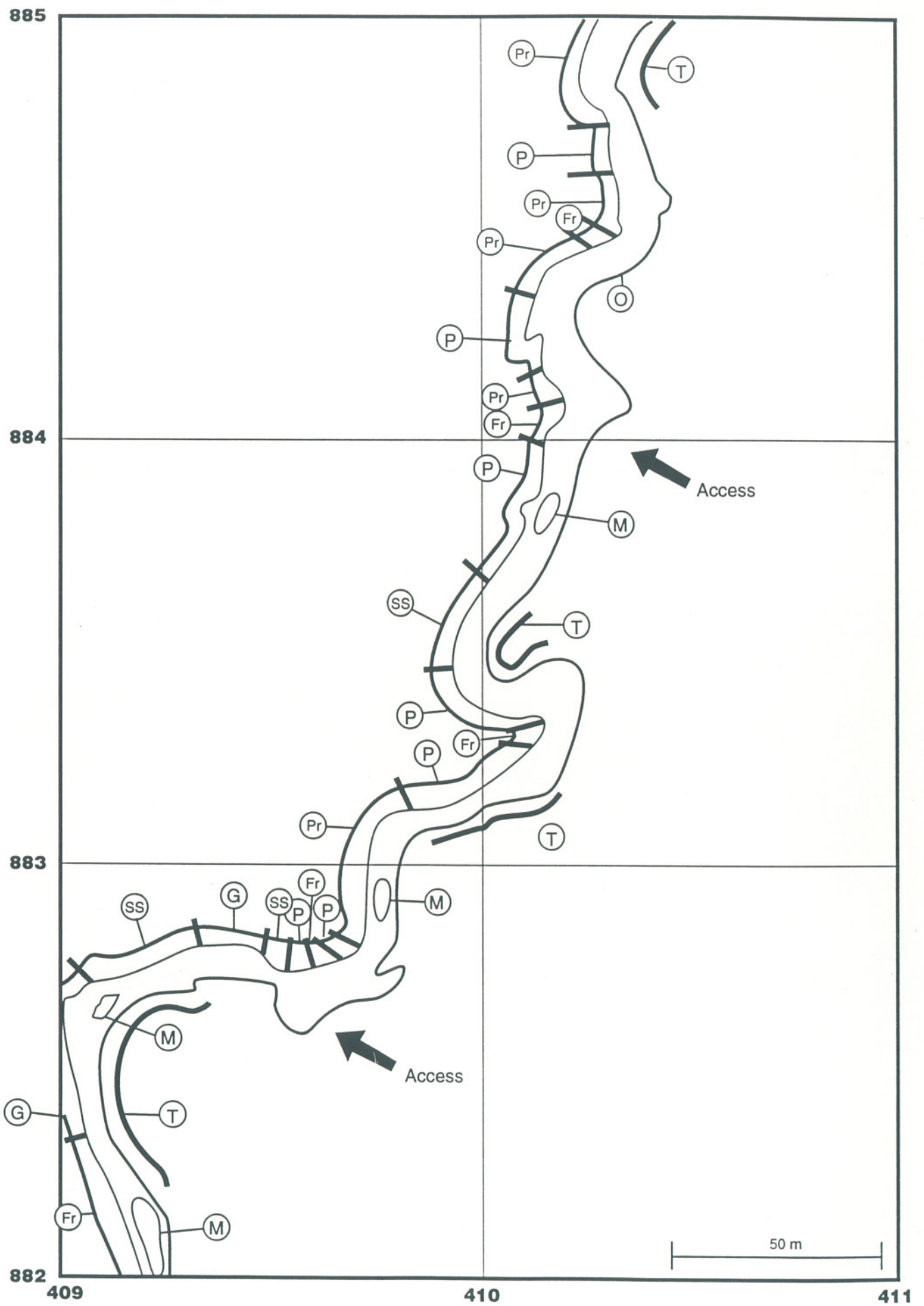|	
(S)	Spawning Habitat
(SS)	Silted Spawning Habitat
(P)	Pool
(G)	Glide
(Fr)	Fry Habitat
(Pr)	Parr Habitat
(T)	Tunnel Vegetation
(M)	Macrophyte Beds
(F)	Flow Constriction
(O)	Obstruction to Migration
(A)	Access Point

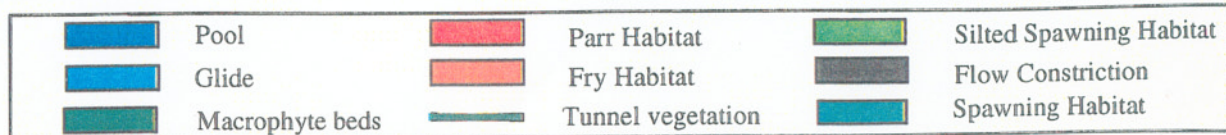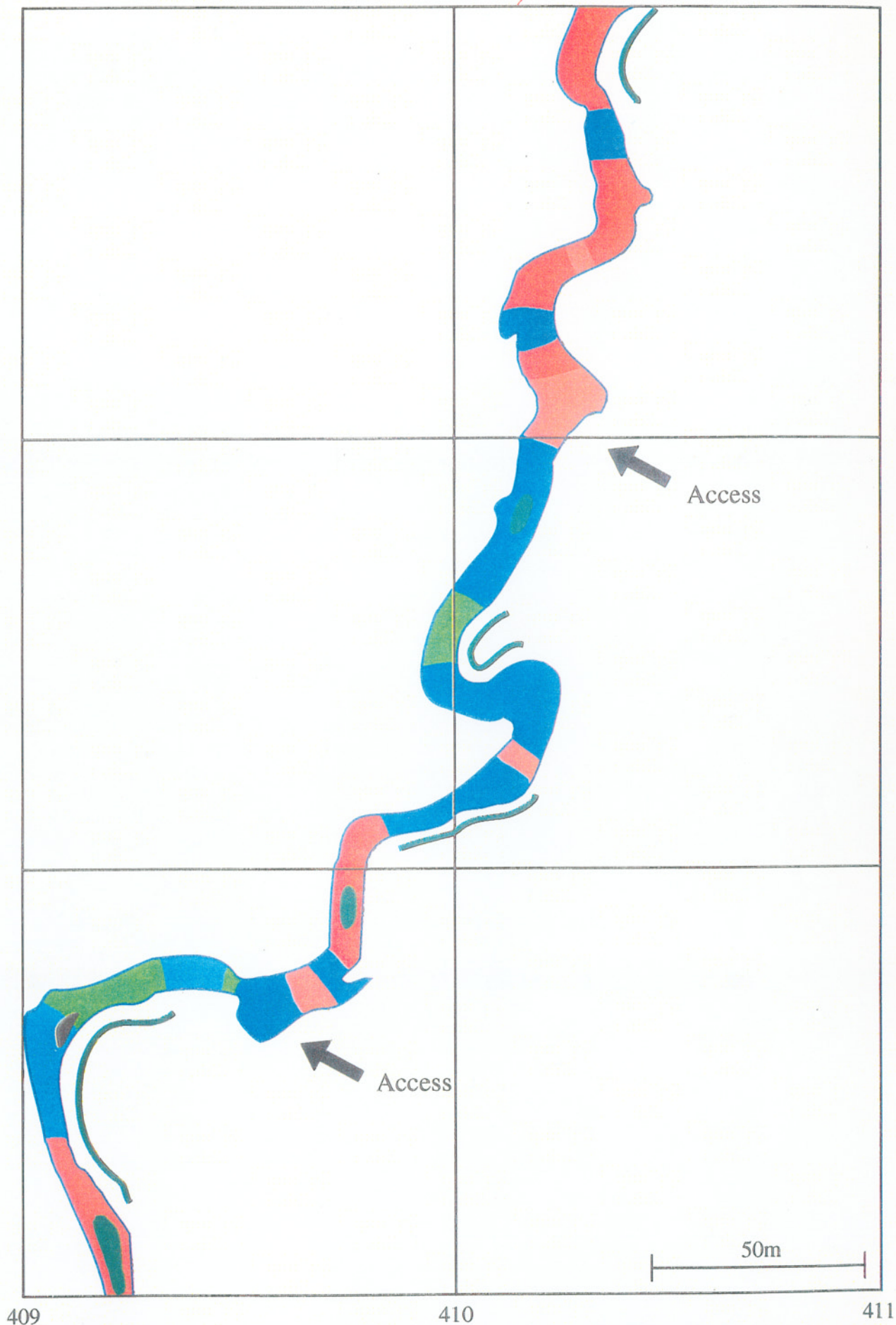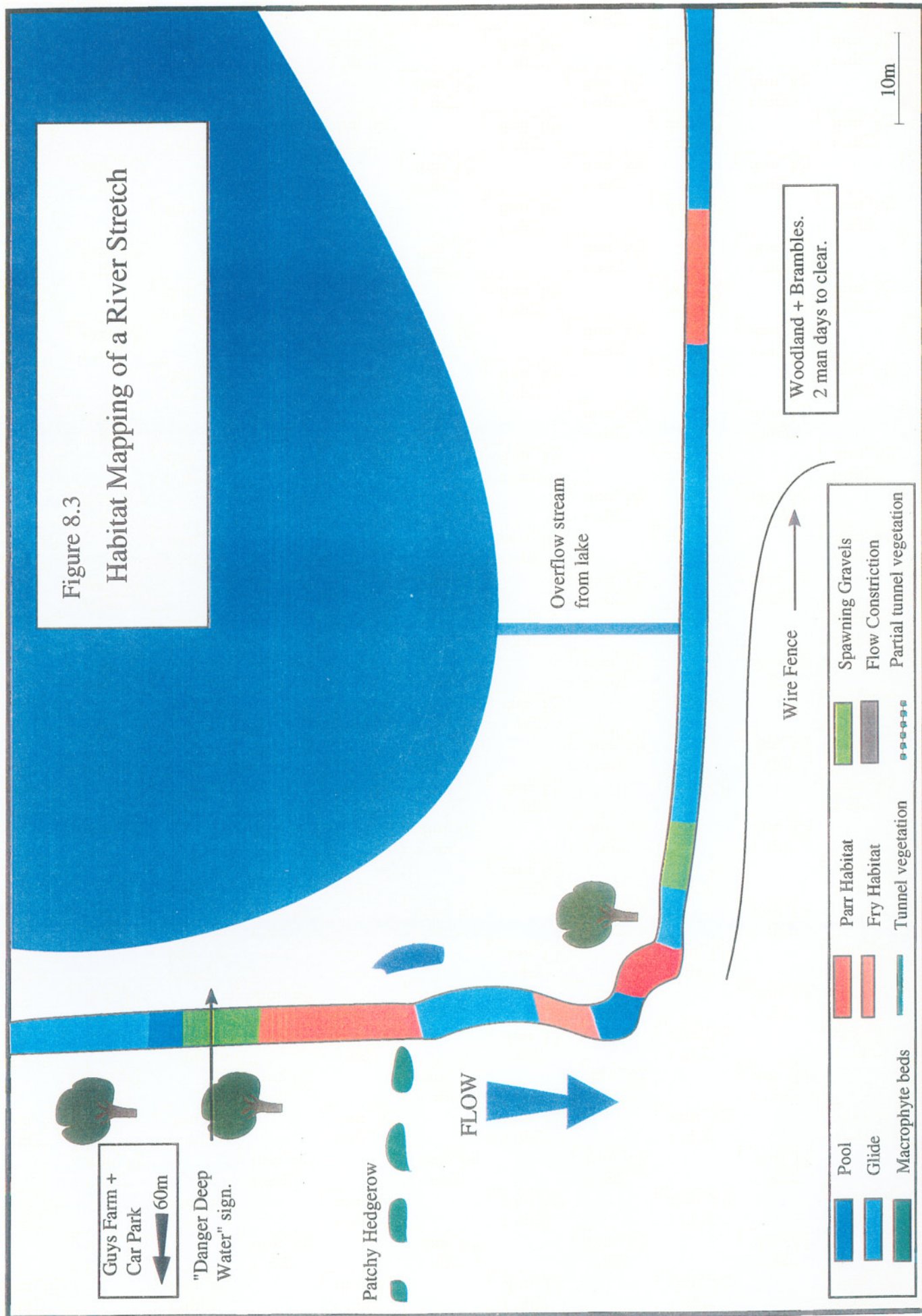Key to Field Survey Map - Figure 8.1

Figure 8.1 Field Survey Map

Figure 8.2 Habitat Mapping at the Reach or Tributary Level
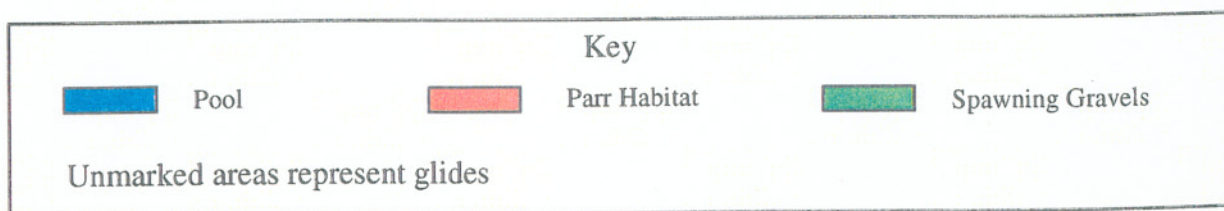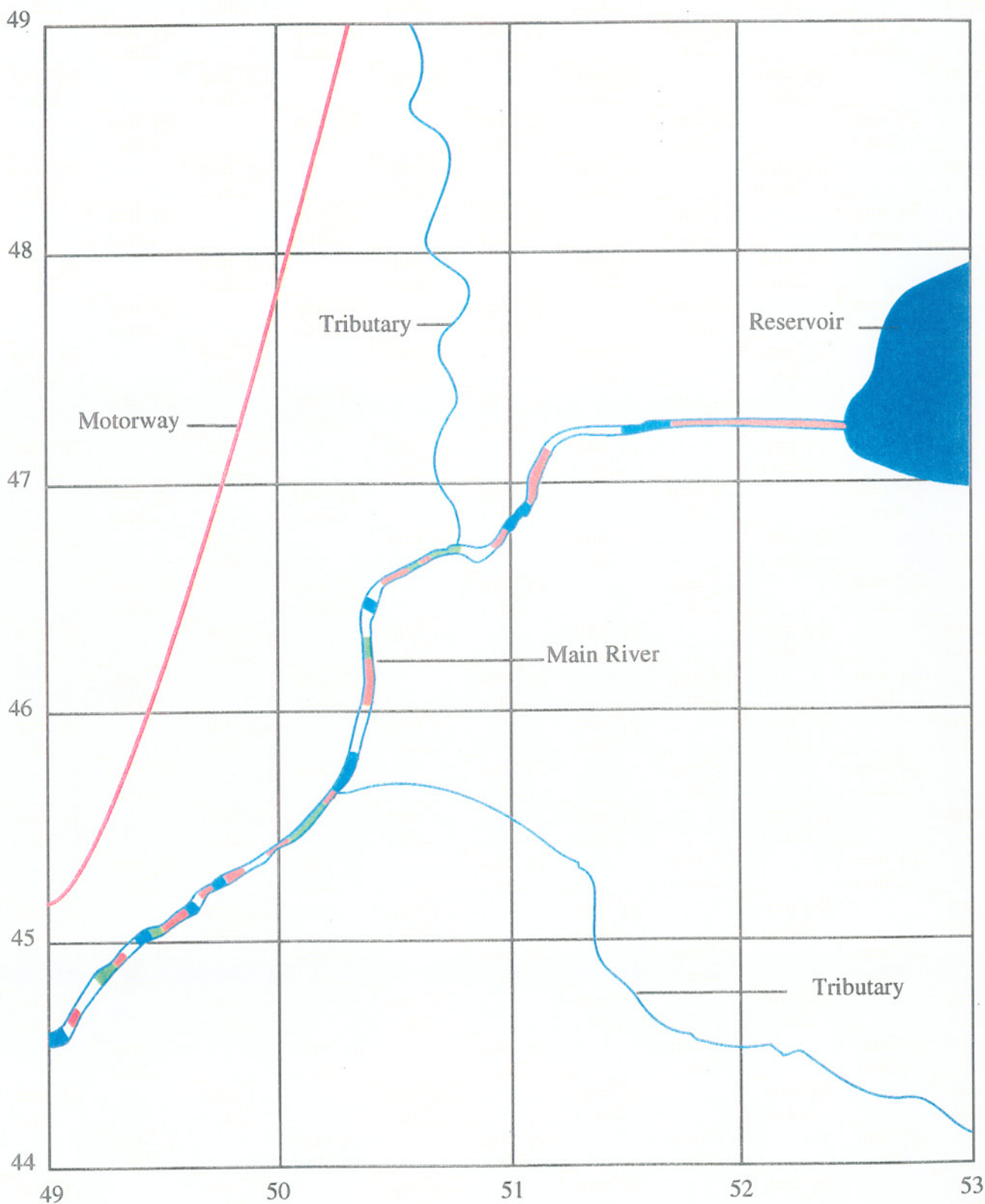
Figure 8.3 Habitat Mapping of a River Stretch

Key

Pool		Parr Habitat		Spawning Gravels	

Unmarked areas represent glides

Figure 8.4 Habitat Mapping at the Subcatchment or Main River Level

9. LIMITING FACTOR DETERMINATION

9.1 Introduction

With the information on the quantity and relative spatial distribution of habitat types available, an analytical approach to identify problem areas can be adopted. This can be achieved by using a habitat overview approach, which reviews the quantity and distribution of the different habitat features, or by a more quantitative stock assessment based method. The approach used will depend upon the spatial scale of the system being evaluated and the availability of historic data. However, it should be noted that the two approaches can be used in conjunction in order to facilitate a comprehensive understanding of the current situation.

9.2 Habitat overview

9.2.1 Spawning Gravels

i)   Location

The location of spawning gravels can be identified from the habitat maps and the significance of obstructions evaluated. Historic redd count data can be superimposed on habitat maps, giving an indication of spawning gravel usage and any changing patterns over time. An example of this approach for main river level of resolution from North West England is given in Figure 9.1. In this case, comparison of redd count locations over a ten year interval indicated that the area available for spawning was decreasing in size, primarily due to a paucity of gravel, caused by an upstream reservoir acting as a gravel trap.

ii)   Quantity

The quantity of spawning gravel available can be determined by multiplying the length of mapped gravel by the average measured or estimated river width. This data is important for subsequent productivity estimates but can also be used to provide a basic characteristic of the river system, the ratio of spawning habitat to juvenile habitat.

iii)   Quality

A further characteristic of gravels that should be recorded is the general quality. This relates to both the size of gravels relevant to salmon spawning requirements, (i.e. are they too large or too small) and the perceived degree of siltation, compaction and concretion. The assessment of gravel quality, by definition, will be subjective without the aid of expensive and time consuming freeze core analysis. Nevertheless, at this stage the objective is to identify potential problems and hence it is acceptable for the outcome to be a

recommendation that detailed studies on the quality of gravels are initiated in order to establish whether or not there is a genuine problem. Attention should also be given to indications from other information sources with respect to the quality of the gravels. For example, do redd count data suggest that quality is deteriorating?

iv)   Stability

Gravel stability is another question that can only be categorically answered by detailed studies. Implications for spawning habitat can, however, be obtained by examining hydrographs, comparing gravel mapped before and after spates, and consulting local knowledge with respect to the nature of the river e.g. its flashiness and the appearance/disappearance of gravel shoals.

9.2.2   Juvenile habitat

i)   Quantity

The quantity of juvenile habitat can be used in a ratio determination to establish whether the amount of rearing habitat relative to the quantity of spawning gravel is appropriate. The figure quoted by various authorities is that 25-30% of total juvenile habitat ought to be exclusively fry habitat. This statistic will be of value in the productivity estimates discussed later.

ii)   Shading

The degree of shading by tunnel vegetation in juvenile habitat is of fundamental importance as it can severely limit productivity. A knowledge of the extent of shading will be of great importance to evaluate the significance of selective bankside trimming to open up the canopy and its potential advantages for productivity. Although productivity estimates are possible (see later), it may be sufficient to act in the knowledge that trimming back dense foliage can increase salmon parr densities by as much as five times.

iii)   Juxtaposition of spawning gravels

The proximity of juvenile rearing habitat to spawning gravels may prove to be significant. This is particularly true if spawning gravels are not spread evenly throughout the system and are concentrated in individual tributaries. Attempting to maximise production from juvenile habitat by, for example, canopy trimming may be totally ineffective if spawning areas upstream and in close proximity are not available to seed fry into the nursery.

iv)   Drought susceptibility

Susceptibility to drought or low flows is an important characteristic that can be determined from habitat mapping. Reduced wetted area may significantly decrease juvenile salmon productivity due to reduced rearing area. Wide ford

sections, which largely dry out or become intolerably shallow, can be identified and quantified so that suitable remedial action can be taken.

9.2.3 Adult habitat

i)   Obstructions

Obstructions to upstream adult migrations have already been mentioned. Of importance here is the influence they may have on access to spawning grounds and nursery areas. This may include permanent habitat features such as impassable falls but may also include recently engineered features such as dams, weirs and fords and natural occurrences such as trash dams. The latter are becoming more evident as routine river maintenance is on the decrease due to manpower constraints. As such trash dams have significant implications by temporarily blocking access.

The number of obstructions is particularly relevant when considering trash dams, as this has cost implications for management. In addition, this will provide an understanding of the extent to which the area contains large woody debris, improving a valuable resource not only providing diversity of fish habitat but also improving conservation value.

Location is significant in that it will allow wider management issues to be taken into consideration when contemplating removal of obstacles to achieve a specific objective, such as improved access to spawning areas. Removal should, therefore, be undertaken in an informed manner, balancing the obstruction risks against the general conservation benefits of large woody debris.

Adults may also be severely affected by drought, rendering otherwise passable areas obstructions to migration, resulting in fish being more susceptible to both poaching and predation. Identifying such areas will provide a focus for restoration solutions and greater surveillance, for example by initiating anti-poaching patrols.

9.3   Stock assessment

Utilising the habitat information alone provides a basic indication of areas where physical habitat features may negatively influence salmon productivity. However, determination of the critical factors limiting salmon stocks requires a more analytical approach. This can be achieved by creating simple interrelated salmon production models utilising a combination of habitat and stock data. A similar approach is proposed for rivers where SAPs are in place.

This assessment will allow a determination as to whether the following are limiting the productivity of a river.

- Spawning gravel availability

- Returning adult stocks

- Juvenile nursery areas

To illustrate the principles adopted in estimating current and anticipated salmon productivity from habitat mapping, hypothetical worked examples are provided in the boxes below. The data used in the worked example are taken from Tables 9.1 and 9.2 which represent habitat survey data and historic fish population data.

Table 9.1   Hypothetical river habitat types and features

Feature	Total Length (m)	Total Area (m²)	Percentage of River on which feature can be found
River	10,000	70,000	100
Pool	3,000	21,000	30
Glide	1,200	8,400	12
Spawning Gravel	1,000	7,000	10
Macrophyte Beds	300	2,100	3
Fry Habitat	2,000	14,000	20
Parr Habitat	2,500	17,500	25
Tunnel Vegetation	3,200	22,400	32

The total area of the river is 70,000 m² based upon an average river width of 7m.

Table 9.2   Hypothetical data for observed fisheries statistics.

Parameter	Data
Observed Salmon Parr Densities From Electric Fishing Surveys	2 parr 100 m⁻²
Observed Trout Parr Densities From Electric Fishing Surveys	2 parr 100 m⁻²
Mean Salmon Redd Count	60
Average Weight of Female Salmon	2.73 kg
National Fisheries Classification	E

9.3.1   Theoretical maximum productivity of a river

Objective: To determine whether spawning gravels are limiting.

Following a walk-over survey of the river, the area of existing spawning gravels can be determined. Beall and Marty (1983) suggested that the area required for the successful cutting of a redd was 9.5 m^2. Therefore, the theoretical maximum number of redds for a particular river can be calculated by dividing the total area available for spawning by the area required for each redd. From the potential maximum number of redds, productivity estimates for the different life stages of salmon can be made:

Maximum number of redds	Spawning area / area required for a single redd
Average Fecundity	Number eggs per unit weight x average female weight
Likely egg deposition	number of redds x average fecundity
If 10% (Harris, in press) survive to summer 0^+ stage[3], then the standing crop will be to the order of	Egg deposition / 10
From electric fishing juvenile survey data and habitat mapping, calculate fry density	Fry density/100m^2
Assuming a fry to parr survival of 33% (*Milner et al., 1993*) a typical density for $>1^+$ parr would be	Fry Density x 0.33

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3 This figure is based upon the utilisation of pristine spawning gravels. If the gravels are of a lower quality then the survival rate will be correspondingly lower.

Example 9.1 Maximum theoretical productivity estimates from available habitat.

Using the hypothetical data from Table 9.1, the following productivity estimates have been calculated:-

Maximum number of redds (spawning gravel area /area required by each fish)	*736 redds.*
Assuming average size of a spawning female is 2.73 kg (6 lb.) the average fecundity (Mills, 1990) will be	*4,340 eggs per redd.*
Likely egg deposition (number of redds x average fecundity)	*3,194,240 eggs.*
If 10% (Harris, in press) survive to summer 0^+ stage, then the standing crop will be to the order of	*319,424 fry.*
From Table 9.1 the available fry habitat (0^+) is 14,000m^2, therefore the potential maximum density is	*2,282 fry 100 m^{-2}.*
Assuming a fry to parr survival of 33% (Milner et al., 1993) the equivalent density for $>1^+$ parr in fry habitat would be	*752 parr 100 m^{-2}.*
Corrected for parr habitat (ie 14,000/17,500)	*602 parr 100 m^{-2}.*

It should be noted that the above fry and parr densities are not attainable due to density dependant mortality but are illustrative of the theoretical maximum juvenile seeding capability.

A comparison of the estimated potential maximum parr density of 602 parr 100 m^{-2} from the theoretical maximum redd cutting with the observed value of 2 parr 100 m^{-2} from electric fishing surveys suggests that the availability of spawning habitat is not a limiting factor. Spawning habitat is theoretically sufficient to overproduce juveniles for the available nursery area. Clearly, in this example observed parr densities are well below those which could be attainable (density dependent factors aside) given the amount of spawning habitat available if it were fully utilised.

9.3.2 Productivity estimates based upon redd count data

Objective: To determine whether the returning adult stock is limiting.

Through the use of historic redd count data, the theoretical maximum value can be compared to the actual productivity value obtained. Although redd count data are not ideal, due to the notorious subjectivity of counts, they do provide a provisional basis on which to compare productivity estimates. Using the mean redd count data over a number of years, the productivity of the river can be calculated in the same manner as above.

Example 9.2 Theoretical productivity using actual redd count data

Through the use of the hypothetical data in Table 9.1 and 9.2 the productivity is as follows:-

Mean redd count	*60 redds*
Assuming average size of a spawning female is 2.73 kg (6 lb.), *average fecundity (Mills, 1990) will be*	*4,340 eggs.*
Likely total egg deposition	*260,400 eggs.*
If 10% (Harris, in press) survive to summer 0^+ stage, the standing crop would be to the order of	*26,040 fry.*
The available fry habitat from Table 9.1 is 14,000m^2, therefore the theoretical maximum density is	*186 fry 100 m^{-2}*
Assuming a fry to parr survival of 33% (Milner et al., 1993) a typical density for >1$^+$ parr would be	*61 parr 100 m^{-2}.*
Corrected for parr habitat (ie ratio 14,000/17,500)	*49 parr 100 m^{-2}.*
The overall productivity figure for this theoretical river would therefore be to the order of	*8,575 parr.*

The above comparison shows that, although the actual adult returning stock is lower than the level for the maximum theoretical utilisation of the available spawning gravels, the returning adult stock provide sufficient fry and subsequently parr to classify the river as a grade A salmonid river (Agency National Fisheries Classification Scheme).

If the average redd count had been 10, then the standing crop of parr would have been to the order of only 8 parr 100m^{-2}. As such, the river would have been classified as a grade C river. This would suggest that, in this instance, the adult returning stock may be limiting the productivity of the river. This could be confirmed by HABSCORE assessments at selected points to compare actual juvenile densities with predicted values. An appropriate management strategy would be to reduce the exploitation rate of the returning adult stock.

9.3.3 Productivity estimates based upon electric fishing survey data.

Objective: To determine whether juvenile habitat is limiting the productivity of the river.

Following the elimination of low numbers of returning adults as a limiting factor, an assessment of existing parr numbers can be made from electric fishing survey data. The purpose of this exercise is to determine whether the extent and quality of juvenile

habitat is limiting the productivity of the river. This can be accomplished by comparing parr production figures derived from the electric fishing survey data with the estimate derived from the redd counts.

If the productivity estimates from the electric fishing and redd count data were of a similar value then the habitat would be deemed of sufficient quality to rear the juveniles produced from the available spawning habitat.

Example 9.3 Comparing observed productivity with theoretical calculations

For illustrative purposes, a hypothetical mean density of 2 parr 100 m^{-2} of juvenile habitat is used. It should be noted that only data from stretches of river classified as juvenile habitat should be used in the calculation of mean parr density. Using data from Table 9.1;

The total observed parr productivity for the river is 350 parr.

The estimated parr productivity for the from the redd count data
is 8,575 parr

The observed production value of 350 parr is much lower than the estimate of 8,575 parr derived from the redd count data. This suggests that habitat is limiting, either in terms of area and/or quality. Habitat restoration techniques targeted at elevating juvenile densities and/or production should therefore be considered.

It is essential that the production models are viewed very much as theoretical tools at this stage and not necessarily population predictors. Their primary function is to allow assessments of potential and actual productivity so that comparisons can be drawn and informed decisions taken on the suitability of various habitat rehabilitation techniques.

9.4   Scale of study

By utilising a combination of the general overview and stock assessment techniques identified above, limiting factors which impact negatively on salmon production can be identified from an informed perspective. The smaller river reaches at the higher level of resolution (less than 1 km) will tend to rely more on the general overview to identify limiting factors, whereas the larger river reaches will be more dependant on stock assessment techniques. Obviously, each case will be unique and hence common sense must prevail when applying this methodology. However, the basis for a rational approach to habitat factors which are limiting to salmon production has been identified.

Outputs from this stage will vary but the objective should be to produce a clearly identified statement on one or more of the following:-

- Spawning gravel quality and quantity

- Juvenile habitat quality and quantity

- Access and obstructions to adult migration

Identification of individual life stages and their associated habitat constraints will then allow the subsequent stages of the project management process to be progressed. The restoration objectives can be defined, specific appropriate habitat solutions identified and the habitat enhancement scheme designed and costed. However, without proceeding in a logical fashion to identify critical factors, considerable resources could be wasted in inappropriate and ineffective salmon habitat enhancement schemes.

9.5   Defining restoration objectives

Having ascertained the limiting factors, those aspects of the habitat which are to be restored are defined. The physical creation or restoration of these habitats then becomes the means by which the **overall objective** of maximising salmon productivity is achieved.

The objectives of a scheme will dictate the manner in which the restoration of habitat is carried out and also set the criteria by which the effectiveness of the scheme is to be assessed. The SMART (Specific, Measurable, Achievable, Realistic and Time-based) concept can be employed to determine **specific objectives** that are appropriate to the scheme.

As stated in the Project Management Model, an indication as to what is anticipated or required from habitat restoration is essential. These objectives should take into account the importance of the river as a salmon fishery, other fisheries present and conservation issues. SAPs have specific objectives which are defined, e.g. deposition targets. Whilst this is appropriate for relevant catchments which fall under the aegis of SAP schemes, less significant salmon rivers will require an alternative approach in defining targets.

Objectives can take any number of forms but obviously should be measurable. It is suggested that the primary indicator of success should be rod and/or net catches. Restoration to historic catch levels may be preferable but not achievable given external constraints, such as high seas fisheries. However, an informed decision should be made allowing for natural temporal variation specific to the individual river.

The objectives should also determine whether the corrective action taken is short term **symptomatic restoration,** which may have an immediate effect (i.e. cleaning of gravels), or a long term **strategic restoration** of catchment, requiring a significant input of resources over several years.

In addition, other measurable parameters such as juvenile densities and adult trap data can be examined and targets defined. Once a connection between adult stock and juvenile numbers has been made, it will be possible to examine a variety of habitat improvements, calculate productivity estimates and compare predicted productivity from restoration schemes with desired target objectives set for adults or juveniles or both.

An advantage of using juvenile density figures is that both current status and objectives can be expressed using the relative score of the National Fisheries Classification Scheme. This is desirable as the objectives of the scheme can be presented in an easily assimilable form, such as:-

"to progress from a Class D to a Class B salmon fishery"

Not only is this definition of the objective succinct and readily identifiable, it is also easily measurable, an essential feature identified in the project management model.

At this stage of a project, appropriate techniques such as HABSCORE or PHABSIM may also be considered. They will enable sections of specifically identified and mapped juvenile habitat to be assessed for potential salmon productivity. Hence they may be of great value in setting objectives in the absence of historic juvenile survey data.

Example 9.4 Restoration scheme measurable objectives

The aim of the restoration programme of the example river is to increase the productivity so that the classification of the river will be raised from its current level of Grade E to Grade C.
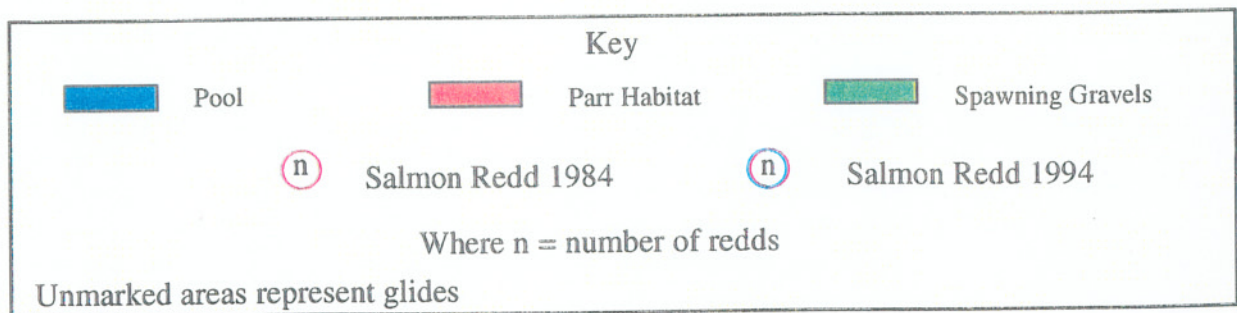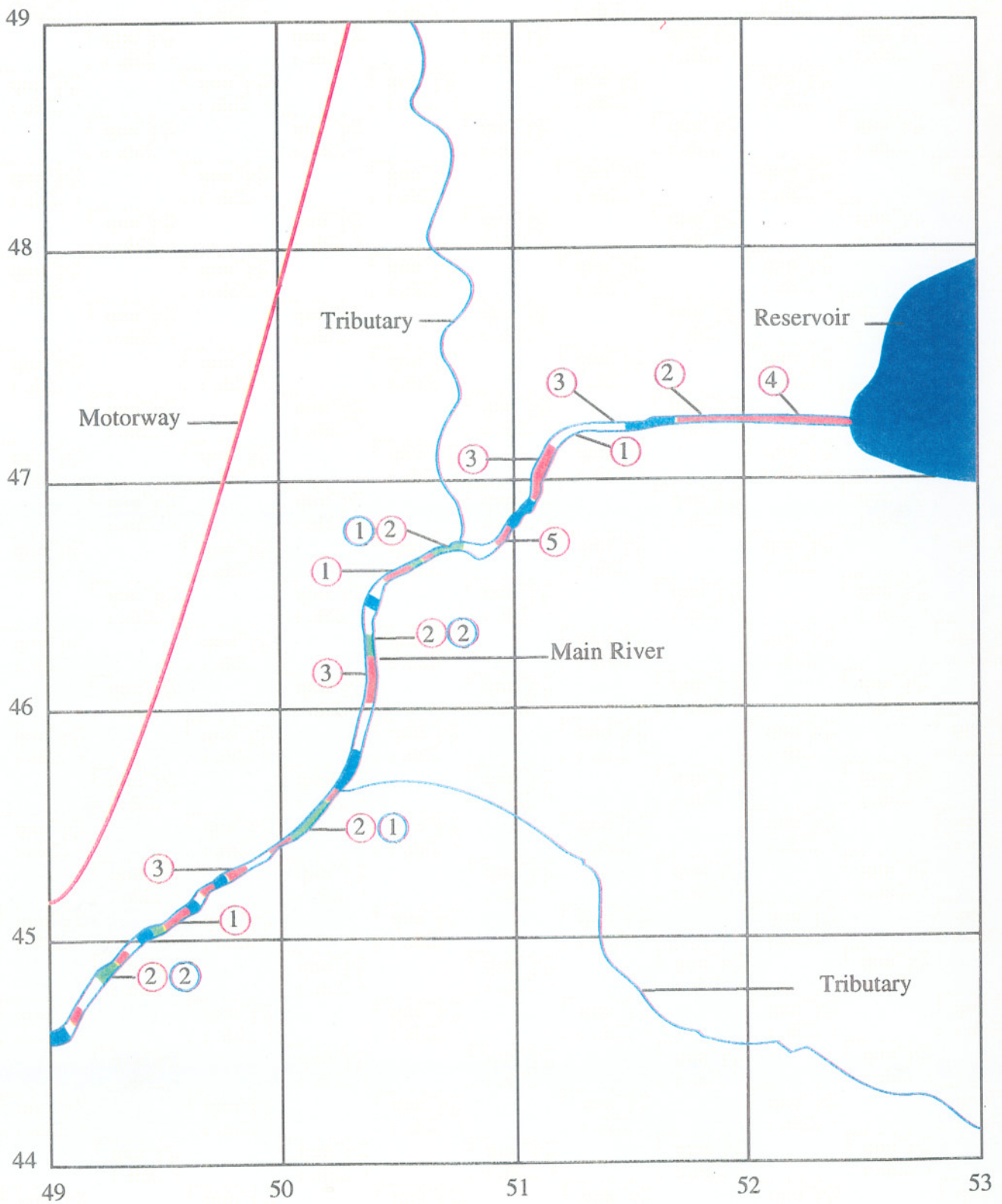

Figure 9.1. Location of Redds in Relation to Habitat

10. RESTORATION SCHEME DESIGN & COSTING

10.1 Introduction

Following identification of limiting habitat factors, definition of objectives and identification of appropriate solutions, the restoration scheme design can be developed. This stage utilises the different techniques used for creating and restoring salmon habitat detailed in Section 5 and involves:-

- Precise location and extent of habitat improvement structures and preparation of design plans.

- Evaluation of the anticipated improvement in salmon productivity.

- Cost estimation and cost benefit analysis.

10.2 Location and extent of restoration schemes

Using the habitat maps produced in Section 8, the precise location and extent of stream improvements can be determined. The physical area affected by a particular technique is important as this will be used subsequently in productivity analysis and costing. Proceeding along the river, individual problem stretches can be identified and the appropriate habitat restoration techniques applied.

Obstructions - Obstructions such as large woody debris can be individually identified for potential removal. The precise location of fish passes to improve access can be identified.

Adult holding area - The provision of adequately spaced holding pools and overhangs to provide refuge for upstream migrating adults can be determined relative to the availability of existing holding areas. These may need to be considered in relation to angling (i.e. location of beats), conservation considerations and the defined objective(s). For example, a pool may be created to encourage fish to be held up within a reach to be available to rods or as a conservation measure, clearly with greatly differing objectives in mind.

Spawning gravels - The exact location of gravels requiring some form of restoration can be identified (e.g. manual or mechanical raking, high pressure hose cleaning). Sites where gravel additions are considered appropriate can be specified, as can the exact location of features such as artificial spawning channels. Use of habitat maps is crucial with regard to the latter to ensure that adequate juvenile nursery area is available downstream of the structures intended to provide additional spawning habitat.

Juvenile habitat - Areas of tunnel vegetation can be identified for pruning back and the length of improved river assessed. Similarly, deep glides considered appropriate for rubble mat additions can be located and the areas available quantified. Specific areas where flow constrictions would appear appropriate can also be identified and sized.

During this process, the actual location and extent of restoration structures or techniques can be precisely recorded directly onto the habitat maps with a view to production of an overall enhancement scheme design for the river reach in question using appropriate symbols (see Figure 10.1). In addition, an inventory table of the type and number or extent of structures can be drawn up. This information can then be used to provide cost and productivity estimates for the overall scheme.

Outputs from this stage, together with the individual structure drawings, can be used as the basis for tender documents and can be given directly to contractors for pricing. Experience has shown that, due to the comparatively simple nature of many of the structures and techniques used in this manual, the location maps, structure drawings and summary table are often sufficient for contractors needs both for pricing and implementation, although close on site supervision is essential during construction.

10.3 Productivity associated with restoration schemes

Once the type, location and detailed plans for the enhancement scheme structures have been determined, the additional productivity can be estimated using the productivity data discussed in Section 5. However, it should be noted that the productivity estimates described are based upon a limited number of sources and are not necessarily transferable to all river types. Hence, whilst there is a requirement to establish anticipated levels of productivity from a given restoration scheme, the productivity gains mentioned here should not be regarded as prescriptive. Rather they represent reasonable estimates based on the data currently available. As more restoration programmes and appraisals occur, the productivity estimates will certainly be revised, particularly with respect to different river types. This emphasises the need for pre and post scheme appraisal and most importantly, reporting of results.

To illustrate the approach that can be taken in assessing the level of productivity increases that might be anticipated from a given scheme the following example is given based on the hypothetical data from Table 9.1.

Example 10.1 Estimated productivity associated with various habitat restoration techniques

a)   *Trimming Tunnel Vegetation*
50% of the tunnel vegetation (1,600 m) occurs concurrently with juvenile nursery habitat and is the main factor limiting salmon productivity. Cutting back tunnel vegetation along the 1600 m length (11,200 m^2) that encroaches upon juvenile habitat should have the effect of increasing parr densities from 2 parr 100 m^{-2} to 10 parr 100 m^{-2}.

Additional 896 parr from trimming tunnel vegetation.

b)   *Addition of Rubble Mats To Glides*
Extensive areas of unproductive glide exist in the river (1,200 m). If all of the glide reaches were turned over to rubble mats, an additional 8,400 m^2 (average width 7 m) of juvenile habitat would be created. Based on O'Grady's figures up to 5 salmon parr per 100 m^2 should be produced.

Additional 420 parr from addition of rubble mats.

c)   *Flow Constrictions*
365 m of linear river length was suitable for the addition of flow constrictions. Of the total 365 m, 200 m (1,400m^2) was suitable for full width flow constrictors and 165 m (1,155 m^2) for low level flow constrictors. Similar production figures are anticipated to those above (say 5 parr per 100 m^2), based on similar water chemistry and primary productivity.

Additional 128 parr from flow constrictions.

d)   *Total Enhanced Salmon Production*

Current Production (observed electric fishing data)	*350 parr*
Trimming tunnel vegetation	*896 parr*
Addition of rubble mats to glides	*420 parr*
Flow constrictions	*128 parr*
Total Enhanced Production	**1,794 parr**

The enhancement scheme will raise the classification of the river from
a **Grade E** *to a* **Grade C** *under the National Fisheries Classification scheme.*

10.4 Cost of the restoration scheme

Following an evaluation of the expected productivity from different restoration structures, the preliminary costs detailed in Section 6.10 allow the restoration scheme to be fully costed. It should be noted that the costs given are for sites where access to the river bank can be easily achieved. Ease of access to the river should be taken into account when locating individual enhancement schemes.

Example 10.2 Construction costs for restoration scheme

The construction costs for the schemes within the 10 km of the hypothetical river reach are detailed below.

Trim Canopy Vegetation (1,600 m linear river length)	£2,720
Addition of Rubble Mats (1,200 m linear river length)	£18,480
Flow Constriction (200 m liner river length)	£8,000
Low Level Flow Constriction (165 m linear river length)	£6,930
Total Cost	**£36,130**

10.5 Maintenance costs

Maintenance costs for many of the proposed enhancement structures are low due to the low degree of complexity in their design. However, in order to maintain the efficiency of each structure throughout its lifespan, annual maintenance should be carried out. The cost of maintaining each structure should be incorporated into the overall costing of the enhancement scheme. Maintenance costs will vary for each of the structures and also for similar structures placed in different localities which are subject to differing hydraulic conditions and riverine conditions. The costs detailed below for the hypothetical river used in the working examples, are given as guideline values, as the actual costs may obviously vary.

Gravels should be cleaned on an annual basis prior to the spawning season. This can be achieved by hand raking. Based on these assumptions, a budget of £50 per site (using a labour rate of £10 per hour and 5 hours work) should be allowed. A small amount of gravel will also be lost from the gravel addition sites over the year due to spate conditions. As a consequence, an annual budget of £75 (£50 materials and £25 labour) per site should be allowed for augmenting gravel addition sites. Experience of the flow regimes present at a particular site may alter this figure.

There is a possibility that the in-river structures may fail over their lifespan. Therefore, an annual **contingency factor** of 10% of the capital cost should be allocated to renewing and repairing the structures along a particular river reach.

Due to the re-growth of trees forming the tunnel vegetation along the river, trees will have to be trimmed on an annual basis. Therefore, the annual cost of keeping the canopy open along the river will be £42.50 per 25 m stretch of river. However, this cost may be reduced as the trimming of canopy vegetation in the first year will be more arduous. In subsequent years trimming will be limited to cutting back annual re-growth of vegetation.

10.6 Additional costs

In addition to the construction and maintenance costs of enhancement schemes, an allowance for additional costs incurred by estate way leave fees and compensation/liability fees during the construction of structures should be made. These costs will vary greatly depending upon the riparian land use, other users of the river and the scale of construction works involved. No such costs have been included here, but they should be borne in mind for individual schemes and should be included in the overall budget for restoration works.

10.7 Monitoring

An appropriate monitoring programme should also be identified at the planning and design stage. A statistically valid appraisal methodology should be determined such that an evaluation of the success or otherwise of the restoration scheme can be made. The costs associated with the monitoring programme can then be included into the overall budget for the project.

10.8 Cost benefit analysis

Once the additional numbers of parr and costs associated with each habitat enhancement scheme are known a cost benefit analysis can be undertaken. Subsequently, the individual schemes can be ranked according to their cost effectiveness. The economic value of conducting a particular restoration scheme can be appraised using the **NRA Economic Appraisal Manual** (1993b).

Data required for the analysis include:-

- Additional number of salmon and trout produced from each structure
- Life stage survival rates.
- Construction cost for each enhancement structure.
- Annual maintenance cost for each structure.
- Anticipated operational lifespan of each structure.

Monitoring costs can also be incorporated at this stage. However, for clarity of presentation, they have been omitted here.

10.8.1 Estimate 1. Capital cost per fish

The benefit of an enhancement scheme may apply to both salmon and trout. As such, the cost of the structure should be split proportionally between the number of salmon and trout produced i.e. if trout account for 53% of the total number of extra fish, then 53% of the structure cost should be assigned to the production of trout.

Following the apportioning of the construction cost to each species, the cost per fish of a particular species is estimated. If the survival rate of parr to adult is known then the cost per fish can be estimated for parr and adults.

The annual cost for maintaining a structure should be split on a pro rata basis for individual fish in a similar manner to the capital costs. It is assumed here that the maintenance costs for each structure will be zero during the first year after construction.

These calculations should result in the construction of a table detailing the additional production of fish and the capital and maintenance costs associated with producing each parr and adult.

Example 10.3 Cost per fish

The cost of trimming canopy vegetation along 1600 m of river length equates to £2,720 and will produce an extra 896 salmon parr and 448 trout parr. Due to the regrowth of the vegetation, the annual maintenance cost will be £2,720. The cost to produce each additional parr is therefore £2.02.

Assuming a parr to adult survival rate of 4.5% for salmon and 16.5% for trout (Harris, in prep), trimming the canopy should produce an additional 40 adult salmon and 74 adult trout.

A similar methodology can be used for the other restoration techniques producing the table overpage.

Example 10.4 Additional Productivity Associated with the Hypothetical Restoration Scheme.		
	Salmon	**Trout**
Trimming Canopy Vegetation		
Total Parr Produced	*896*	*448*
Total Adults	*40*	*74*
Cost Per Parr	*£2.02*	*£2.02*
Cost Per Adult	*£44.88*	*£12.24*
Rubble Mats		
Total Parr Produced	*420*	*504*
Total Adults	*19*	*83*
Cost Per Parr	*£20*	*£20*
Cost Per Adult	*£441.05*	*£121.44*
Flow Constrictions		
Total Parr Produced	*128*	*153*
Total Adults	*6*	*25*
Cost Per Parr	*£53.13*	*£53.13*
Cost Per Adult	*£1,133.44*	*£325.16*

10.8.2 Estimate 2. Cost benefit relationship

This calculation details the projected capital and maintenance costs associated with a restoration scheme throughout the operational lifespan of the structure. The costs detailed in Estimate 1 represent the year 1 costs associated with producing the additional fish. The **total capital cost** of each structure should be depreciated over the operational lifespan of the particular scheme, i.e. if the structure has a lifespan of 10 years then the capital cost should be depreciated over 10 years. The example below is for rubble mats although the same technique can be applied to all restoration schemes.

Example 10.5 Cost of Salmon Parr Associated With Rubble Mats Over a 10 Year Period.				
Year	*Total Number of Parr*	*Capital Cost Per Fish*	*Maintenance Cost Per Fish*	*Total Cost Per Fish*
1	*420*	*£20.00*	*£0*	*£20.00*
2	*840*	*£10.00*	*£2.00*	*£12.00*
3	*1,260*	*£6.67*	*£2.00*	*£8.67*
4	*1,680*	*£5.00*	*£2.00*	*£7.00*
5	*2,100*	*£4.00*	*£2.00*	*£6.00*
10	*4,200*	*£2.00*	*£2.00*	*£4.00*

Assuming a parr to adult survival rate of 4.5%, the Year 1 and Year 10 costs for adult salmon are £444.44 and £88.89 respectively. The corresponding figures for adult trout are £121.21 and £24.24 respectively.

10.8.3 Comparison of costs associated with different structures

The calculation of total cost per fish over a ten year period will allow different enhancement schemes to be ranked according to their cost, allowing the best use of available resources for improving salmon habitat. In addition, predicted productivity gains can be interpreted in the context of performance targets set in the overall objectives.

Example 10.6 Comparison of cost per fish for each restoration scheme.		
Enhancement Scheme	*Cost per adult in Year 10*	
	Salmon	*Trout*
Trimming Canopy Vegetation	*£44.98*	*£12.24*
Addition of Rubble Mats	*£88.89*	*£24.24*
Construction of Flow Constriction	*£236.00*	*£64.36*

Example 10.6 above illustrates a summary of the cost of producing each adult salmon in year ten of operating each structure. Cost benefit analysis indicates that trimming of the canopy is the most cost effective method of improving the number of salmon produced in the river.

In the worked example, by instigating trimming of the canopy and addition of the rubble mats, 88% of the total increase in production can be accomplished at 59% of the total cost. In addition, the original target of elevating the classification of the river from a Grade E to a Grade C can still be accomplished. Hence the overall capital cost of the scheme to restore the 10 km of salmon habitat would be reduced from £36,130 to £21,200.
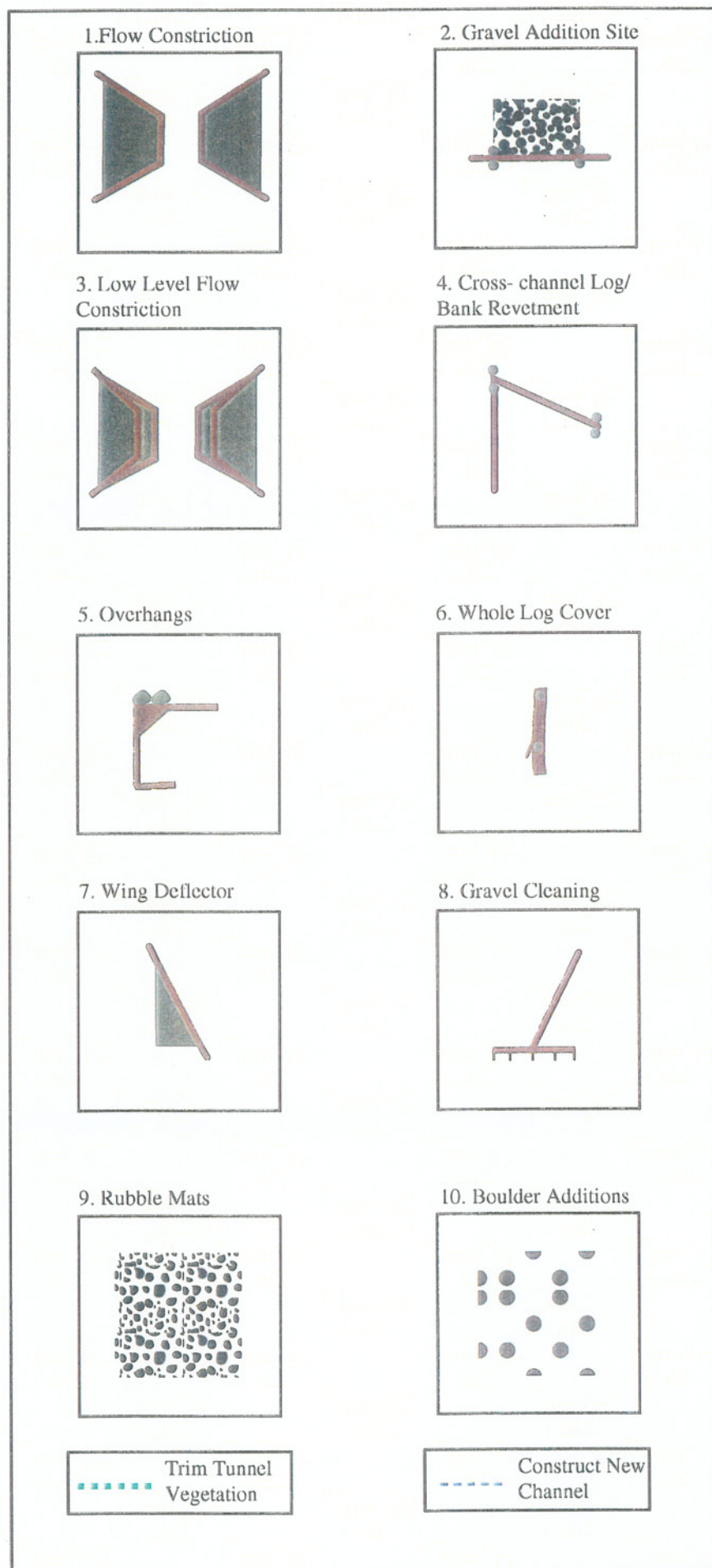
10. 9 Cost benefit for strategic catchment measures

Cost benefit analysis for strategic, large scale catchment based schemes is a much more difficult undertaking than that described above for restoration in smaller rivers (<100 km). Whereas costs may be comparatively easy to define (e.g. large scale fencing), the benefits will be inherently difficult to measure directly due to factors of scale.

Large scale **fish enumeration studies** (adults and smolts) would be required utilising fish counters, traps and extensive electric fishing surveys. To be truly representative such studies would need to be undertaken on major tributaries and sub-catchments and must include the main river with all the attendant problems of sampling large flowing water courses. Hence accurate assessment of the benefits may be prohibitively expensive.

Whereas measurable benefits include increases in fish produced, angling catches, increased numbers of anglers fishing, value of the fishery etc., it is also prudent to mention other benefits which accrue from restoration schemes which may not be measurable in financial terms. These include conservation benefits arising from the improvements in the ecological status of the river, wider economic benefits for local service industries, related tourism and amenity. The latter are likely to be more significant the larger the scheme.

1. Flow Constriction

2. Gravel Addition Site

3. Low Level Flow Constriction

4. Cross- channel Log/ Bank Revetment

5. Overhangs

6. Whole Log Cover

7. Wing Deflector

8. Gravel Cleaning

9. Rubble Mats

10. Boulder Additions

Trim Tunnel Vegetation

Construct New Channel

Key to Figure 10.1 Location Map of Habitat Restoration Schemes
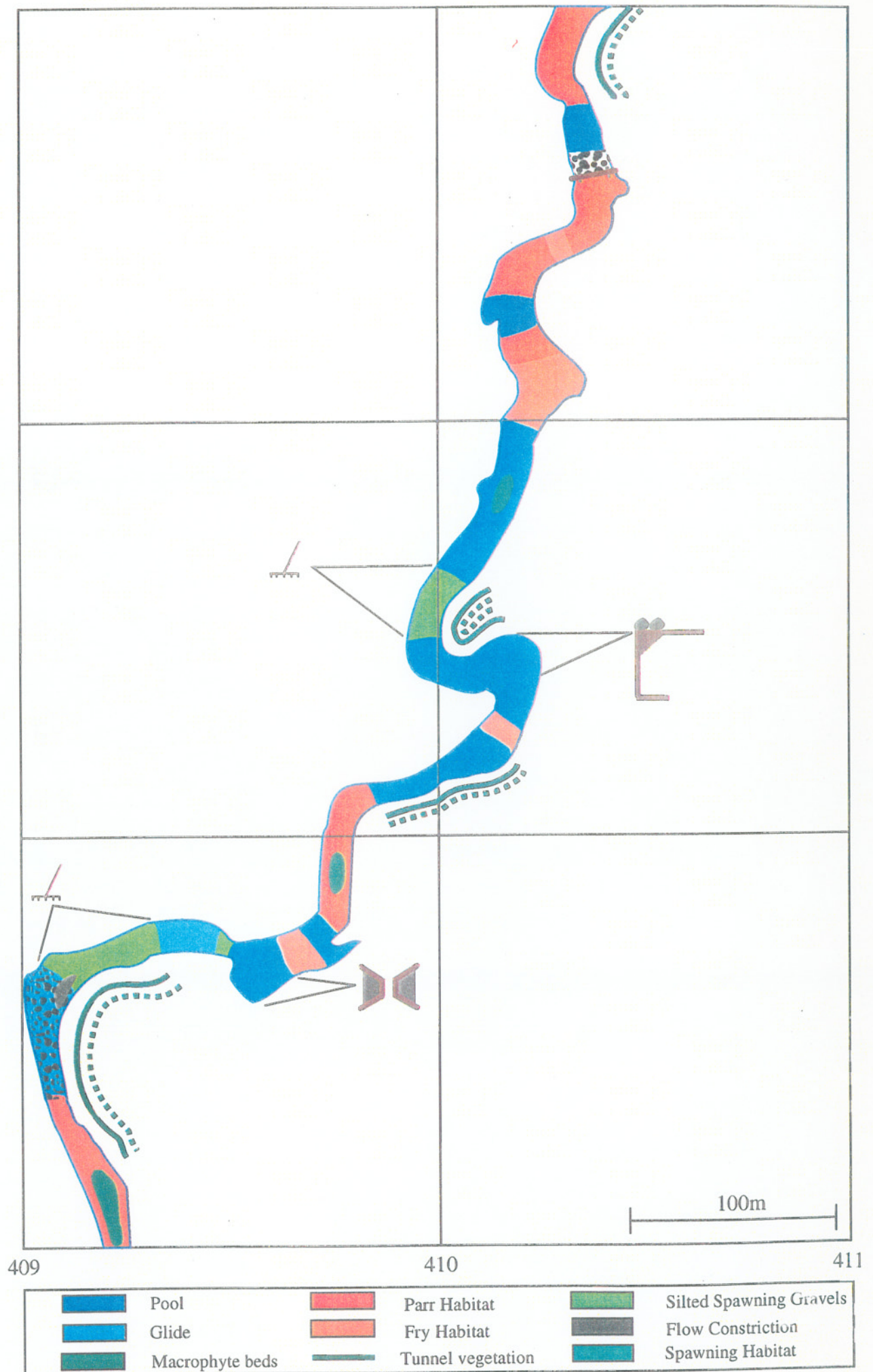
Figure 10.1. Location Map of Habitat Restoration Schemes

11. SCHEME CONSENTS AND CONSTRUCTION

11.1 Introduction

Prior to the construction of instream restoration structures, the environmental impact that these structures will have on the river requires assessment. To this end an environmental statement is necessary such that restoration schemes can be assessed in the wider context of the catchment.

The need for an objective assessment of proposed restoration schemes can be illustrated using the example of a scheme that created a series of holding pools and fishing platforms within a short stretch of the River Moy in Ireland (O'Grady, pers comm.). Historically, the section of river used to yield less than 20 salmon a year to the rods. However, after the implementation of the scheme, in the region of 300 adult salmon were caught annually by anglers. Whilst immediately beneficial to the riparian owner, the consequences of additional exploitation needs careful consideration, both locally, with respect to adjacent beats, and in the context of the catchment stock as a whole. Hence, an evaluation and decision making protocol is necessary to assess the validity of the requirement and effects of such schemes in a holistic manner.

In addition, in rivers that have been classified as semi-natural by River Habitat Survey (RHS), the construction of instream structures may be unwarranted as they may potentially disrupt the natural stream hydraulics and morphology (Bird, 1996). As such, the construction of in-stream structures on semi-natural rivers needs to be carefully and objectively evaluated.

11.2 Legal requirements

Habitat restoration schemes will by their very nature, influence many aspects of a waterway and as a consequence, they must be undertaken with due regard to the legislative framework operating in the UK. The aspects of habitat restoration falling within this framework can be placed into the four main categories of instream structures, riparian bank developments, impounded waters and the construction of fish passes.

Table 11.1 provides a summary of the Acts of Parliament and regulatory bodies that should be consulted for each of the different scheme types.

Table 11.1   Summary of acts of parliament relating to restoration schemes.

Scheme Type	Act of Parliament	Regulatory Agency
Instream Structures		
	Land Drainage Act, 1976	Environment Agency
	Land Drainage Byelaws	Environment Agency
Riparian Bank Developments		
	Land Drainage Byelaws	Environment Agency
Impounded Waters		
	Water Resources Act, 1963	Environment Agency
	Water Act, 1989, 1995	Environment Agency
Fish Passes		
	Salmon and Freshwater Fisheries Act 1975, Environment Act, 1995	1. Environment Agency 2. Local Planning Authorities.

11.2.1 Instream structures

Proposed instream engineering schemes within the river channel, or any other works likely to cause interference to land drainage through the construction or modification of an obstruction to the flow of a water course, require consent from the Agency under the Land Drainage Act, 1976 and the Land Drainage Byelaws.

11.2.2 Riparian bank developments

The erection of any building or structure, or the planting of trees, shrubs or other growths in or within eight meters of the top of the bank of a watercourse designated as a 'main river' require consent under the Land Drainage Byelaws.

11.2.3 Impounded waters

The impounding of water on any watercourse through the construction of a weir or dam, requires the consent of the Agency, under the Water Resources Act 1963.

In addition, the clearance or de-sludging of dams, weirs or sluices requires the consent of the Agency, under the regulations outlined by the Water Acts 1989 and 1995. The raking of gravel beds to reduce their silt content is also likely to require consent as this activity may impact on water quality further downstream. Consequently, the Pollution Control and Conservation functions of the Agency should be consulted prior to raking of gravels.

11.2.4 Construction of fish passes

The Environment Act, 1995, removed the requirement for the Agency to obtain consent from MAFF for the design or construction of a fish pass. The Agency has also

taken over responsibility for the approval of fish passes being installed by bodies other than the Agency.

Where the Agency is constructing a fish pass, using its powers under Section 10 of the Salmon and Freshwater Fisheries Act, 1975, the Agency is required to notify the owner or occupier of the structure of its intentions (Salmon and Freshwater Fisheries Act, 1975, Section 18, (2).

Where a fish pass or other structures such as fish counters or traps are planned, it is likely that planning consent will also be required from the local planning authority, who may well impose conditions of their own. For example, the local authority may stipulate the type of materials to be used in the construction of the fish pass or want to influence how the structure will be landscaped into the surrounding environment.

11.3 Agency consent framework

In addition, to specific legal requirements, the Agency has designed a framework to assess the impact a restoration scheme will have on the river. This framework is in addition to the legal requirements stated in Section 11.2. The framework should be applied with due regard to the LEAP for a particular river and also with regard to the National Salmon Management Plan (NRA, 1996).

A flow chart describing a suggested protocol through which the Agency might assess a particular scheme is given in Figure 11.1, (taken from Bird 1996). The Environmental Statement to be used in the assessment of a particular scheme should be provided by the developer and must include the effects that the scheme will have on the river throughout the envisaged lifetime of the structures.

11.4 Construction phase

Construction may be undertaken by individuals, angling clubs, riparian owners, government agencies or civil engineering contractors covering a range of scales of operation and finance. 'Civils Project Management', dedicated exclusively to the construction phase, will be wholly dependant on the scale and resources of the enhancement scheme.

11.4.1 Agency guidelines for construction

The Agency has detailed project management guidelines which provide considerable information on what is required for large and small schemes. The following publications should be consulted:-

- NRA Procurement Manual (Volume 14)

- NRA Project Management Manual (Volume 9)

- NRA Civil Engineering Contract Administration Manual (Volume 21)

Depending on the capital value of the scheme, differing levels of project management and procurement apply. For example:-

- Projects valued at between £10,000 and £50,000 - Detailed tender procedures required (terms of contract).

- Projects valued at under £10,000 - Written quotations required.

- Projects under £1,000 - Straight forward purchase.

11.4.2 Construction project management guidelines - small projects

At the lowest level of resolution (<1 km), it is likely that much of the work will be undertaken on an individual or small group basis, probably with little in the way of resources. Invariably, the schemes will be small and of low capital value. Hence the use of contractors is probably limited. However, where they are used, basic principles of construction tendering should be adhered to including competitive tender, on-site supervision and possibly retention of final payment until satisfactory completion. Providing location maps and summary tables are sufficiently detailed, little further input should be required other than on site supervision. Site visits during the tender process are advisable. These should identify access difficulties and ensure compliance with relevant guidelines to address pollution and health and safety issues.

In summary:-

- Competitive Tendering - on site visits, access awareness, feasibility etc. Statements of competence, proven ability to work in riverine conditions.
- Tender Assessment - Price, quality, environmental awareness and experience.
- Award Tender - Timescale, mobilisation.
- On-site Supervision - Performance checks.
- Quality Checks - Stability, bank protection etc. Particularly important for gravel cleaning.
- Stage Payments - Progress Control.

Most of the above can probably be undertaken adequately by experienced fisheries managers with knowledge of employing building contractors.

11.4.3 Construction project management guidelines - large projects

If major civil structures are envisaged, such as an off-line spawning channel, then involvement of chartered civil engineers is essential. Detailed engineering design will be required, outside of the scope of this manual, together with quantity surveying, detailed site surveys, and much more complicated civil engineering project management techniques being applied than those identified above.
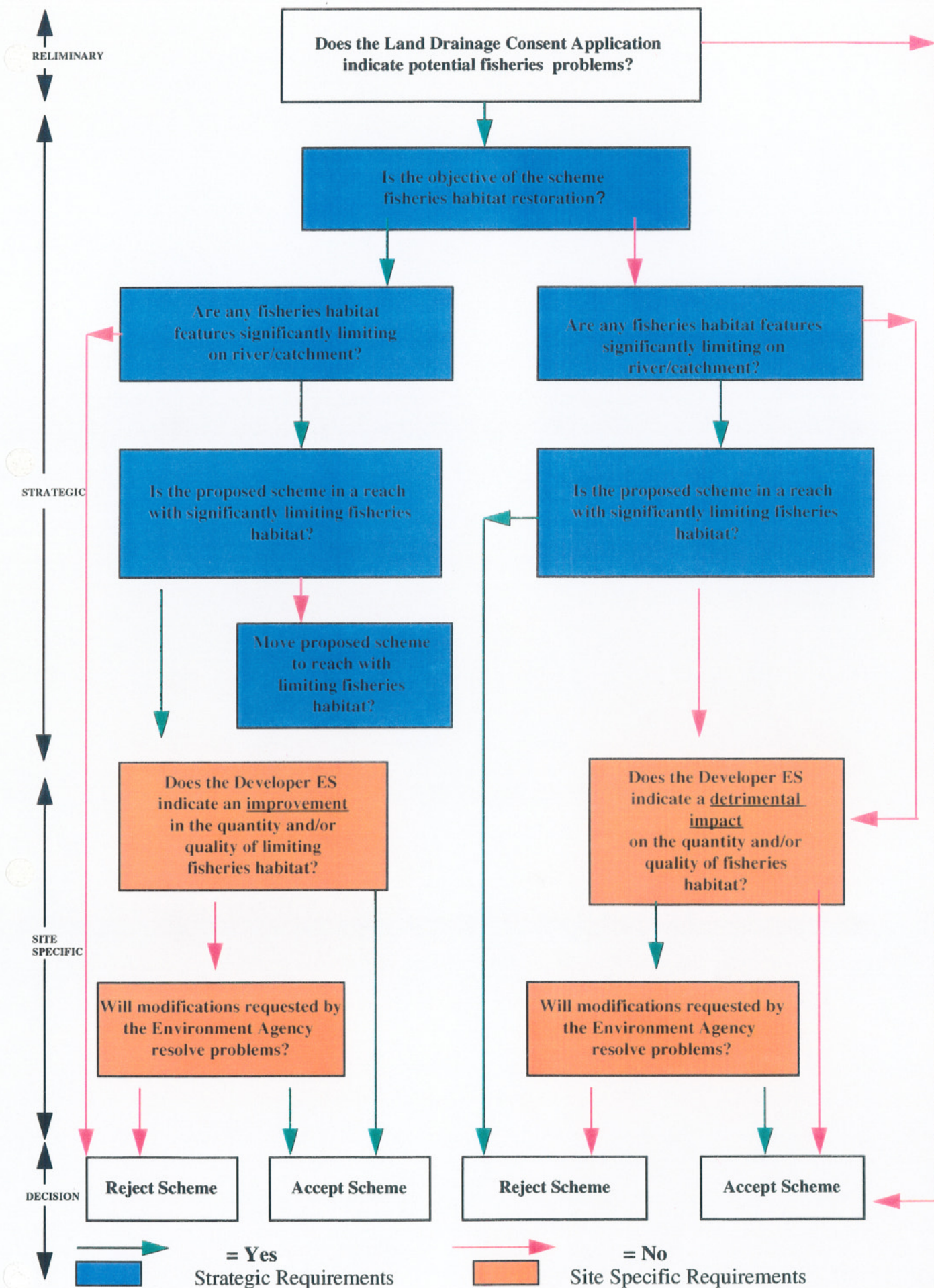
Does the Land Drainage Consent Application indicate potential fisheries problems?

Is the objective of the scheme fisheries habitat restoration?

Are any fisheries habitat features significantly limiting on river/catchment?

Are any fisheries habitat features significantly limiting on river/catchment?

STRATEGIC

Is the proposed scheme in a reach with significantly limiting fisheries habitat?

Is the proposed scheme in a reach with significantly limiting fisheries habitat?

Move proposed scheme to reach with limiting fisheries habitat?

Does the Developer ES indicate an _improvement_ in the quantity and/or quality of limiting fisheries habitat?

Does the Developer ES indicate a _detrimental impact_ on the quantity and/or quality of fisheries habitat?

SITE SPECIFIC

Will modifications requested by the Environment Agency resolve problems?

Will modifications requested by the Environment Agency resolve problems?

DECISION

| **Reject Scheme** | **Accept Scheme** | **Reject Scheme** | **Accept Scheme** |

→ **= Yes**

→ **= No**

Strategic Requirements

Site Specific Requirements

FIG 11.1 FLOW CHART FOR THE FISHERIES ASSESSMENT OF INSTREAM STRUCTURE SCHEME PROPOSALS

Plate 1. Alternating series of deflectors to create a thalweg.

Plate 2. Flow constriction to constrain flow in a reduced channel width to create additional juvenile habitat.

Plate 3. Area to the left of the photograph shows a fenced off section of river with a stable vegetated bank. The area to the right shows an eroded unfenced section subject to cattle poaching.

(Photograph courtesy of the Tweed Foundation.)

Plate 4. Left bank shows well developed riparian vegetation that is protected from grazing. The right bank shows the effects of uncontrolled grazing to the stream edge, resulting in poor riparian vegetation.

(Photograph courtesy of the Tweed Foundation.)

12. PROJECT APPRAISAL TECHNIQUES

12.1 Introduction

The purpose of post-project appraisal is to determine how successful a project has been in achieving its objectives, and to evaluate whether it has been cost effective. Different levels of appraisal will be appropriate depending on the scale of the scheme. However, in all cases, basic questions can be asked which will include:-

- Have the physical improvements identified been implemented?

- What were the hydrological effects?

- Have the biological objectives of the scheme been realised?

- Is there a detectable difference in some component of the salmon population in the affected beat, tributary, river or catchment?

- Have the perceived benefits of the scheme justified the cost?

12.2 Monitoring methodologies available

Various methods are available for monitoring the effectiveness of habitat restoration, depending on the stage of the life cycle being investigated. Again, the scale of scheme will be a critical issue influencing the appropriate level of resource allocation. The section below outlines experimental design and provides detail on a variety of investigative techniques.

12.2.1. Experimental design

Fish communities at a given site within a river are inherently variable with natural fluctuations being caused by temporal and spatial variations in fish populations. In addition, the physical method of sampling fish populations will also introduce variations in the number of fish recorded at a site. In order to overcome these variations an appropriate experimental design is required. Wyatt and Lacey (1994) provide guidance on designing statistically robust fish surveys.

Conventional survey design advocates comparing post-scheme population data with pre-scheme and/or control reach data. The resources allocated to monitoring must account for the following factors if responses to habitat restoration measures are to be accurately measured.

- The timescale needed for the physical structures and salmon populations to establish a population equilibrium.

- The natural variation in salmon populations within a given reach of river.
- The precision and accuracy of the method used to sample populations.

Hunt (1976) studied brook trout responses to habitat restoration and found it took five to seven years for populations to stabilise. He considered an appraisal need not have commenced until three years after the restoration. As many **salmon habitat restoration** techniques are more simple in design and are oriented towards juveniles, a lesser time span for stabilisation of population levels might be expected.

A robust experimental design is necessary to determine the natural variation in salmon populations within a given reach of river. The traditional approach involves long term monitoring of fish populations before and after restoration so that statistically defensible averages can be compared. Unfortunately the resource and planning implications of this approach have reduced its popularity in recent years. Alternatively, a paired design approach is used when sections are sampled pre and post restoration in addition to restored sections, testing the null hypothesis that there is no difference between the restored and control sections. This approach can alleviate the need for extended surveys. Replication of restored and controlled sections is however, important if statistically significant differences are to be detected.

12.2.2 Location and counting of redds.

Mapping the number and location of salmon redds can provide a direct indication as to whether salmon are utilising new spawning grounds, although it should be stressed that redd counting is not recognised by the Agency as a quantitative stock assessment technique. It can only be undertaken under normal flow conditions with no excessive colouration of the water. New redds should be recorded on a detailed map of the river in order to establish their location in relation to any newly created or cleaned spawning areas.

The size of the redd will be dependant upon the size of the spawning fish, although an average size would be 3m by 1m for a 2.8 kg female salmon (Crisp and Carling, 1989). Due to a similarity in size between smaller salmon redds and larger sea trout redds, it is possible to confuse the two species, leading to errors in the estimation of the number of salmon redds.

Redds can be comparatively easily identified as, initially, gravel disturbed by the cutting of the redd will be free of epiphytic algae and consequently lighter in colour. Over a period of time, algae will grow on the exposed gravel surfaces and subsequently obscure the redd. Therefore, in order to accurately record the presence of individual salmon redds, mapping should performed on a minimum of a fortnightly or weekly basis.

Redds can also be identified by the changed topography of the river bed, via the construction of a 'pot' at the top of the redd and a heaped up 'tail', which can be seen in a newly dug redd. However, it should be noted that spates readily flatten these features, rendering them difficult to locate.

Due to the inherent subjectivity of identifying and counting redds, this exercise should only be performed by trained and competent personnel. In order to achieve consistency in results, the same person should map the same section(s) on different sampling occasions.

12.2.3 Estimate of abundance of juvenile stages by electric fishing surveys.

Electric fishing surveys can be used to assess the success of habitat restoration schemes through the estimation of changes in juvenile salmon populations. Depending upon the spatial scale of the system being evaluated, the depletion method of sampling water courses can be applied at either quantitative, semi-quantitative or qualitative levels of accuracy. It should be noted that the efficiency of electric fishing decreases with a decrease in the length of fish caught. As a result, electric fishing can not be used as a reliable method of capture for fish with a fork length of less than 40 mm. When designing an electric fishing survey it is imperative that the inherent variations in juvenile salmon populations are taken into account. To this end, NRA R&D Note 292, Guidance Notes on the Design and Analysis of River Fishery Surveys, should be consulted.

12.2.4 HABSCORE

The Habitat Quality Score (HQS) derived through performing HABSCORE can be used to estimate the change in the long term density of fish that would be expected in a short stretch of river following the implementation of a restoration scheme (NRA Draft R & D Note 338/16/W). A review of the HABSCORE technique is given in Section 8.2.4.

12.2.5 Rod catches

As low rod catches are often the factor initiating concern over habitat, they are often used to assess the outcome of restoration schemes. However, a number of factors which will influence rod catches are not attributable to a change in fish population. The number of fish caught will depend upon the amount of effort expended in catching fish and may be influenced by the number of hours spent actively fishing, angler skill and the method of fishing employed. In addition to variations in the catch per unit effort (CPUE) caused by anglers, catch is further influenced by discharge, temperature, time of year and the location of the beat where the fish are caught.

Bylaw licence requirements regulating angling for migratory salmonids require anglers to record and report their catches. This data collection exercise has been expanded upon by Aprahamian (1993) with the distribution of log books to anglers within the North West Region. Analysis of the returned log books indicated that over the period June to October, CPUE was a reasonable measure of within-season abundance of salmon.

12.2.6 Net catches

Most major salmon rivers in England and Wales support commercial fisheries in their estuaries. These fisheries are strictly regulated, and there is a requirement for the fishermen to send in returns to the Agency, detailing their catches. However, to be of value in monitoring changes in stock size, information on fishing effort, for example the number of tides fished, is also required.

Any changes in the numbers of fisherman licensed and in the gear they use will need to be taken into consideration when looking at trends in commercial catches.

Although catch returns are compulsory, there is no guarantee that they are accurate. Under reporting of catches is suspected to occur in some areas, although the risk can be minimised by supervision of the netsman by bailiffs.

A disadvantage of using catch returns, common to both angling and commercial fisheries, is that only the part of the run entering during the fishing seasons is monitored.

12.2.7 Counting of adults by automatic fish counter

An automatic fish counter provides the opportunity to estimate the returning adult population entering a whole catchment or sub-catchment, depending upon the citing of the counter. The counter should provide information on the number of fish migrating upstream, an estimate of their length and, subsequently, an estimate of their weight and potential fecundity.

The use of fish counters as a stock assessment tool is described by Nicholson *et al.*, (1995). Following the guidelines set down by Nicholson *et al.*, care should be taken in extrapolating the results from a fish counter unless the counter has undergone a thorough evaluation of the output under different environmental conditions, such as varying conductivity levels. This is particularly relevant when attempting to identify species of fish counted, i.e., discriminating between salmon and sea trout on the basis of length.

12.2.8 Trapping and counting of smolts

Smolt traps consist of either permanent or temporary structures that direct downstream migrating smolts via a sieve into a collection facility. The traps can vary in size, depending on the size of river and whether the trap spans the full width, although they can only be located where there is a sufficient head of water.

The most commonly used smolt trap is the Wolf trap (Mills, 1989). This consists of a horizontal framework covered with a wooden or metal grill. The majority of the water falls through the grill whilst the downstream migrating smolts are sieved out of the water and directed to a holding pool. A method of controlling the amount of flow entering the trap is usually incorporated into the structure.

Due to the myriad of designs of smolt traps, individual traps on different rivers will have their own operating characteristics and limitations. However, it should be noted that all the traps are inevitably expensive in terms of capital, running and maintenance costs.

12.2.9 Trapping of adults

The use of traps to capture upstream migrating fish generally involves enticing the fish to enter a trap using either screens or river features, such as an impassable weir, to guide fish in the desired direction. Fish pass upstream through a set of inscale screens into a holding pool. The design of the inscale screens discourages fish from leaving the holding pool and retreating downstream. Adult traps are similar to smolt traps in terms of the costs involved in their construction and operation. Adult traps are usually built at the same location as smolt traps and fish counters.

12.2.10 Gravel quality assessment

Quality of spawning gravels can be determined by undertaking **freeze core analysis.** A hollow metal tube is forced into the gravel and liquid nitrogen or carbon dioxide poured into it. The frozen gravel core can then be extracted and particle size analysis undertaken to reveal not only the fines content but also the relative vertical position within the core. In this way the suitability of gravels for spawning can be assessed. In addition also the long term effects of restoration strategies such as erosion control via fencing can be evaluated.

12.2.11 Water quality analysis

Basic water quality analysis can also be performed to determine long term reductions in parameters such as suspended solids loadings following changes in land management practices. Obviously specific determinants (e.g. ammonia) can be included in the analytical suite to evaluate the effects of buffer strips etc. on non point source pollution. Alternatively invertebrate analysis can be used to analyse long term trends.

12.2.12 Land cover surveys

Effectiveness of strategic catchment schemes employing bank protection and erosion control strategies can be evaluated by undertaking periodic land cover surveys. Issues such as percentage bank cover following fencing, frequency and extent of upland erosion following reduction in grazing pressure etc. can be evaluated in this way.

12.3 Monitoring strategy

The monitoring strategy adopted will depend on the type of habitat restoration work being carried out and on the nature and extent of the river reach involved. Projects may be purely local, involving only a short length of river, or may extend to entire catchments.

12.3.1 Restoration work covering less than 1 km of river.

These schemes are likely to consist of **localised habitat improvements**, such as improvements to the quality of existing spawning gravels, creation of new spawning sites, and improvements to the carrying capacity for fry and/or smolts by channel restructuring and provision of cover. In most cases such schemes are unlikely to have a large enough impact on adult runs to be detectable within the normal variation in adult numbers, and appraisal should therefore concentrate on immediate local impacts.

The success of creating or improving spawning areas is obviously best assessed by observation of utilisation by spawning adults, i.e. by location and counting of redds. Where only a limited length of river is involved, the precise location of all redds should be recorded on maps and comparisons made with unimproved areas.

Where restoration work is aimed at improving habitat for juveniles, an assessment of the potential increase in carrying capacity can be made by the application of the HABSCORE technique. Habitat Quality Scores should be estimated at selected 50 m length sites within the river reach before and after the improvement works are carried out, and the theoretical increase in carrying capacity calculated.

The success of both spawning area and juvenile habitat improvement schemes should also be assessed by undertaking population estimates by electric fishing, preferably during the summer months. At this level of scheme, it would not be too demanding on resources to carry out population estimates at a relatively high level of precision, using catch depletion methodology. Comparison with control sites will be required to measure the effectiveness of the improvements. Such controls can be obtained either by carrying out population estimates at sites within the length to be restored before improvement, or by selecting sites in nearby unimproved areas, preferably upstream. Site selection can be carried out as recommended in NRA R&D Note 292, Guidance Notes on the Design and Analysis of River Fishery Surveys, where resources allow and sufficient data is available.

12.3.2 Restoration work covering 1 - 10 km of river.

At this level of scheme it is possible that a detectable impact could be made on adult numbers, particularly if a whole tributary is involved. In addition to examining local impacts, it will be necessary to monitor adult numbers.

Spawning should be monitored by counting redds and mapping their location. Impacts on the abundance of juveniles should again be assessed by electric fishing surveys, with suitable control sites for comparison or "before and after" studies. However, as the length of river involved increases, the resources required to carry out detailed stock assessments using catch depletion estimates at all sites may become prohibitive. If this should be the case, an alternative strategy should be adopted which allows a larger number of sites to be assessed with the same resources. This can be achieved by carrying out single catch estimates at most sites, calibrated against multi-catch depletion estimates at some sites. A stratified sampling schedule, concentrating on specific habitat types, e.g. riffles, is an alternative way of reducing the number of sites,

and hence the resource requirement. Again, site selection should be based on the recommendations given in R&D Note 292, if appropriate.

Such schemes may result in significant numbers of smolts being produced. Hence installation of temporary smolt traps at the downstream end of the restored area should be considered to enable smolt output to be monitored.

The most effective means of monitoring returning adults is by use of automatic counters. Purpose-built counting weirs are expensive (£50k +), and the cost of such a facility would be unlikely to be justifiable at this level of scheme. However, if a counter could be installed in an existing structure, such as a fish pass, the cost may not be prohibitive. Adult traps can also be installed in structures such as fish passes, but their use for stock assessment is man-power intensive, and therefore costly. They do, however, provide a facility for catching brood stock, or fish for tagging programmes.

As it is feasible that a significant change in the number of returning adults could be detected, the use of anglers' log books should be encouraged to determine changes in catch records over time. Due to the inherent variation in rod catch analyses, this method should be used in conjunction with other techniques, where available.

12.3.3 Restoration works covering 10 - 100 km of river and above.

At this level of restoration, significant enhancement of existing runs of adults would be expected to develop over a period of time. Installation of a fish counter or trap at the lower limit of the restored section, taking advantage of any existing structure such as a fish pass, should be given a high priority. Monitoring of smolt production by trapping will again be appropriate. Catch records, both from anglers and commercial fisheries, where these are present, should be collected. The use of angler log books will facilitate the collection of more valid catch per unit effort data.

Monitoring of redd counts and their distribution and the assessment of juvenile stocks will still be necessary. However, the sampling strategy for juvenile stock assessment will need to take account of the resources required to provide an adequate coverage of a relatively long stretch of river. Emphasis should therefore be on single catch samples, calibrated by multi-catch depletion estimates wherever possible. This will allow density estimates to be calculated that may be used in the Agency National Fisheries Classification Scheme. At this level, satisfactory control sites will be more difficult to obtain, and temporal changes in densities obtained from 'before and after' studies will be more appropriate.

In large scale studies involving whole catchments, monitoring of adult salmon runs by use of counters and/or traps is a high priority, as is the collection of catch data from anglers and commercial fisheries. Where significant tributaries are present in the catchment, more than one counter or trap may be required. Large scale redd counting will also give a measure of adult abundance.

Adequate monitoring of juvenile stocks becomes even more resource demanding in large systems. Rapid assessment methods such as timed single catch samples are

appropriate, using a stratified sampling approach concentrating on typical juvenile habitat. Returning to the same sites in successive years enables trends in stocks to be identified and approximately quantified. On this scale, main river smolt trapping is also likely to involve the provision of permanent trapping facilities.

12.4 Reporting

In order that the experience gained during a habitat restoration scheme can be disseminated to other fisheries managers, it is vitally important that the relevant parts of the procedure are documented in a consistent and accessible manner. It is realised that due to the different scales of restoration schemes, the particular requirements for appraising and reporting will differ. However for all schemes four basic categories of information are required and should be comparatively easy to collate:

Pre-scheme assessment

i)   Situation before commencement of restoration scheme.
ii)   Type and cost of restoration scheme(s) implemented.
iii) Projected effect of restoration scheme.

Post- scheme assessment

iv)   Observed effect of restoration scheme.

Reference to further sources of information (publications, internal reports, individual contact names) will also be useful in providing access to further detail on the work performed and the success or otherwise of the project.

If reporting guidelines outlined below are followed it will be possible to create a **structured data base** of key findings from previous schemes. Regional and national contacts should be established within the Agency to co-ordinate such an exercise. Over the long term this will allow potential conflicts created by proposed schemes to be identified and would greatly improve the overall effectiveness of habitat restoration as a fisheries management tool.

Table 12.1 summarises the types of data that are required. Obviously the size of scheme and resources available will dictate the level of investigation and hence the quality and quantity of data available for reporting. However, a minimum requirement should be the completion of proforma reporting sheets, an example of which is included with this report in Table 12.2. They are designed to provide a summary of the main aspects of a restoration scheme in a standardised reporting format. They are not intended to act as a substitute for scientific or operational project reports. Following completion of the forms, the data should be recorded onto the national or regional database, to allow for the dissemination of results, irrespective of the success or otherwise of the scheme.

Table 12.1   Reporting requirements

A . PRE-SCHEME ASSESSMENT	
Situation before Commencement of Restoration Scheme	
i) Fish Population Data	
	Juvenile Survey Data
	HABSCORE (HQS)
	NFCS (Level 1 relative grade)
	Rod catch
	Net catch
	Trap Data (adults and smolts)
	Fish Counter data
	Redd counts and location
ii) Water Quality & Hydrology	
	River Type
	General Quality Assessment
	Invertebrate data
	Flow data
	Known water quality problems
iii) Habitat Assessment	
	Quantity of habitat types
	Quality of habitat
	Limiting factor identification
	Location of obstructions
Type and Cost of Restoration Scheme(s)	**implemented**
i) Scheme Design	
	Description of the type of habitat restoration techniques employed
	Location and extent
	Estimated costs
Projected Effect of Restoration Scheme	
i) Projected Stock Enhancement	
	Increased juvenile density
	HABSCORE (HQS)
	NFCS (Level 1 relative grade)
	Increased returning adults
	Egg deposition estimate/target

B. POST-SCHEME ASSESSMENT	
Observed Effect of Restoration Scheme	
i) Fish Population Data	
	Juvenile Survey data
	HABSCORE (HQS)
	NFCS (Level 1 relative grade)
	Rod catch
	Net catch
	Trap data (adults and smolts)
	Fish counter data
	Redd counts and location
	Egg deposition rates
	Have objectives been achieved?
ii) Scheme Performance	
	Actual cost
	Structure robustness & Longevity
	Identify design problems and failures
iii) Other Information	
	Location of data, reports etc.

Table 12.2   Restoration scheme appraisal form

Contact Name:	Address:
	Phone No:
River:	**EA Region:**
Pre Scheme Assessments:	
Scheme Description: **Scheme Cost:** **Undertaken By:**	
Post Scheme Appraisal:	

13. Conclusions & Recommendations

13.1 Conclusions

The literature review has revealed that with one or two exceptions, habitat restoration and creation for Atlantic salmon is still very much in its infancy in the UK. Despite the apparent widespread use of certain practices such as gravel cleaning, project management is generally poor and very little pre and post scheme monitoring is undertaken. As such, the habitat work undertaken in the UK to date has invariably been inadequately evaluated. The consequence is that much has still to be learnt about the various techniques and their applicability to UK rivers and Atlantic salmon in particular.

From a project management perspective, at the conceptual and planning level salmon habitat restoration fundamentally requires a more co-ordinated and interdisciplinary approach. It needs to be recognised and fully understood by fisheries habitat restoration practitioners that the catchment in which they are operating is a continuum. Hence, broader catchment issues need to be considered when initiating individual schemes. In other words, local problems which are to be resolved by habitat restoration need first to be viewed in the catchment-wide context. The LEAPs process will facilitate this integration.

Taking this argument further, often it will be found that restoration is treating the symptom of a problem which operates on a catchment scale. Hence in the long term addressing the cause of the problem, e.g. riparian issues, may prove markedly more successful than any number of individual small scale, in-stream schemes. This point is all the more pertinent when it is remembered that instream works (e.g. gravel cleaning) can in effect work in opposition to catchment scale processes (e.g. erosion and siltation), and hence may be regarded as not sustainable in the long term.

The concept of habitat bottlenecks also needs to be fully appreciated both with regard to the physical manifestation of poor habitat and, perhaps more importantly, how that impacts on salmon populations. The key to successful habitat restoration is to work with natural stream processes to alleviate limiting factors, reducing or eliminating bottle neck effects. Habitat restoration is in effect attempting to harness these natural physical and biological processes to both create and maintain favourable habitat. Harnessing processes in nature is a tricky business, fraught with reaction and counter action when control of a process is the objective. Hence, it is better to work with natural processes, avoiding direct confrontation wherever possible. To quote Dr Martin O'Grady, whose experience from Ireland has contributed significantly to this manual, when referring to instream structures and their potential impacts on stream hydraulics;

"Don't knock it, nudge it!"

In this context incorporating the experience of other professionals such as hydrologists, hydrogeologists, engineers and terrestrial biologists becomes all the more important.

An understanding of the impact of physical habitat processes on the catchment system at all levels is an imperative to fully comprehend and predict the outcome of a given habitat restoration scheme on salmon populations. This holds both locally and within the wider catchment context. Sound advice would be to think first about the desired change to habitat required and then determine the technique best suited to achieving the objectives under the stream conditions that exist.

This manual has attempted to introduce practitioners to the concepts of quantifying habitat areas, considering juxtaposition of life stages and identifying areas that are not currently utilised as habitat. These important areas do require development and are currently being addressed to some extent by the habitat inventory project. However, there is a need for strategic experimental research into these areas and the difficult subject of limiting factors.

13.2 Recommendations & future work

Following the review of literature, consultation and site visits, which together constitute the experience from which the manual was constructed, the following key recommendations are made.

13.2.1 LEAPs process

Salmon habitat restoration has been identified as a multi-functional initiative and hence should be implemented through the LEAPs process.

13.2.2 Project management model

Wherever salmon habitat restoration schemes are undertaken efforts should be made to implement the project management model. A minimum requirement is for some form of project appraisal.

13.2.3 Scheme appraisal

Pre and post scheme appraisal should be encouraged by the Agency wherever possible. With internal schemes use of the reporting proforma proposed in Section 12.4 should be mandatory. Other organisations outside the Agency should be encouraged to complete the proforma and assess the success of their scheme if only in the most fundamental manner (i.e. did they create the physical habitat they wanted?).

The Agency can recognise the role and importance of habitat restoration by nominating 'experts' within each region who can act as conduits for opinion and advice on best practice new techniques. A specific individual, possibly within the newly created National Salmonid Fisheries Centre could act as a national co-ordinator

to whom completed proforma sheets are returned. This will facilitate the operation of a national data base of restoration schemes and their effectiveness, allowing dissemination of best practice information to nominated 'experts' in the regions.

13.2.4 Research

A co-ordinated national programme of field research into habitat restoration techniques in UK rivers is required. To a degree, this will be facilitated by the centralised and co-ordinated approach to scheme appraisal identified above. However, specific areas for experimentation are suggested. They have been divided into the following broad areas, ranked according to their perceived priority.

- **Gravel cleaning** (evaluating effectiveness of different techniques such as high pressure water pumps, ploughing, and mechanical cleaning using a modified hydraulic machine bucket).

- **Spawning bed creation** (low cost weirs constructed from gabion mattresses, block stone and logs used to hold gravel additions in place should be evaluated on a variety of river systems with gradients varying from 0.3 to 4%.)

- **Rubble mats** (the use of rough quarried stone 20 to 40 cm in diameter to create juvenile salmon habitat in deep glides [up to 2.0 m] should be evaluated).

- **Tunnel vegetation** (the impact of removing tunnel vegetation on juvenile salmon populations in a variety of different river systems should be evaluated).

- **Adult holding pools and lies** (investigations into various methods of creating holding pools and lies are required, including excavating pools with hydraulic machinery, and creating scour pools by careful siting of flow constrictions and weirs).

- **Spawning channels** (evaluation of spawning channels for stock enhancement as an alternative to stocking hatchery reared fish utilising both purpose built structures and natural features such as weir bypass channels).

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