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TECHNICAL REPORT

Revetment Techniques Used on the River Skerne Restoration Project

The River Restoration Centre

R&D Technical Report W83

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Statement of use
This report describes the work carried out on the River Skerne demonstration site in Darlington, County Durham and provides guidelines about the design, construction and effectiveness of several 'soft' revetment techniques.

Research contractor
This document was produced under Environment Agency R&D Project W5-i600 by:

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The Environment Agency were key participants in the River Skerne Restoration Project and additionally, supported the demonstration of revetment techniques that are the subject of this report.

The revetment works were installed by the in-house workforce of the Agency's North East Region.

The following Agency personnel have been consulted in the course of preparing this report:
Dr Liz Chalk - Skerne Project Manager, Dales Area, North East Region - Sept 94 to June 96
Olivia Clymer - Skerne Project Manager, Dales Area, North East Region - July 96 onwards
Stephen York - Works Agent, Dales Area, North East Region,
David Clarke - Flood Defence Engineer, Dales Area, North East Region.

The project was undertaken under the direction and guidance of a Project Board and a Working Group within which participating organisations were represented. Principal representatives were:
Dr Chris Spray - Northumbrian Water, Darlington and RRP Skerne Project Board Chairman,
Bob Pailor - Environment Agency, NE Region,
Ray Sunman (retired) - Darlington Borough Council,
Jim Gordon - Darlington Borough Council,
Sue Cornwell - Countryside Commission, Newcastle,
Chris Shaw (retired) - English Nature, Newcastle.

The Revetment demonstration project forms part of a wider Agency R&D Project managed by:
Professor Colin Thorne - Dept. of Geography, Nottingham University.

RRP are indebted to the above for their support throughout the successful completion of the project and during the preparation of this report. Support from the Heritage Lottery Fund is also gratefully acknowledged.

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EXECUTIVE SUMMARY

This report records the details of revetment works undertaken as part of the Environment Agency's Research and Development Programme on revetment techniques. It describes 'soft' revetments installed on the River Skerne in Darlington, County Durham as part of a comprehensive river restoration project between August 1995 and May 1996. The Skerne is one of three river restoration demonstration sites part financed by the EU financial instrument LIFE.

Bioengineering is increasingly advocated by the Agency and although widely used, examples are often scattered. At this easily accessible location practitioners can, within a 600m reach, view several revetment techniques under similar hydraulic conditions. Revetments were needed due to the possibility of erosion jeopardising a gas pipeline, a main sewer and industrial spoil alongside the river.

The aim of this report is to provide information about the design, construction and initial effectiveness of the revetments.

The report provides information on the following techniques developed for the River Skerne site:

- Rock layer below water (common to each technique);
- Willow mattress;
- Willow spiling;
- Log toe and geotextile (incorporating willow slips);
- Transition revetment (using preplanted coir rolls and pallets).

Design drawings and installation guidance for each of the above is provided. All can be adapted for use in different situations. A variety of willow species have been used namely *Salix caprea* (goat willow), *S. cinerea* (grey willow), *S. viminalis* (osier), *S. alba* (white willow), *S. fragilis* (crack willow) as well as other materials including marginal aquatic plants.

Indicative costs for construction and maintenance have been summarised and these compare favourably with prices estimated for revetment works by the National Rivers Authority (Hey, *et al,* 1991).

After the first year, and being subject to several out of bank events, each revetment is fully intact. The timing of installation (autumn and spring) appears to have little effect on the success of the plant material used. All species except goat willow were flourishing after one growing season. The most growth was gained by the crack and white willow used in the mattress technique.

These techniques are largely regenerative relying on the growth of bankside trees and marginal plants to sustain them but will require maintenance. Thinning and pollarding of trees, consistent with river bank maintenance in general, is all that should be needed.

The principle benefits of the techniques demonstrated are the inherent flexibility accommodating any bank movement, the regenerative nature of the designs and the wildlife habitat and visual amenity provided. If materials are indigenous and can be harvested locally, namely riverside trees and marginal plants, then costs will be significantly less than those indicated. An essential aim of the design is to facilitate the use of indigenous materials although these were not available on the Darlington site.

The striking contribution made by the revetments to visual amenity and wildlife habitats is widely acknowledged by local people. This is of particular note as it can only improve with time - a living infrastructure has been created within which many desirable ecological processes are active.

KEY WORDS

Revetment; Spiling; Willow; Soft Engineering; River Restoration Project; River Skerne; Bank Erosion; Bank Protection.

1. BACKGROUND AND SCOPE OF THE RIVER SKERNE RESTORATION PROJECT

1.1 Background and Project Participants

The demonstration site on the River Skerne at Darlington was promoted and led by the River Restoration Project (RRP) in partnership with the Environment Agency (formerly National Rivers Authority), Northumbrian Water, Darlington Borough Council, English Nature, Countryside Commission and the Rivers Agency (formerly Department of Agriculture for Northern Ireland). Funding for the project came from the partners, the EU financial instrument LIFE and supported by the Heritage Lottery Fund.

RRP was established in 1993 by a group of individuals with a professional interest and expertise in the river environment. Its initial aim was to set up demonstration projects that apply state of the art techniques to river restoration.

The site is one of three linked under the EU-LIFE project; River Restoration: Benefits for Integrated Catchment Management -1993/DK/A25/INT/2504.

1.2 Location

The three LIFE demonstration sites are shown in Figure 1.1. Located in the United Kingdom are the urban River Skerne in Darlington and the rural River Cole on the Wiltshire - Oxfordshire border. The Danish site, the River Brede, flows through farmland in the County of South Jutland.

A tributary of the River Tees, the River Skerne is approximately 50 km long with a catchment of 250 km^2. It flows through fairly flat rural land to the north of Darlington, with an annual precipitation of 600 - 650 mm. Cohesive, fine grained, alluvium in the floodplain forms moderately stable river banks even where near vertical.

The 2.1 km restoration reach is between Haughton Road Bridge NZ30701575 to Skerne Bridge NZ29151555. The river flows through an open amenity grassland over the upper half of the reach and in a 'ravine' of industrial landfill and development downstream. The reach where the revetments are located is shown in Figure 1.2.

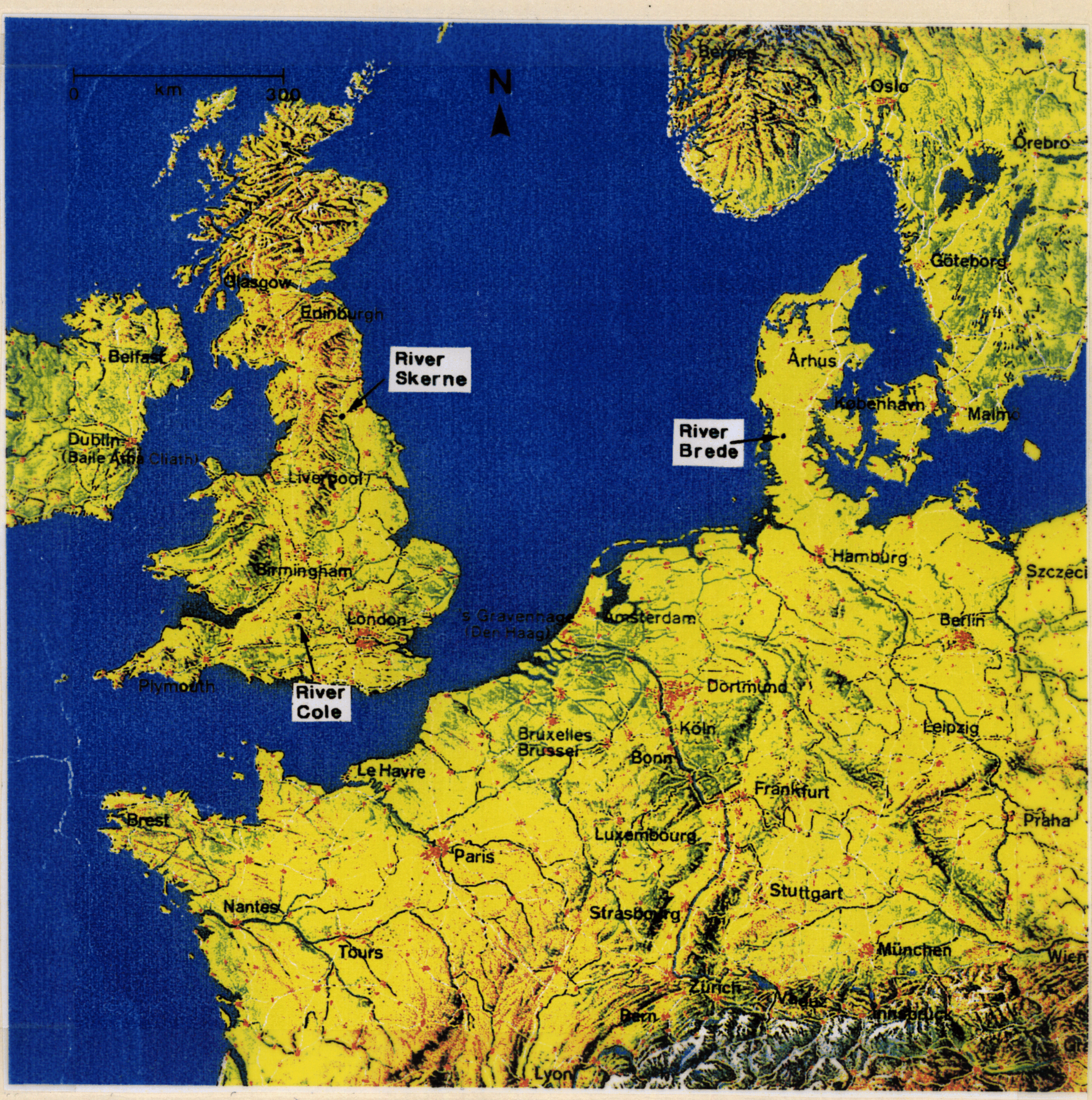
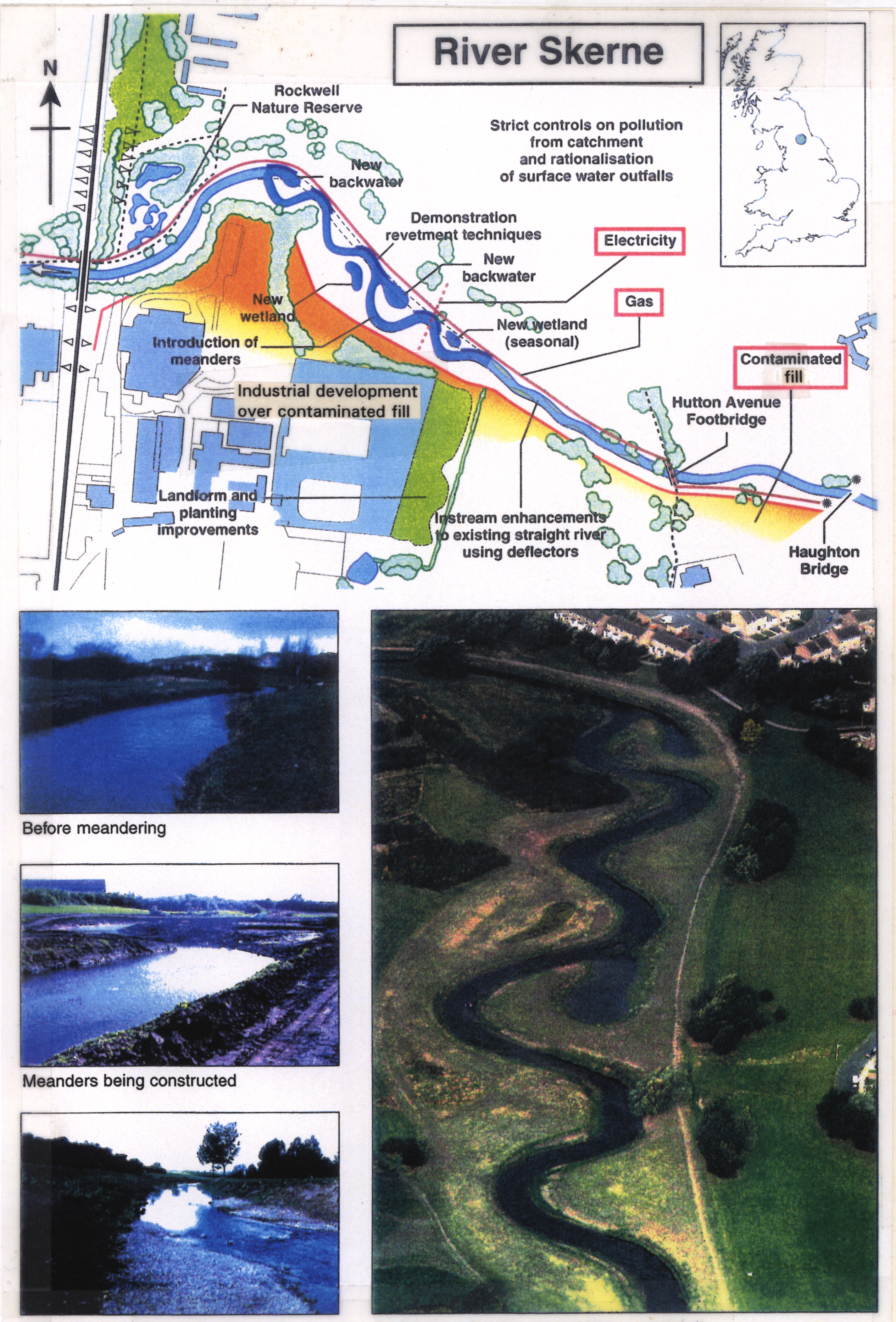


Figure 1.1 Locations of the 3 EU-LIFE demonstration sites



Before meandering

Meanders being constructed

Riffle with deflectors in background

Aerial view showing meandering completed

Figure 1.2 Site plan showing scope of works

1.3 Scope of river restoration works

The project involved enhancing and restoring the River Skerne; the main engineering work included creation of new meanders, wetlands, backwaters and the redesign and rationalisation of surface water drains. Much of this is concentrated in the upstream reach where sufficient floodplain was free from underground constraints to allow the meanders to be cut. During this work a large amount of spoil (more than 25 000 m^3) was removed from the floodplain for use in landscaping areas on the valley sides. A technical summary is included in Figure 1.3.

The revetments are situated on the north bank where they protect utilities and infilling of the original straight channel. A high pressure gas main and main sewer pipe run parallel to the river on this side. A high voltage electricity cable runs perpendicular to these, crossing under the river in the meander reach. Other constraints on the site include industrial landfill, contaminated land and a local nature reserve.

The proximity of housing is also an important factor in this reach. Some houses are within 100 metres and have flooded in the past.

THE RIVER RESTORATION PROJECT

Case Study RIVER SKERNE

Contact for Further Information: RRP - Martin Janes, c/o Cranfield University, Silsoe, Beds, MK45 4DT. 01525 863341. Environment Agency NE Region - Olivia Clymer/Liz Chalk (Project Managers), 01904 692296, Darlington Borough Council (landowner), 01325 380651.

Location: Haughton-le-Skerne, Darlington, Co. Durham. **OS 1:50,000 Map No:** 93 **Grid Refs:** NZ 307157-297160

River type: Low energy, lowland urban river, clay catchment, daily variable flows due to abstraction and industrial discharges.

Length affected: c.1.3 km

Area: 7.6 ha

Years: 1995/6

Cost: £220K construction works, plus extensive monitoring (at additional cost)

Techniques/features:

- restoring meandering plan form;
- in-channel deflectors to create 'sinuosity';
- bank and channel re-profiling;
- channel narrowing;
- spoil disposal and landscaping;
- outfall rationalisation;
- community involvement;
- increased floodplain storage;
- extensive marginal planting;
- backwater creation.
- wetland scrapes;
- demonstration of variations in soft revetment.

Objectives: Restoration/rehabilitation/enhancement of a degraded reach of urban, lowland river in terms of physical plan form, cross-section and features, flood storage, habitat and visual appearance. Demonstration of current and innovative restoration/rehabilitation/enhancement techniques and best management practice applicable elsewhere.

Background: The River Skerne at Haughton-le-Skerne has been progressively realigned and straightened for flood control, drainage and housing development over the past 200 years. Much of the historic floodplain has been raised above flooding levels by the tipping of contaminated/waste materials. The area of the project still retained some floodplain as amenity parkland, however, the river was unsightly with concrete outfalls, steep inaccessible banks smothered in alien Himalayan Balsam and Oilseed Rape.

Scheme design: The River Skerne project was led by the RRP in partnership with the EU LIFE programme, landowner (Darlington B. C.), NRA/Environment Agency, English Nature, Countryside Commission and Northumbrian Water plc. The project design drew on a team of multidisciplinary, independent, experts and partner organisation staff. For such a heavily visited site a key design principle was to seek involvement and promote 'scheme ownership' of the river with local inhabitants (c5000 live within 1 km of the scheme). The finished design was based upon geomorphological and hydraulic principles drawn from background monitoring and an historical study of the site, together with information on present day hydrology and the constraints imposed by development and services (especially gas, electricity and sewerage). These constraints, although problematic, were representative of many urban situations, and techniques for rehabilitation applicable elsewhere.

For greater than half of the reach these constraints allowed only minimal bank works, mainly consisting of topsoil stripping (to remove the build up of nutrient enriched dredgings and the seedbank of aliens) and reprofiling to a shallower slope (to form wet and dry berms for planting or channel narrowing). Downstream of the footbridge flow sinuosity was introduced into the channel by the use of two types of deflectors, this had the effect of creating a more self sustaining flow pattern that is drowned out in times of flood.

A section of the floodplain was identified with sufficient room to enable channel remeandering. Four large meanders were constructed together with wetland scrapes and backwaters. The whole floodplain area, incorporating the meanders, was lowered (25,000 m^3 of spoil moved to land-form sites on the valley sides) to increase conveyance and storage capacity as well as wetland habitat.

To protect a high pressure gas main on the north bank, a series of 'soft' revetments were constructed to illustrate the benefits of using natural/live materials and their applicability in high risk situations. More than 15, visually intrusive, surface water concrete headwalls were replaced by underwater outfalls discharging from new inspection /collection chambers (by Northumbrian Water). Involvement of the community was aided by the employment of a Community Liaison Officer, providing advice and leaflets, as well as hosting school/college visits and liaising with local interest groups. The project scope and timescale has been extended (to July '97) supported by the Heritage Lottery Fund.

Figure 1.3 Technical summary

2. INTRODUCTION TO THE REVETMENT PROJECT

2.1 Background to the revetment project

The use of soft vegetative engineering revetment techniques for the protection of river banks is recommended by the Environment Agency in all but the most extreme situations that demand the use of materials such as concrete or steel. Experience in the use of such techniques is widespread but not well documented. On-site inspection of these techniques is rendered difficult by the need to travel to diverse locations that may not be easily accessible. The River Skerne Project afforded the opportunity to incorporate a range of such techniques at an established demonstration site thereby providing practitioners a viable means of experiencing them, in conjunction with numerous other aspects of river restoration practice.

Darlington is easily accessible being located on the A1M, the main rail link between London and Edinburgh and very close to Teesside international airport. A location plan is shown in Appendix 1.

The Agency accordingly provided funding to enable several different revetment techniques to be incorporated in preference to utilising a single technique. This funding also supported the documentation of the revetment works in the form of this report.

2.2 Purpose of the report

The aim of this report is to record the design, construction and short term effectiveness of the revetment techniques utilised.

The objectives of this report are:

- To explain the designs and the rationale behind the use of chosen materials.
- To indicate construction costs and maintenance implications.
- To describe initial performance and indicate future performance expectations of the different revetments.

3. REVETMENTS

3.1 The need for revetments

The potential for erosion to occur on the outside of meanders is self evident. In a rural situation small scale erosion can be a desirable aspect of river morphology. In the urban environment of the Skerne the consequences of erosion would be serious due to the presence of the following features in close proximity:

- a gas main running alongside the north bank;
- a main sewer parallel to the north bank;
- industrial waste tipped along the south bank;
- an underground high voltage electricity cable crossing the river;
- a proposal to establish a formal path along the south bank.

Site investigation was undertaken to determine the nature of the soils through which the new meanders would be excavated. The same soils would be used to backfill the existing river course. Evaluation of the soil characteristics were undertaken by a geomorphologist who advised that, in their undisturbed state, soils would be sufficiently strong to resist erosion in the relatively low energy River Skerne. However, if the soils were disturbed, ie used as backfill, then the stability was much less certain.

In the light of this advice the following decisions were made:

- bends excavated in undisturbed soils on the south side would not be revetted unless unexpected weaknesses were encountered during works (see note below);

- bends on the north side would be revetted due to the necessity to construct these within the backfilled river channel and the proximity of the gas main;

- revetment design to take account of the requirement to excavate 'pools' at the outside of bends in accordance with geomorphological principles.

The location of the revetments are shown on Figure 3.1 compromising bends at the entry and exit of the re-meandered reach and intermediate bends numbered N1, N2 and N3.

Note: During excavation of the south side meanders, one bend (S3 - see plan) proved to be unstable due to water seepage through a localised gravel layer. The river bank is heavily surcharged by industrial tipping at this location. Stability was restored by installing a rock-filled toe to the river bank below normal water level - details are available from RRP.

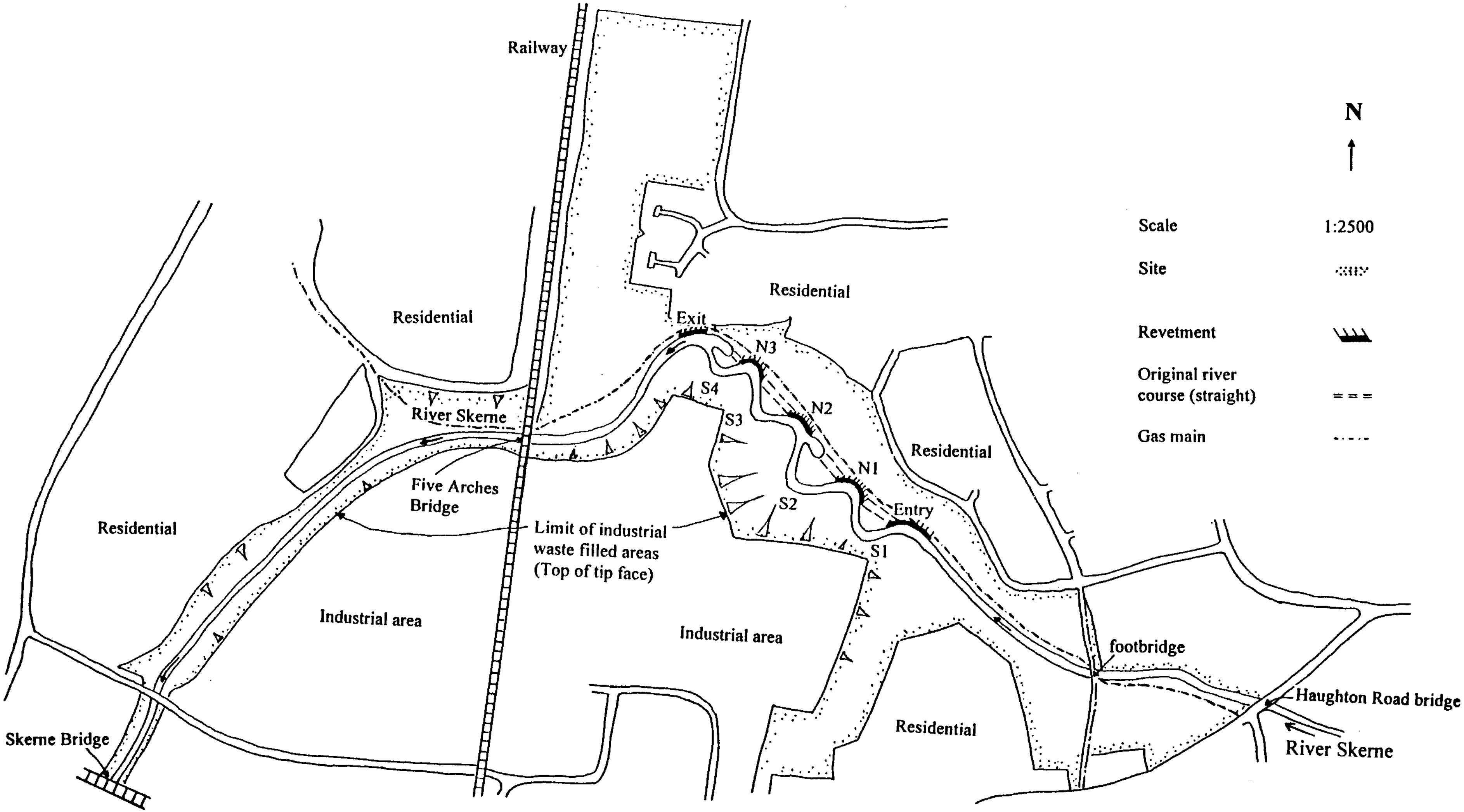


Figure 3.1 Site plan showing position of revetments

3.2 Design rationale

Figure 3.2 shows a simplified cross section of the type of bend to be revetted. The risk of scour varies in the vertical plane as does the potential to sustain desirable vegetative habitats as an integral part of the design. Similarly, the practical aspects of revetment construction and the practicality of compacting backfill are markedly different above and below normal water level.

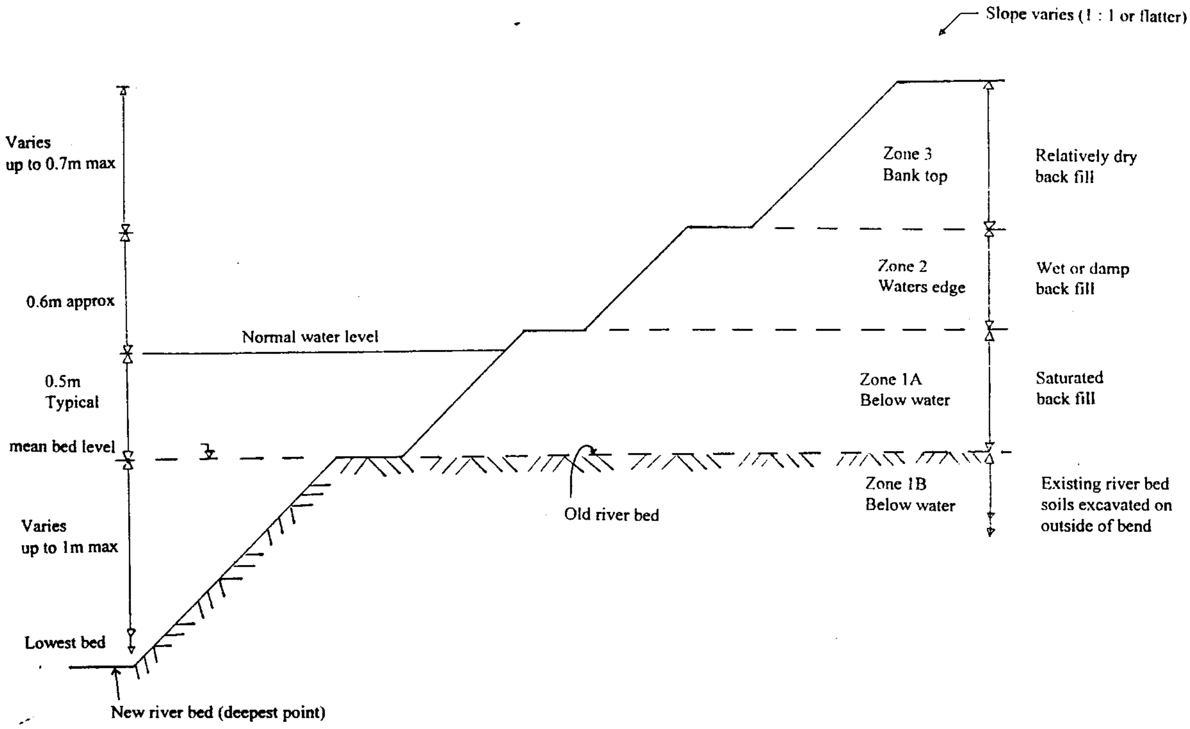


Figure 3.2 River Skerne, Darlington
Schematic river bank section at bends on North bank (Existing channel filled)

Three vertical zones are shown on the cross section leading to the following design considerations.

Zone 1 - Below normal water level
This zone is generally at greatest risk from scour and is the least accessible for both initial construction and any subsequent maintenance. Tree roots are the only vegetative medium that can penetrate this area to any significant degree. The following design criteria were applied.

- Construction: this should ideally be feasible without the need to de-water the reach to be revetted to save costs.

- Reliability: being least accessible for inspection and repair and the foundation for everything above, a low risk of failure was essential - the presence of a gas main also demanded low risk.

- Flexibility: the slopes of the finished river banks were to vary considerably over the length of revetment - this demanded a flexible form of construction that would also accommodate any subsequent movement of the river bank arising from the natural settlement of the underlying backfill or from any minor adjustments caused by localised erosion.

- Vegetation: the design should be compatible with vegetative cover utilised at the water's edge zone. Notably, it should be capable of incorporating tree roots and marginal plants.

The use of a densely graded rock layer was considered to be the only practical material that met all the above criteria for the River Skerne location.

Zone 2 - Water's edge
This zone varies in height because of seasonal variation in normal water level caused by increased winter base flows or by the density of aquatic plant growth in summer obstructing flows. Extreme low flows can cause lower than 'normal' water levels. At Darlington, a daily cycle of discharge from a major industrial user causes significant low flow water level fluctuations. The river levels are also highly responsive to storm run-off from local urban areas. However, a weir located downstream of the revetments ensures that a 'lowest' water level can be sustained; all the water level variations described are therefore above this local 'datum'.

Conditions for plant growth are generally excellent due to the proximity of water; these include saturated submerged marginal ledges, soils close to water level that are wetted by capillary properties and damp soils overlying these. Each condition represents a potentially different habitat niche providing opportunities for incorporating a range of living material into revetment designs.

Erosion forces in this zone are fairly high when submerged under flood conditions. Wind or boat generated waves can also lead to erosion although neither occur to any significant degree on the Skerne. People can generally be relied upon to force access down to the water's edge and alongside it where possible, so damaging plants. This proved to be a very real occurrence at Darlington. In the rural environment, livestock will similarly poach the water's edge.

The following criteria were adopted:

- Visual: in the urban parkland location a visually attractive riverside was required to enhance the landscape as quickly as reasonably practical.

- Flora and fauna: the use of plants, indigenous to the area, in as wide a variety as practicable was favoured. Fauna was expected to utilise these areas early on as this vegetation cover, introduced to the site as part of the revetments, might be the only cover available. Elsewhere, natural colonisation may take some time to evolve due to the extensive channel works undertaken.

- Functional: introduced plants take time to establish and become self-sustaining, short term erosion protection should be incorporated using compatible materials. The design of water's edge revetments needed to integrate with that submerged below it, to avoid any separation of the two. Flexibility to adjust to settlement of the underlying backfill was equally important.

- Maintenance: the incorporation of willow species was envisaged from the outset knowing that these would require future maintenance. This was acceptable as maintenance of riverside trees was considered to be an intrinsic part of 'best practice' for riparian environment. As a precautionary measure, the hydraulic design of the newly meandered river channel assumed that no maintenance would, in practice, be undertaken and that each revetment would present a dense mass of willow within the flood corridor.

- Demonstration of techniques: the water's edge zone was considered to provide the greatest scope for demonstrating various revetment designs under similar conditions. This was also consistent with the key project objective of demonstrating different techniques.

Zone 3 - Bank top

Marked by relatively dry soils, the bank top is favoured by arid or deep rooted plants typically derived from the seed bank of rape, nettles and other undesirables deposited by winter floods. Trees located here can thrive once their roots reach down to the wetter soils beneath; it helps if the trees are planted part way down the bank closer to the water's edge. As trees such as ash (*Fraxinus excelsior*) mature they help to shade out undesirable ruderal species. The tree roots should, in time, reach right down to water level and serve to further reinforce the soils against erosion.

Erosive forces are dominated by eddy currents generated as water leaves the river to pass onto the flood plain. Conversely, water draining from the floodplain, towards the river, can erode gullies in this zone.

The following criteria were adopted:

- Visual: specimen trees were considered to have landscape value, particularly if they could eventually complement or even replace faster growing willow utilised in the water's edge zone.

- Ruderals: these were known to dominate the bank top zone of the slope and were likely to continue to do so. Grass seeding was favoured as an immediate post-construction measure in anticipation of ruderal colonisation which could only be controlled by mowing for many years.

- Maintenance: where practical, bank top slopes should facilitate mowing as part of the parkland maintenance regime.

Note: Although the south bank meanders were not revetted, standard trees were planted on ledges cut into the bank about one metre above water level - Details from RRP.

3.3 Extent of protection - planform

The linear extent to which meanders require revetment was largely determined from practical considerations but with due regard to the relevant geomorphological principles. Sinuous meanders of the type introduced into the Skerne are known to be most susceptible to erosion downstream of the geometric apex of the bend. The risk of erosion is less upstream whereas at the downstream end the risk is intermediate, erosion often extending surprisingly far beyond the apex. It was decided that full scale revetment would not be necessary throughout the entire length of each bend and that a partially revetted transitional reach at each end would suffice.

The transitional revetment needed to provide a smooth progression from full scale revetment to the profile of the unrevetted river bank.

The overriding practical considerations were the need to ensure the security of the gas main running parallel to the old, straight, river course and also to support /protect the backfilling of the old channel on the downstream side of each bend where erosion risks are highest.

This entailed a length of full scale revetment extending across the old river bank as well as along the downstream backfill. The transitions at each end served to avoid a sudden change from unrevetted to fully revetted.

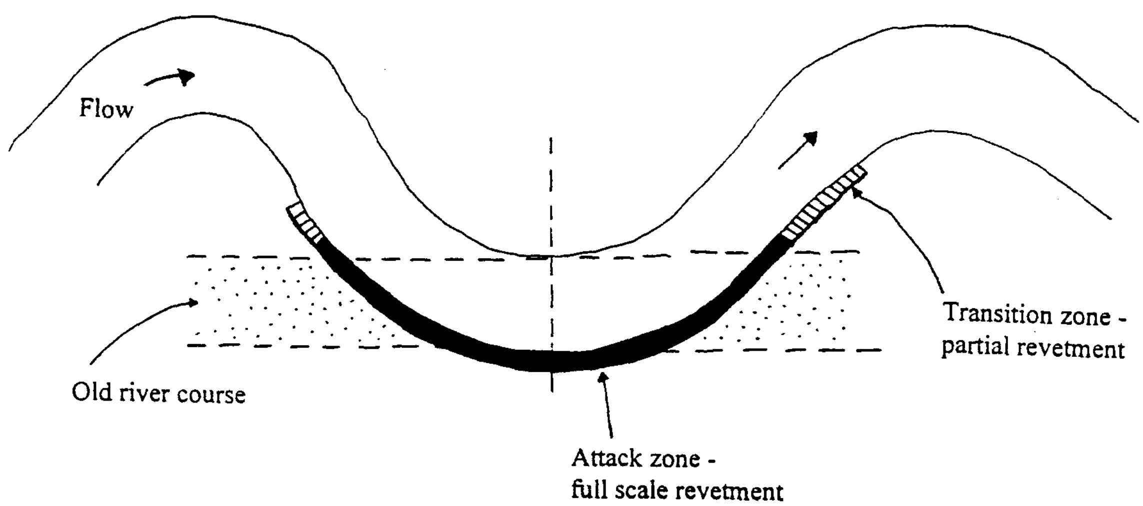


Figure 3.3 Planform of revetment zones

3.4 Techniques utilised

Building on the rationale set out above, four different designs were developed to construction. These designs are shown in the following figures:

Figure 3.4	Willow mattress;
Figure 3.5	Willow spiling;
Figure 3.6	Log and geotextile;
Figure 3.7	Transitional (preplanted fibre rolls over rock rolls).

Each figure includes a summary of the installation sequence. Key aspects of the design are set out below. A list of materials used and suppliers can be found in Appendix 2.

3.4.1 Rock layer below water (common to each technique)

The rationale for the use of a rock layer is set out above (Section 3.2). Although not bioengineering, the scope of alternatives in the underwater zone is limited. The rock provides niches in which invertebrates will shelter and it will readily accommodate the rooting of trees and marginal plants growing above. Hidden below water its visual impact is negligible.

The specification of rock size and grading was crucial. (See Figure 3.4 for grading). The predominant rock size was 300 mm, enough to avoid being moved by river currents but able to be picked up and placed in an excavator bucket. Of equal importance was the grading of the smaller sizes to ensure a densely formed finished layer. This would reduce the risk of soils being washed out from behind the layer causing it to settle unduly. Geotextile (open weave nylon) layers are sometimes used to control this risk but they are difficult to place underwater.

The thickness of the rock layer (500 mm) reflected the practicality of working with the material.

The practical advantage of using rock includes its flexibility to accommodate varying bank slopes, its inherent durability and widespread availability. Repairs are rarely necessary but if they are it is usually a case of reinstating or adding to the original materials.

The most common causes of failure are considered to be using rock that is either too large or does not have intermediate sizes incorporated (seek geomorphological advice). Utilising smaller rock held in steel wire can be appropriate but it does reduce flexibility and even galvanised wire has a shorter life span than rock. Another cause of failure can be scour underneath the rock - it is important to anticipate the depth of scour around the outside of bends and design accordingly.

3.4.2 Willow mattress

This willow mattressing is a development of that which is fully described in The New Rivers and Wildlife Handbook, RSPB *et al*, (1994) - Case study 3.7(c) - River Clwyd, North Wales. The essential difference is that, at the River Skerne site, stone has been used to revet the underwater zone whereas on the Clwyd, mattressing alone was successfully used in both underwater and water's edge zone. Stone was necessary because of the extra security essential to the adjacent gas main and fill used in the old channel.

The technique is extremely flexible and it largely utilises materials (willow branches) that are often available on the river bank as a by-product of routine maintenance. Virtually any willow species is suitable; ideally they will be indigenous to the reach. In practice, willow was supplemented by 30% sycamore as willow was not readily available. All the sycamore died as expected but served to give short term erosion protection.

The technique's success arises from the rapid growth of the willow that covers the river bank breaking up the water currents as well as encouraging the deposition of silt. Root development binds the underlying soil and will, in time, penetrate the underwater rock layer. Experience at the Clwyd site shows that the wire sheep netting used to hold the willow branches in place is not detrimental to their growth - after some twenty years the wire is completely enmeshed in the roots and trunks of maturing willow.

Plant pallets (proprietary coir mats preplanted with marginal aquatics) placed along the water's edge, though doing little to strengthen this technique, add considerably to its appearance and ecological diversity.

3.4.3 Willow spiling

This technique is described in the New Rivers and Wildlife Handbook - pages 288/9. It is probably the best known of the revetment techniques using willow. The design developed for the River Skerne site comprises a vertical wall of spiling that is *set just above normal water level*; but within the damp water's edge zone. The spiling is separated from the underwater stone revetment by a run of wooden toe boarding.

The functionality of this design derives from the strong growth of willow roots that develop if planted *close to* water, rather than *in* water. The development of dense willow roots is expected to supersede the toe boarding as it begins to decay. Roots will also extend into the underlying stone.

Plant pallets placed along the front of the toe boarding effectively screen this from view as well as providing additional habitat diversity.

The use of geotextile fabric behind the spiling and toe boarding is a precautionary measure to reduce the risk of fine soils (backfill) washing out during flood flows. Spiling is intrinsically less flexible, once installed, than other techniques, eg mattressing, and cannot readily 'settle' into any erosion pockets that develop before it has matured. The technique relies on the local availability of long, pliable willow lengths (withies), such as osier (*Salix viminalis*), whereas mattressing can utilise a wider range of willow types. Spiling can, however, incorporate different live willow species driven as vertical stakes - see Figure 3.5.

It is important to note that the introduction of osier to reaches where they are not indigenous is not necessarily desirable.

3.4.4 Log toe and geotextile

This technique is designed to incorporate whole tree trunks, or large boughs, that may be available on the river bank or nearby. The log(s) may be installed live or dead; the use of live willow will lead to regeneration of water's edge trees if desired.

At the Skerne site, toe logs were placed upon the underwater stone revetment and secured with twist wires fastened to anchor stakes (set well behind the logs) prior to backfilling. These wires will ensure that the logs will not float away from the bank, but can still move and resettle, in the event that any localised scour undermines them before the revetment matures.

This risk is negligible on the Skerne but is very real in other field situations where logs may be placed directly on the river bed where it is shallow and generally hard enough to naturally resist downward erosion.

The river bank above the log is protected with a proprietary geotextile to reinforce the soils used as backfill. Although simple grass seeding can be sufficient to complete the geotextile revetment, the Skerne design incorporated low growing willow plants and cuttings. Goat and grey willow (*Salix caprea* and *S.cinerea*) were selected as these do not so readily propagate from the driven stakes, spiling or mattressing techniques used elsewhere on the site. Standard trees were incorporated above the goat/grey willow. Plant pallets are used to face the logs at water's edge.

The effectiveness of this design derives from its flexibility and succession of species introduced - the willow and the marginal plants should subsume the tree logs as they decay and the standard trees should eventually reinforce the whole as they mature.

Alternative methods of reinforcing backfill placed above the toe logs include the building in of brushwood placed in layers perpendicular to the logs - almost the whole of a fallen tree can be used in this revetment technique.

3.4.5 Transition revetment (plant rolls over rock rolls)

This technique was developed to suit the upstream and downstream ends of the preceding techniques, (see Figure 3.3). The risk of erosion is much less and the design reflects this. The technique may be applicable to other locations where risks are low (relatively straight river reaches where the main objective is to hold the river bank toe in place). On the Skerne it was used on river banks that were mainly excavated into undisturbed soils, in contrast to the preceding techniques that all incorporate backfill.

Proprietary fibre rolls (coir 'sausage' in an open mesh sleeve) pre-planted with marginal aquatic species are the primary revetment material. Each fibre roll is underpinned by a proprietary stone 'sausage' comprising graded rock supplied in an open mesh nylon sleeve (known as rock roll). Proprietary plant pallets were placed above the fibre roll to complete the revetment.

The use of proprietary materials throughout this design was intentional, widening the range of techniques demonstrated at the Skerne location. Such materials are increasingly available.

Rock rolls are primarily secured by the use of twist wires and stakes, set well back to ensure that they are not displaced if under-scoured, but can nevertheless settle vertically in this eventuality.

Each fibre roll is wedged against a rock roll using vertical stakes. These stakes used are not treated with preservative and will be short-lived relative to the proprietary materials. The planted pallets are pinned directly into the river bank as prescribed by the manufacturers.

This technique provides cover with appropriate plants within the water's edge zone that are underpinned by a flexible rock roll to a depth of c.450 mm which was considered sufficient in this location(see Figure 3.7).

A relatively smooth connection between full scale revetment and transition was achieved by maintaining the ledge located just below water level(suitable for marginal aquatics). Similarly the rock roll easily ran into the stone that underpinned all full scale revetments.

3.5 Installation methodologies

Installation guidance is included on the design drawings which are presented as separate 'stand alone' sheets for easy reference (Figures 3.4 - 3.7).

Installation of each revetment was carried out behind a clay bund. This allowed the labour force to work in almost dry conditions. Water behind the bund was pumped into the river during the working period. Although the contractor decided to work in the dry and so needed to import clay, each technique is known to be suited to installation without de-watering. The contractors decision was influenced by the ease with which river flow would be diverted around the temporary bunds given the nature of the river works under way at the time.

An important disadvantage of de-watering is the uncertainty that arises in ensuring that the revetment is located at normal water level. Working with the water present avoids this uncertainty in most circumstances.

See Appendix 3 for photographs of revetments under construction.

Storage and handling living materials
The use of living materials in construction brings specific implications that need to be considered at an early stage. Due regard to the following should be taken when utilising proprietary plant rolls and pallets:

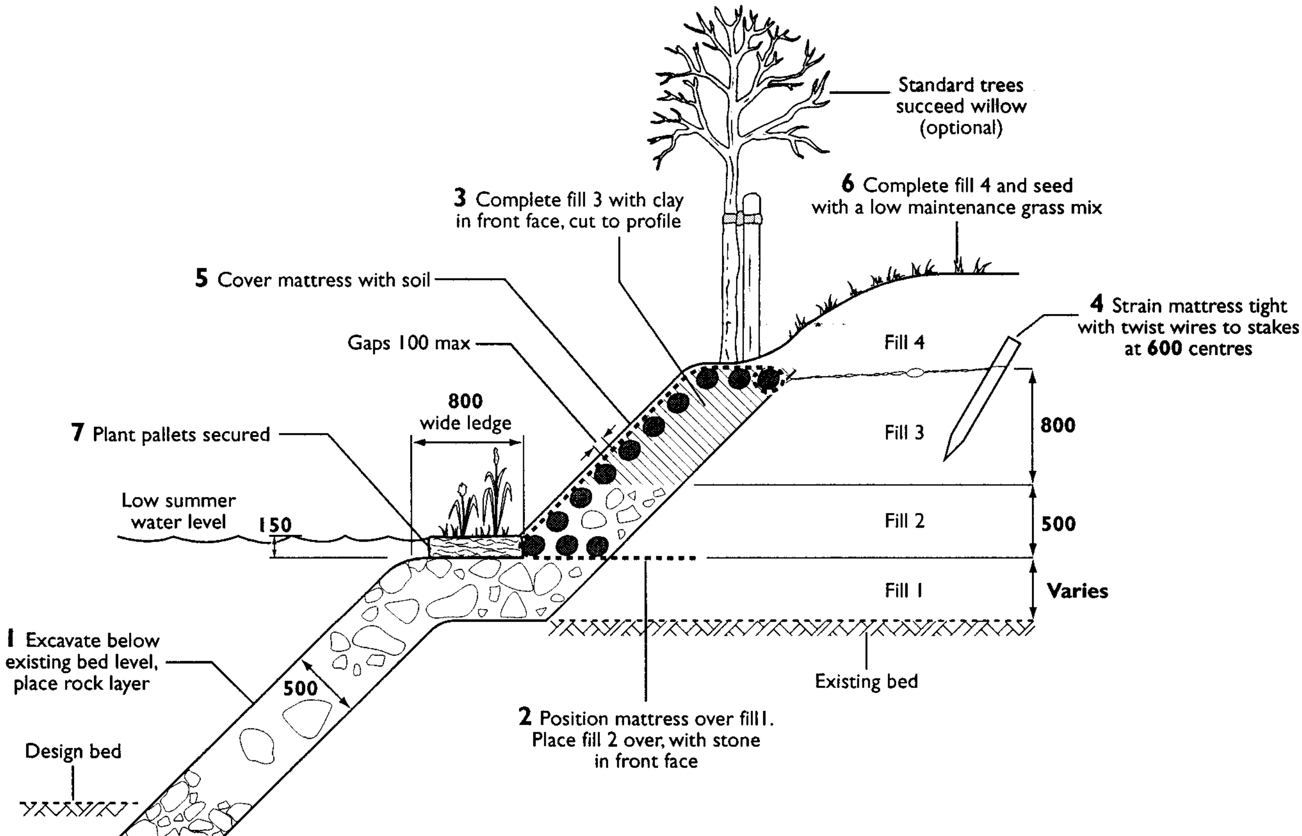
- order well in advance to ensure suitable species are available,
- install as early as possible in the growing season,
- liaise with suppliers to deliver immediately prior to installation,
- once on site, they need to be stored in water (a backwater was used on this site).

Coordination of willow harvesting with installation will reduce storage time and so retain viability of the material. Cut willow can be stored in water but this is not recommended for long periods.

3.5.1 Willow mattress

Installation

1. Excavate below exiting bed level to profile, fill old channel to ledge level (fill 1) and place rock toe below water level. (See note spec. below).
2. Position mattress over the top. Mattress made by stapling live willow poles (60%) and other timbers to sheep netting). Place fill 2 over, with stone in front face.
3. Complete fill 3 with good clay in front face, cut to profile.
4. Pull mattress over and secure, pressing logs into clay (and stone toe if possible).
5. Cover mattress with soil, (turfy topsoil).
6. Complete fill 4 and seed with a low maintenance grass mix.
7. Plant pallets secured in front of mattress on ledge just below water level.



General Rock Revetment Specification (used throughout)

Hard, dense, homogeneous, frost resistant, local rock free from foreign matter

% passing	Sieves size (mm)
100	300
40 – 50	125
30 – 45	75
20 – 40	37.5
10 – 30	10
5 – 20	5
0 – 10	0.6

Figure 3.4 Detail of willow mattress and installation

3.5.2 Willow spiling

Installation

1. Excavate to new bed level.
2. Drive stakes to line and level. Tanalised larch 100 mm dia (nominal) x 2 metres long.
3. Place rockfill around stakes. (Size 300 mm down – standard spec).
4. Drive stakes to line and level at 600 mm centres.
   Tanalised larch 100 mm dia (nominal) x 2 metres long.
5. Place and fix toe boards.
6. Back fill toe boards with clayey soil. Incorporate geotextile ('Enkamat 7220' used on Skerne site) 50 mm below finished level.
7. Weave live willow spiling around stakes and drive live willow stakes (50 mm dia x 1000 mm long) behind spiling at 600 mm centres.
8. Back fill to spiling. Incorporate geotextile ('Enkamat 7220') behind spiling.
9. Secure plant pallets in front of toe boards on ledge just below water level.
10. Upper slope seeded with low maintenance grass mix.

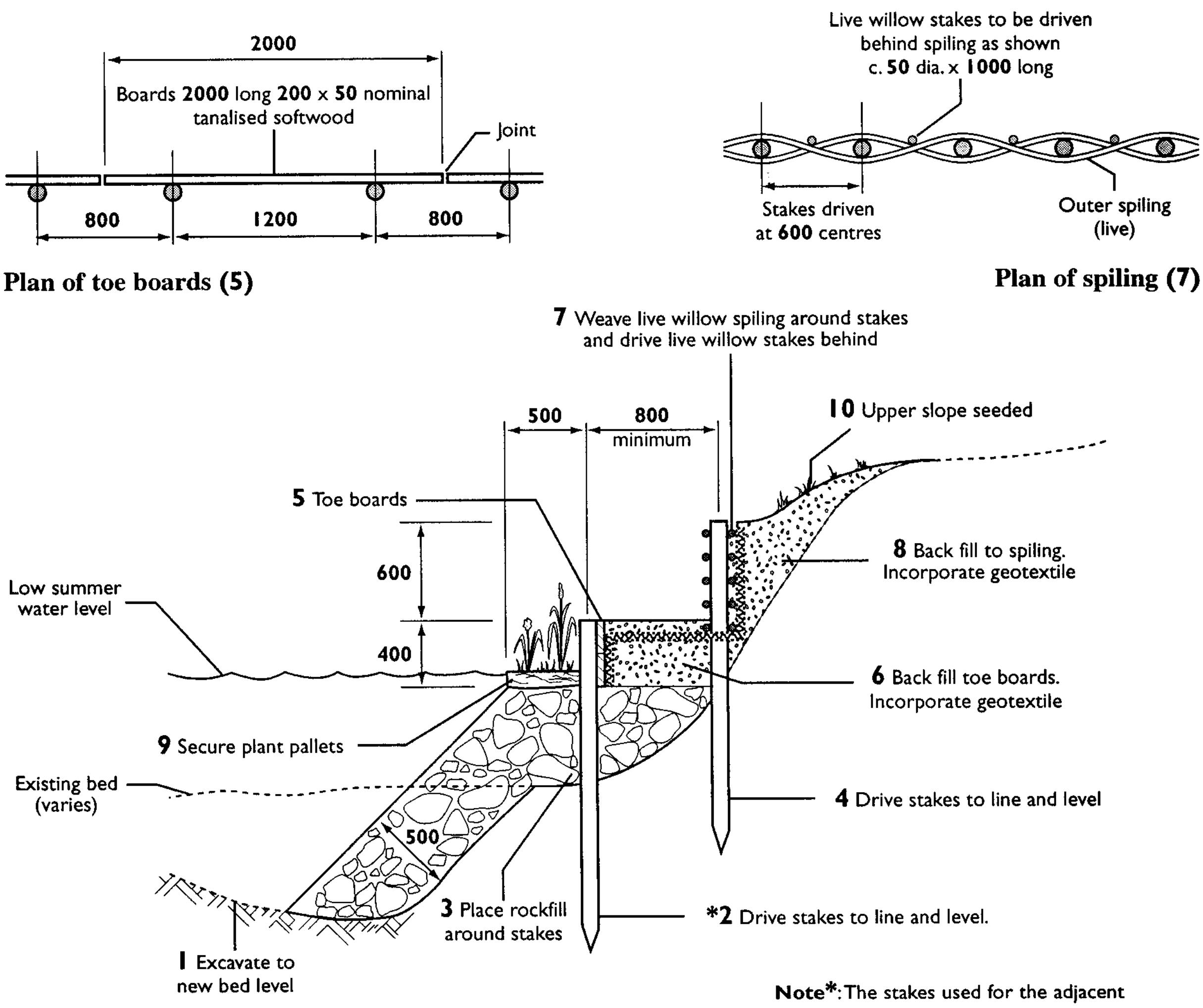


Figure 3.5 Detail of willow spiling and installation

Note*: The stakes used for the adjacent transitional zone revetments are to line up with these stakes

3.5.3 Log toe and geotextile

Installation

1. Excavate to 300 mm (minimum) below designed bed level.
2. Place 500 mm thick rock layer below water level. (size 300 down – standard spec).
3. Form 800 mm wide ledge, 150 mm below water level.
4. Timber stakes to mark line of toe (untreated).
5. Extend rockfill above water level behind and around stakes; commence soil backfill.
6. Position hardwood log on ledge in front of stakes.
7. Angular stone in front of log to secure.
8. Wire the logs to stakes to prevent floatation.
9. Logs further secured with timber stakes and 4 mm dia twist wire in filled ground.
10. General backfill behind and above logs. (Progressive up to top of bank).
11. Geotextile ('Enkamat 7220') secured to logs using 100 x 25 nailed wooden boards then laid up the slope, pegged down and covered with fine soil.
12. Upper slope seeded with a low maintenance grass mix.
13. Plant pallets secured in front of logs just below water level.
14. *Phalaris* planted in clumps on damp ledge just behind log.
15. Willow slips planted in a band approx 1500 mm wide.
16. Standard trees planted.

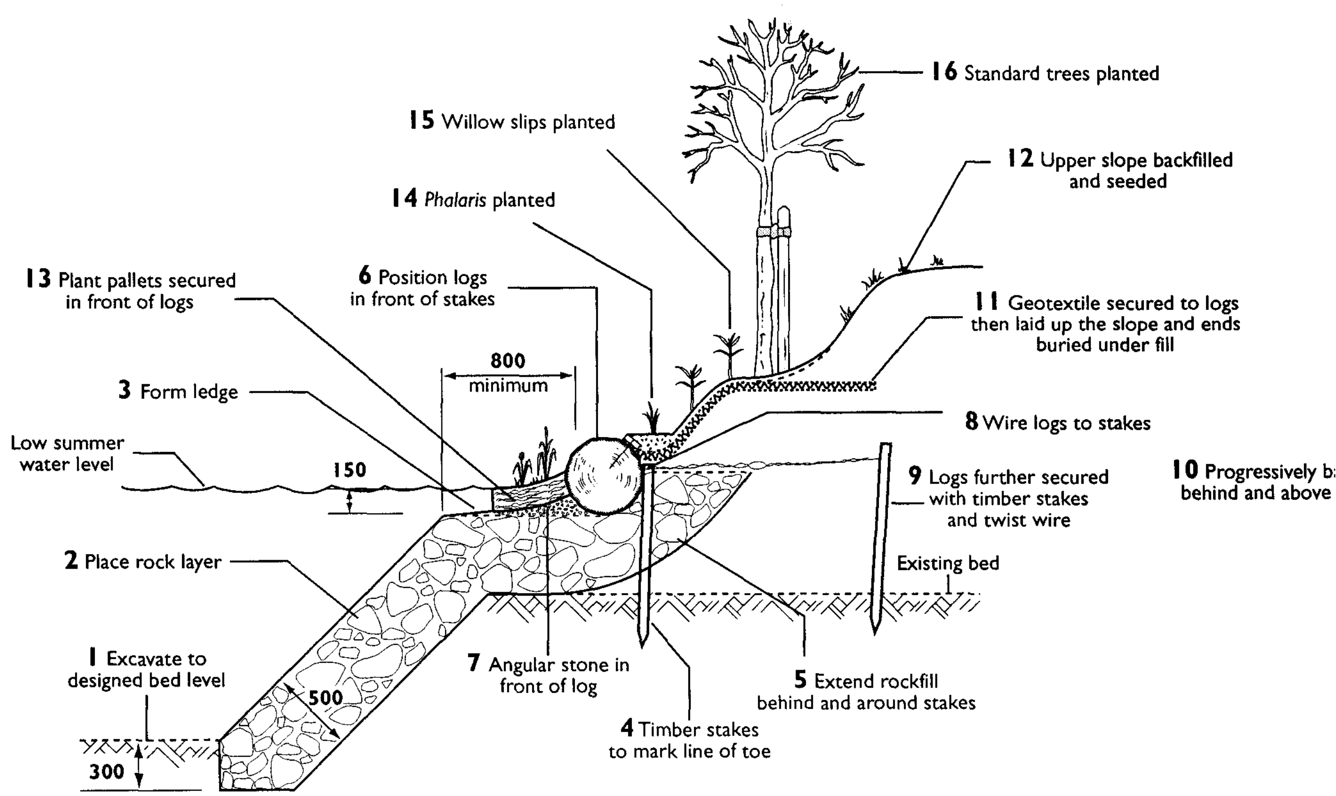


Figure 3.6 Detail of log toe and geotextile and installation

3.5.4 Transition revetment (plant rolls over rock rolls)

Installation

1. Cut ledge 450 mm below low summer water level.
2. Cut slit trenches 1500 long at 2000 centres to suit tie wires (narrow as possible).
3. Place rock rolls in position at ledge.
4. Drive stakes through netting at 1000 mm centres at rear of rock rolls (untreated).
5. Rock rolls tied back to stakes with wire tourniquets.
6. Back fill slit trenches with soil.
7. Gravel backfill behind rock rolls to ensure fibre roll is bedded in at the correct level.
8. Position fibre rolls, 2/3 below mean summer water level.
9. Drive round stakes through netting at 1000 mm centres at rear of fibre rolls, (secure in contact with rock roll, ensuring gaps filled with gravel.
10. Position plant pallet behind fibre roll, secure with metal or wooden pegs.
11. Seed slope above with low maintenance grass mix, raking soil into plant pallets.

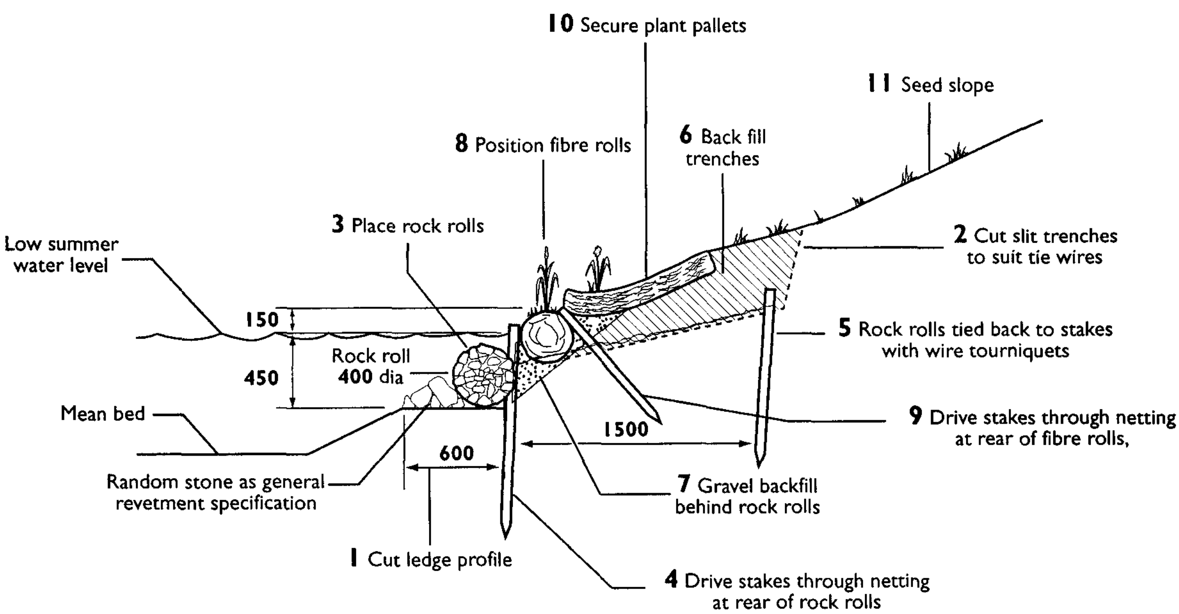


Figure 3.7 Detail of trasition revetment (plant rolls over rock rolls) and installation

4. COSTS

4.1 Material costs

The prices indicated in the tables below were 1995 prices excluding VAT. They give a guide to the costs that can be expected for similar revetment work. Labour costs are additional. All materials were sourced remote from the site.

Table 4.1 Material costs for constructed revetments (excluding VAT) per linear metre

Revetment Type	Transition	Spiling	Log toe	Mattress
Length (m)	119	75	91	59
Total cost (£)	10 710	5 250	10 101	6 844
Material costs (£ per lin.metre)	**90**	**70**	**111**	**116**

These costs are further itemised in Table 4.2 where possible savings or additions are evident.

Table 4.2. Itemised material costs (£) per linear metre

Material	Transition	Spiling	Log toe	Mattress
Plant pallet	25	13	13	13
Plant roll	22			
Stakes	6	5	9	5
Rock	10	14	28	42
Rock roll	25			
Geotextile		6	6	
Toe boards		10		
Spiling (withies)		16		
Willow poles*				40
Willow stakes*		4	4	
Willow slips*			4	
Sheep netting				4
Oak logs*			45	
Clay				10
Seed	2	2	2	2
Total (£ per lin. metre)	**90**	**70**	**111**	**116**

*Costs include harvesting, transport, storage and delivery to site.
Significant reductions in costs are possible if willow and other vegetative materials are harvested locally, notably for the mattress technique where available timber may negate the need to import any rock.

4.2 Installation costs

The cost for installation of revetments will vary with location, weather conditions and skill of the workforce. Where the workforce is familiar with the techniques and they are used regularly, labour costs will be lower.

The Skerne revetments were installed by the Environment Agency workforce who had no previous experience of similar work.

Estimates of labour and plant costs for constructing the revetments used on the Skerne site are shown in Tables 4.3. These estimates assume the following:

- the cost of labour charged at £17/hour;
- clear site instructions and drawings available;
- a workforce of 3 or 4 with the usual range of skills (including revetment construction) for working in rivers;
- reasonable weather conditions;
- contract supervision **not included.**

Table 4.3 Estimated labour and plant costs (excluding contract supervision) for installation of each revetment type

Revetment Type	Transition	Spiling	Log toe	Mattress
Revetment length (m)	119	75	91	59
Total cost (£)	4998	3375	3185	2832
Cost (£ per lin.metre)	**42**	**45**	**35**	**48**

The costs shown in Table 4.3 are site specific but give a general idea of the costs involved. Plant costs include the daily cost of transporting heavy machinery to and from site. Savings are possible if plant can be safely left on site overnight.

Table 4.4 Total revetment costs per linear metre (materials, plant and labour)

Revetment Type	Transition	Spiling	Log toe	Mattress
Materials(£)	90	70	111	116
Labour and plant(£)	42	45	35	48
Total(£ per lin metre)	**132**	**115**	**146**	**164**

Bringing together estimates of total costs allows each revetment type to be compared (Table 4.4). These prices relate to linear metres on the River Skerne where the bank height varies between 2 and 3 metres. For other sites, the cost of willow mattressing, in particular, will reduce if material is gained from local routine tree maintenance. When compared to prices estimated for revetment works from analysis of a CIRIA, the Construction Industry Research and Information Association, survey undertaken by Hey *et al.* (1991) (Table 4.5), even without inflation adjustment, they look favourable. For example, willow revetment of various types and composites had a typical cost of £216/square metre.

Table 4.5 Reported methods of bank protection (1978-85) (After Hey *et al.* 1991)

Method of bank protection	Typical cost (£/square metre of bank)
Steel trench sheeting below water	58
Rip-rap, ungrouted	25
Steel sheet piling	130
Concrete blocks, interlocking	116
Gabions, boxes/mattresses	87
Geotextile mats and fabric	18
In situ concrete wall	347
Willow, various types/composites	216
Rip-rap, grouted	43
Concrete filled bags	85
Concrete blocks, grouted	128
Concrete blocks, cable tied	309
Brickwork wall	549
Concrete filled mattress	291
In-situ concrete slab	463

Note: Costs are indicative only and depend on bank height and local labour/plant/material prices

4.3 Maintenance implications and costs

Regular maintenance of willow and other trees in or near the river can provide a source of material for soft engineering revetment work. To increase cost effectiveness, liaison of timing between these two types of work should be encouraged. The use of fast growing willows brings maintenance implications. The species used on the Skerne site are *Salix cinerea* (grey willow), *S. caprea* (goat willow), *S. viminalis* (osier), *S. fragilis* (crack willow), and *S. alba* (white willow).

Riverside willow species need regular maintenance. At this location, once the willows have established they will be divided into three equal sections and cut in rotation to give sections of differing maturity and density. Thin and flexible willows are most effective at deflecting high water flows and cause least obstruction (Coppin and Richards 1990). The objective of the rotation is to maintain willow cover which supports the bank and acts as a haven for wildlife.

Work should be carried out in the winter months and the arisings could be utilised in other areas if needed. Any work should be sympathetic to visual amenity and landscape as well as flood defence considerations. Selected trees can be allowed to grow to maturity.

Although not applicable on this site, grazing livestock will destroy all vegetation if not excluded until the vegetation is reasonably mature.

Table 4.6 Estimated yearly maintenance costs (based on 1/3 cut rotation)

Revetment Type	Transition	Spiling	Log toe	Mattress
Cost (£)/lin. metre	**2.55**	**3.4**	**10.2**	**10.2**
Cost (man hours)	0.15	0.2	0.6	0.6

Maintenance needs are prescribed in the ten-year management plan for the site. Estimates for maintenance were derived from a site visit and discussion with catchment maintenance staff within the Agency. The lower cost for the transition revetment is due to the absence of willows. The actual cost will depend on the local rates for tree and shrub maintenance.

Annual maintenance has been prescribed for the Skerne site because of its urban location. It is known that in rural locations bankside willows are usually left to mature without maintenance. Routine inspection is necessary, in common with a check on river bank trees in general. Typically maintenance is reactive to any problems that are noted or anticipated.

5. PERFORMANCE

5.1 Monitoring

Installed between October 1995 and May 1996, the revetments were monitored for growth and condition between June and October 1996 and again the following summer.

For each revetment the following was recorded:
performance of the willows on the attack zone;
performance of the plant pallets on the attack and transition zones;
performance of the plant rolls on the transition zone;
environmental performance.

For each section, the establishment success and growth of individual species was noted. Photographs of the revetments during this period can be seen in Appendix 3.

5.2 Willow

5.2.1 Growth of willow

Before monitoring began, all but the entry spiling had experienced two flood events. During the monitoring period there were further bankfull and out of bank flows.

Table 5.1 records the growth of willow in each revetment technique.

Table 5.1 Overall growth performance of willow

Technique	Installation date	Main species	Aggregated growth recorded (mm)					
			July 96	October 96	Average 96	July 97	October 97	Average 97
Spiling Entry	May 96	osier	50-500	1000-1500	1300	1000-2000	1500-3000	2500
Spiling Exit	Nov 95	osier	1000-1200	1700-2000	1850	2000-2500*	2000-3000*	2500
Log toe and geotextile N1	March 96	75%Grey rooted/ 25%goat slips	300-1200	1000-1700	1500	1200-2000	1500-2000	1800
Log toe and geotextile N3	March 96	75%Goat rooted/ 25%grey slips	300-600	300-600	450	1000-2000	1000-2000	1500
Mattress N2	Oct 95	Crack/ White	100-1100	300-2000	1200	1500-3000	1500-3000+	2800

*growth at u/s end only

All species of willow have increased in biomass since installation. The most successful species were white and crack willow. The least successful, goat willow, did not thrive initially whether inserted rooted or unrooted. Grey willow used on the same revetments grew very vigorously on N1 but few thrived on N3.

5.2.2 General observations on willow performance

Willow mattress

The willow mattress(N2) was installed in October 1995. Initially, high water during the first winter washed some soil from the surface of the revetment. Following this, silts were deposited and have continued to do so with the growth of the willow. Growth has been rapid and a good cover achieved throughout the length of the mattress.

Early in the first season, sprouting was most even at the downstream end; later the best growth was at the upstream end. This revetment was made using crack and white willow. The differences in uptake and growth rate may be accredited to this. By the end of the second season, the length with crack willow had grown 1500 to 2000 mm whereas the white willow reached 2500 to 3000 mm. The most vigorous growth was at the water's edge.

Willow spiling

Entry revetment - Installed in May 1996, the willows used on the entry revetment have established very quickly. Newly harvested material was used within two to three days. Initial observations were made just one month after installation. Between July and September there were increases of 500 mm/month, most of the growth coming from the upright poles.

The entry spiling was very vigorous throughout its length with an average increase of 1000 mm over the second season with an overall range of 1500 to 3000 mm.

Exit revetment - This was installed in November 1995. Where growth has occurred, it has been very vigorous but restricted to vertical live poles in the upstream half, where the average height is 2500 mm. Initially there was some growth in the downstream half but by the end of the second season this growth had died back.

As site conditions do not appear to vary along the revetment, the differences in performance could be attributed to the fact that material for the exit revetment was harvested and stored in water for about six weeks before use. It is feasible that much of the material used at the downstream end of the exit was no longer viable at the time of installation. Only freshly harvested material should be used to ensure successful willow growth.

Willow slips

Revetment N1 - Planted in March 1996, the rooted grey willow established quickly with 100% success nearest the water. In the first season, growth at the upstream end was restricted (on average by 500 mm) by a mature tree.

At the start of the second season, the stands of rooted grey willow at each end of the revetment were most vigorous. The cover achieved in the mid section with mixed planting(grey rooted with goat slips) was patchy until the end of the second season. By the end of the season, the average height was 2000 mm.

Most of the unrooted goat willow has been slow or has failed to establish.

Revetment N3 - The willow slips were planted in March 1996. Rooted goat willow has established in places but the growth rate has been very slow. After the first month some slips were missing particularly at the downstream end. Three months after planting, the rooted goat willow had grown 300 to 600 mm. By the end of the season there was little if any change in growth and the survival rate was only around 10%.

By the end of the second season, growth attained by the remaining goat willow was 1000 to 2000 mm and although patchy, was better at the downstream end. Rapid recolonisation by ruderals such as *Impatiens glandulifera* (Himalayan balsam) within the goat willow in particular may have contributed to their poor initial success.

The establishment of unrooted grey willow has been very limited on this revetment. The taller specimens were lost during the dry months of August and September. This may have been due to drought, contaminated ground or trampling. (Two standard trees on this revetment are suffering stress.)

5.3 Plant rolls

The plant rolls have been very successful on each revetment. In most cases they contained *Phalaris arundinacea* (canary reed grass), mixed with *Iris pseudacorus* (flag iris) and *Carex acutiformis* (lesser pond sedge). All species were vigorous with *P.arundinacea* becoming dominant in some sections.

On all revetments, the height attained from plant rolls was at least 1000 mm over the first summer. Each species flowered successfully and of particular note was the flag iris which proved to be very popular with local people. Most plants grew 1000 to 2000 mm in the second season.

Table 5.2 Overall performance of plant rolls

Position	Installation date	Performance
Entry	May 96	Rapid establishment of all species. Growth >1500 mm.
N1	Nov 95/ June 96	Establishment of all species with *P.arundinacea* most vigorous. Growth >1500mm
N2	Oct 95	Establishment of all speciesbut gaps in upstream section. Growth to 1000mm
N3	Oct 95/ June 96	Establishment of all species. Growth >1500 mm. All species vigorous.
Exit	Nov 95	Establishment of all species. Growth >1500 mm. *P. arundinacea* dominating upstream.

5.4 Pallets

Single species pallets grew better than mixed pallets. The best growth (1-2 metres) has been achieved by the pallets in the attack zones, positioned at or around low water level. Species of particular note are *Iris pseudacorus* and *Carex acutiformis*.

Originally about 1/3 of transition pallets were of mixed species. *P. arundinacea* has since become the dominant species in these pallets. In many positions, growth is limited to a 500 mm strip along the water's edge. Those pallets placed too far up the bank have not thrived. The appropriate positioning of pallets is very important, however, with changing water levels this is often difficult to judge. Some allowance should be made for 'natural selection' of the species range that will survive.

Transition pallets have suffered from invasion by ruderal species such as *Impatiens glandulifera* especially on the landward side.

Table 5.3 Overall performance of plant pallets (Oct 1997)

Revetment	Position	Installation	Performance
Entry	transition d/s	May 96	Growth only 500 mm wide. *P. arundinacea* most vigorous.
	attack	May 96	All species vigorous.
N1	transition u/s	June 96	Growth only 500 mm wide. All species fair.
	transition d/s	Oct 95	All species very vigorous especially *P. arundinacea* *I. glandulifera* invading.
	attack	Oct 96	All species vigorous. *P. arundinacea* suffering from trampling.
N2	transition u/s	Oct 95	*P. arundinacea* surviving best. *I.. glandulifera* invading.
	transition d/s	Oct 95	Growth only 500 mm wide. *P. arundinacea* very vigorous.
	attack	Oct 95	All species vigorous.
N3	transition u/s	June 96	Growth only 500 mm wide. All species very vigorous.
	transition d/s	Oct 95	Growth 1000 mm wide. All species vigorous especially *P. arundinacea.*
	attack	Oct 95	All species vigorous.
Exit	transition u/s	Nov 95	Growth poor except *P.arundinacea.* Too high out of the water.
	transition d/s	Nov 95	Growth is patchy due to competition by *I. glandulifera.*
	attack	Nov 95	Very vigorous and dense especially *Carex* and *Iris.*

5.5 Underwater rock layer

Due to the inaccessibility of the rock layer that underpins all of the main revetments it has not been possible to measure its performance. The rock does, however, appear to be performing satisfactorily as none has been displaced by river currents or vandalism.

Settlement of backfilled soils above water level is evident which suggests that some degree of settlement has occurred below water also - if so the rock has evidently adjusted to accommodate this without any apparent difficulty.

The position of the proprietary rock rolls that underpin the transition revetments is similarly satisfactory at all locations.

5.6 Environmental performance

The visual appeal of the reach has been greatly enhanced by the rapid growth of the willows. The willows readily accentuate the course of the meandering river and give a natural feel to the landscape. They give a vertical dimension to the scene where previously there had been very few points of reference. Their visual impact both at two levels is substantial; they can be seen from a distance as a distinct feature along the river bank, while close up, the characteristics of the species can be appreciated.

The preplanted pallets and rolls have been equally impressive, providing instant visual interest for people and habitat for wildlife. Having decided to plant only species native to the Skerne, the choice was limited due to the poor flora diversity of the river. However, their use has encouraged silt to build up and form further suitable ledges that other species have colonised.

Even at this early stage, the revetments have proved to be magnets for wildlife. Water voles have moved into the revetted lengths. Within the spiling revetments and elsewhere, the ledge features are being used as runs and cover provided by the dense growth in the mattressing is also proving popular. The numbers and variety of birds have increased; kingfishers can be seen in the revetted length where previously there were no suitable perches and moorhens are more numerous due to the availability of suitable nesting sites and amount of cover provided by the plant pallets and rolls. The populations of damsel and dragonflies have greatly increased with the improvement in suitable marginal habitat.

The number of fish found in the meander reach increased dramatically in the first full year after completion. Loose rock at the toe of the revetments and rock rolls may be providing shelter for the smaller fish resulting in a greater survivorship.

Overall the seeding the bank top zone has mitigated ruderal colonisation. It has been most successful where willow growth has been rapid. On N3, poor establishment of willow allowed ruderals to gain a foothold. Initial delays in bank management due to the continued work on site allowed invasion by unsuitable aliens such as *Brassica sp.* (rape) and *Impatiens glandulifera.* Now that the site management plan is being adhered to, the changes to river and bank maintenance will ensure a reduction in such species and result in sustainability of the newly created habitats.

Willows and marginal plants on each revetment have grown vigorously with the exception of one length of spiling. The failure on this length highlights the importance of live willow being utilised while viable. If willow cover with the associated root development is required rapidly, slower growing goat willow may not be suitable. On the Darlington site, this species proved to be the least vigorous species.

6. OVERALL ASSESSMENT

6.1 Techniques Demonstrated

Four different techniques of revetment have been demonstrated: Plant rolls over rock rolls, Spiling, Mattressing and Log toe with geotextile (as well as underwater revetment using rock). Each technique comprises individual components within three vertical zones - below water, water's edge and bank top.

These components have been configured in a way that is most suited to the site specific conditions that prevail, but they may be utilised in different configurations to suit conditions at other sites (toe boarding may be substituted for a log toe; mattressing may be extended underwater as an alternative to a rock layer).

The techniques demonstrated are therefore representative of a much wider range of revetment configurations than may be apparent to those visiting the site. It is important to understand the underlying methodology when assessing the potential of the techniques for wider application.

6.2 Design

The design of the four techniques demonstrated was necessarily subjective. It relied on a clear understanding of the *nature* of the forces present in the flowing river as well as characteristics essential to the achievement of a wholly flexible 'structure' within which plants would thrive to become the principal revetment medium over time.

Numeric calculations were necessary to determine basic river bed and bank profiles that were sustainable and to determine the size and grading of rock utilised.

Despite the subjectivity involved, the design of soft engineering revetments is largely a technical task because the end product is a fairly sophisticated structure that uses a range of different materials.

The support of biologists and other scientists is essential to optimise the design. The creation of sustainable wildlife habitats and landscape features, through river bank revetments, demands expertise in understanding the suitability of plants for the location as well as many other ecological considerations.

It is reasonable to suggest that the design of soft engineering revetments demand more in terms of time, skills and attention to detail than are generally applicable to the 'harder' techniques that might otherwise be selected. The added value gained through the creation of a living, yet functional, environment more than justifies the extra work involved.

6.3 Construction

Each technique demonstrated is designed to minimise reliance on materials that need to be purchased and imported to the site. Instead, each relies mainly on materials that can be found locally in most river bank situations. This approach reduces disruption caused by transporting materials and helps to avoid the introduction of non-native species. It can also save considerably on costs.

In practice, installation of revetments on this demonstration site relied entirely on imported materials, save only the backfill used to create the river banks that were protected. In particular, considerable use was made of proprietary plant mattresses and plant rolls. Since these are now widely available the opportunity was taken to demonstrate, and monitor, their effectiveness.

The need to use imported materials was simply a reflection of the degraded state of the river. This situation is not untypical of urban environments but elsewhere the concept of 'recycling' local materials should be both feasible and appropriate.

The use of rock in the underwater zone is perhaps an exception to this approach since this is not usually found on revetment sites (unless it is a remnant of earlier revetments that have failed). Its use on the demonstration site is explained in 3.4.1 above; the proximity of a gas main and the fact that whatever material was selected, it needed to be imported. Alternatives to the use of rock include extending the mattressing technique underwater - this involves floating the mattress and then sinking one end under the weight of backfill placed on it. Geotextile mattresses can be used in a similar way. In upland situations any surplus of river bed cobbles and gravel may be carefully selected as underwater backfill if used in conjunction with a mattressing technique.

Rock used in the manner demonstrated has much to commend it - also explained in 3.4.1. above. In particular, the choice of size and grading is important; avoidance of block stone or rock filled wire baskets is best if possible.

The knowledge and skill of the workforce undertaking soft revetments has a considerable bearing on the success and the costs of construction. The Environment Agency's in-house workforce employed at the demonstration site were initially unsure of the rationale that supported the designs and requested a short seminar to overcome this difficulty. Subsequently work proceeded with confidence and a marked degree of intuitive improvement to some aspects of construction detail.

At the conclusion, the workforce expressed great pride in their creative achievements and have since gone on to utilise and build upon the experience gained in the course of their routine river bank work.

Training in the technique of soft revetment work will clearly be beneficial to those who may not be familiar with either the design rationale or the practical aspects of construction. The Skerne demonstration site has great potential in this respect.

6.4 Performance

Sufficient high flow events have now passed through the site (including out of bank flows) to enable a subjective assessment that the revetments have achieved their primary purpose of ensuring the integrity of the reformed riverbanks.

The physical processes anticipated in the design are all in evidence. Settlement of backfill has occurred and the revetments have adjusted to this without any loss of continuity or damage. In the immediate post construction period, before any significant plant growth, scour of the river bank surface was apparent in several places but this was mitigated by the short-term provisions made (geotextiles, mattress cover). Subsequently, the growth of vegetation introduced has led to the deposition of silt that has proved beneficial in helping the continuing development of the revetments.

The invasion of *Impatiens glandulifera* and other ruderal plants has been significant, yet unavoidable, due to seed carried by flood waters being deposited along the site. Fortunately, these undesirable plants have not proved detrimental to the effectiveness of species introduced as part of the revetment - most are proving to be dominant and the problem with ruderals is likely to be lessened over time as they are crowded or shaded out by perennial species and trees. Mowing of ruderals where they are accessible above the revetment structures is helping to reduce viable seed supply.

A particularly outstanding aspect of the revetment performance has been the major contribution it has made to the visual amenity and to wildlife habitats. This can only improve with time - a living infrastructure has been created within which many desirable ecological processes are active.

6.5 Achievements of the demonstration objectives

The site is intended to provide an opportunity for the river manager to inspect a range of soft revetment techniques at a single location so that they may be better informed of the appropriateness for application elsewhere.

The restoration site, as a whole, has attracted very many professional visitors and interest in the revetments has been of particular note. It is, however, questionable whether the current level of interest will be sustained. There appears to be a greater demand for documentation of the revetment techniques than for site visits to gain first hand experience.

This report fulfils the demand for documentation. It will be supplemented by inclusions in RRP's Manual of River Restoration Techniques that is under preparation as a post EU-LIFE output to UK Project Participants. This will feature the revetment design drawings and a brief summary text only.

The geographic location of Darlington, in the North East of England, appears to be discouraging visits when given the alternative of visiting the 'companion' EU-LIFE site at Coleshill near

Swindon. The latter is sustaining greater visitor numbers as it is located closer to more centres of population and more Agency offices, yet is not accessible by public transport.

While the River Cole site affords a good overall introduction to river restoration techniques, these are particularly appropriate to rural, not urban, situations. The Skerne site complements the Cole site because it deals with urban river restoration issues. The Cole site does not feature revetment techniques.

Visits to the River Skerne in Darlington invariably prove to be well worthwhile on the part of those attending. Excellent road, rail and air links place Darlington within a days return travel distance from most parts of the UK.

GLOSSARY - DEFINITIONS USED IN THIS REPORT

Aliens	Non native plants
Fibre roll	A proprietary coir 'sausage' in an open mesh sleeve preplanted with marginal aquatic species
Geotextile	Natural or synthetic fabric used for erosion protection
Plant pallets	Proprietary coir mats preplanted with marginal aquatic species
Rock roll	A proprietary stone 'sausage' comprising graded rock supplied in an open mesh nylon sleeve
Slips	Small cuttings of plants such as willow which will easily root
Soft engineering	Bank protection using natural vegetative materials
Spiling	Willow cuttings woven around willow stakes used to protect steep banks
Tanalised wood	Wood impregnated with preservative
Withies	Long lengths of willow (often osier) used to weave spiling

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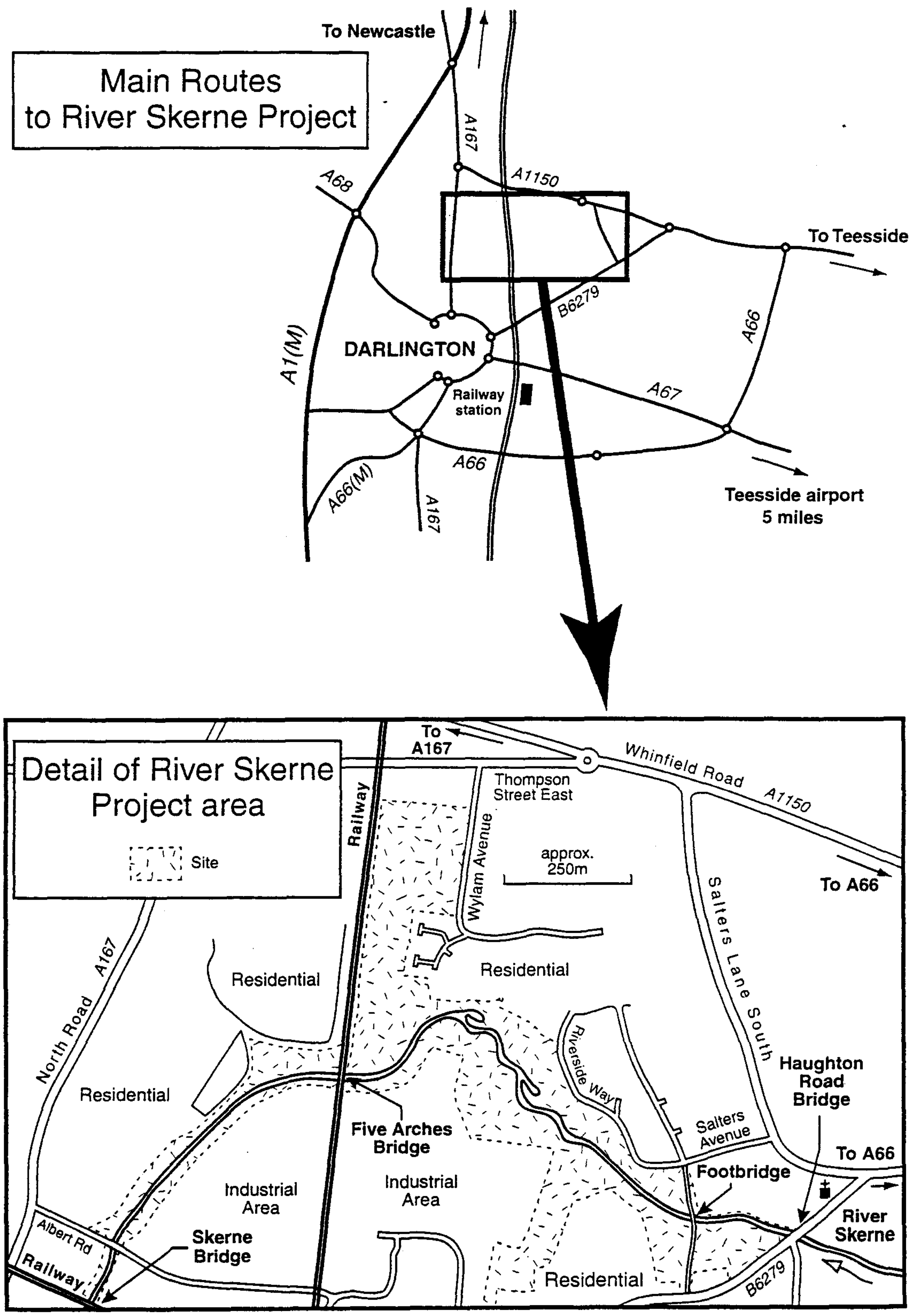
APPENDICES

Appendix 1 Location plan for the River Skerne site



Appendix 2 Materials and suppliers

Materials	Dimensions (mm)	Supplier	Specification
Plant rolls	3000 x 300 dia	MMG	Mix of *Iris pseudacorus*, *Phalaris arundinacea* and *Carex acutiformis* (6 plants/m)
Plant rolls	2200 x 300 dia	Phi Group	*Phalaris arundinacea* with *Lythrum salicaria* or *Iris pseudacorus* with *Lythrum salicaria* (6 plants/m)
Plant pallets	1200 x 800	MMG	Single species - *Iris pseudacorus*, *Carex acutiformis*, *Glyceria maxima*, *Phalaris arundinacea* or *Juncus effusus*, or Mix of *Iris pseudacorus*, *Carex acutiformis*, *Glyceria maxima*, *Phalaris arundinacea*, or Type 1 - *Typha latifolia, Phragmites australis, Carex riparia, Polygonum amphibium, Veronica beccabunga, Mentha aquatica,* or Type 2 - *Phalaris arundinacea, Sparganium erectum, Iris pseudacorus, Mentha aquatica, Myosotis scorpioides, Alisma plantago-aquatica.* All at 18 plants/m.
Rock rolls	2000 x 400dia	MMG	
Geotextile	2000 x 40 000	MMG	'Enkamat' 7220
Coir	2000 x 30 000	Phi Group	900 g/m^2
Willow poles	approx 2000 x 100 dia		At least 50% live for willow mattress (considerable variation in length and diameter)
Softwood toe boards	2000 x 200 x 50		Used in spiling
Softwood boards	2000 x 100 x 25		Used on log toe to hold geotextile
Larch stakes	2000 x 100 dia		Tanalised fencing posts
Osier stakes	1000 x 50 dia		Live
Toe logs	variable length x 300-500 dia		Fir or hardwood
Fence stakes	approx 2000 x 100 dia		
Sheep netting	900 wide		Rolls 100 mesh size
Wire	4 dia		Galvanised
Willow withies	1200 x 10-30 dia		Osier
Willow slips	10 - 20 dia		Goat and Grey willow
Willow rooted	up to 500 height		Goat and Grey willow
Wildflower/ grass mix		Hurrells	Spread rate of 100kgha^{-1}
Rock	300mm down	local quarry	

Suppliers addresses

MMG Civil Engineering Systems Ltd
Vermuyan House
St Germans
Kings Lynn
Norfolk PE34 3ES
Tel 01553 617791
Fax 01553 617771

Phi Group Limited
Harcourt House
Royal Crescent
Cheltenham
Gloucestershire
GL50 3 DA
Tel 01242 510199

Hurrells and McLean Seeds
Beverley Road
Cranswick
Driffield
East Riding of Yorkshire
YO25 9PF
Tel 01377 271400
Fax 01377 271500

Appendix 3 Photographs of revetments during and after construction

1. Entry spiling - spiling still to complete
2. Entry spiling - weaving of osier
3. Entry spiling complete
4. Entry spiling two months after installation
5. Entry spiling after one year
6. Exit spiling - positioning of plant roll
7. Exit spiling - weaving of spiling almost complete
8. Exit spiling eight months after installation
9. Exit after one year - downstream end where few willows have established
10. Log and geotextile during construction - logs wired over rock
11. Log and geotextile(N3) - geotextile laid behind logs and covered with soil
12. Log and geotextile(N1) prior to willow slip planting
13. Log and geotextile(N3) with willow slips in position
14. Log and geotextile(N1) four months after willows planted
15. Log and geotexile(N1) after one year
16. Log and geotextile(N3) four months after willows planted
17. Log and geotextile(N3) after one year
18. Willow mattress - one section under construction
19. Willow mattress in progress
20. Willow mattress after the first winter
21. Willow mattress eight months after installation
22. Willow mattress during the first summer
23. Transition rock rolls wired to posts
24. Transition plant rolls positioned behind submerged rock rolls

1. Entry spiling - spiling still to complete

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12. Log and geotextile (N1) prior to willow slip planting

13. Log and geotextile (N3) with willow slips in position

14. Log and geotextile (N1) four months after willows planted

15. Log and geotextile(N1) after one year

16. Log and geotextile(N3) four months after willows planted

17. Log and geotextile(N3) after one year

18. Willow mattress - one section under construction

19. Willow mattress in progress

20. Willow mattress after the first winter

21. Willow mattress eight months after installation

22. Willow mattress during the first summer

23. Transition rock rolls wired to posts

24. Transition plant rolls positioned behind submerged rock rolls

Appendix 4 Species used in the River Skerne Project (all species native to the catchment)

Species name	Common name
Alismo plantago-aquatica	Plantain, water
Carex riparia	Pond-sedge, greater
Carex acutiformis	Pond-sedge, lesser
Fraxinus excelsior	Ash
Glyceria maxima	Sweet-grass, reed
Iris pseudacorus	Iris, yellow flag
Juncus inflexus	Rush, hard
Juncus effusus	Rush, soft
Lythrum salicaria	Loosestrife, purple
Mentha aquatica	Water mint
Myosotis scorpioides	Water forget-me-not
Phalaris arundinacea	Canary grass, reed
Phragmites australis	Reed, common
Polygonum amphibium	Bistort, amphibious
Salix alba	Willow, white
Salix caprea	Willow, goat
Salix cinerea	Willow, grey
Salix fragilis	Willow, crack
Salix viminalis	Willow, osier
Sparganium erectum	Bur reed, branched
Typha latifolia	Bulrush, common
Veronica beccabunga	Brooklime