SEPA
Scottish Environment Protection Agency

Engineering in the Water Environment
Good Practice Guide

Bank Protection
Rivers and Lochs

First edition, April 2008

Your comments

SEPA is committed to ensuring its Good Practice Guides are useful and relevant to those carrying out engineering activities in Scotland's rivers and lochs.

We welcome your comments on this Good Practice Guide so that we can improve future editions. A feedback from and details on how to send your comments to us can be found in Appendix 5.

Acknowledgements

This document was produced in association with Royal Haskoning.
Cover photograph courtesy of Salix River and Wetland Services Ltd.

Engineering in the Water Environment Good Practice Guide

Bank Protection: Rivers and Lochs

First edition, April 2008

(Document reference: WAT-SG-23)

Contents

			Page
1	**Introduction**		2
	1.1	What's included in this guide?	3
2	**Defining the Problem**		4
	2.1	Bank erosion	4
	2.2	River processes affecting erosion	5
	2.3	River type	5
3.	**Assessing Risk and Demonstrating Need**		6
	3.1	Is there need for engineering?	6
4.	**Making a Decision**		13
	4.1	Introduction	13
	4.2	Alternative approaches	13
	4.3	Selecting options	21
5.	**Design, Implementation and Monitoring**		23
	5.1	Introduction	23
	5.2	Good practice sheets	23
	5.3	Post project appraisal	33
6.	**Sources of Further Information**		34
	6.1	Publications	34
	6.2	Websites	35
7.	**Glossary**		36
Appendix 1: River typologies			i
Appendix 2: Types of bank erosion			iii
Appendix 3: Field survey checklist			v
Appendix 4: Bank protection costings			vii
Appendix 5: Feedback form			viii

1 Introduction

This document provides information and guidance to help identify solutions to bank erosion that balance environmental protection with social, economical and technical constraints. As such, it is a Good Practice Guide, and is one in a series intended for use by SEPA staff and by parties considering undertaking engineering activities in rivers or lochs.

Under the Water Environment (Controlled Activities) (Scotland) Regulations 2006 (also known as the Controlled Activities Regulations, or CAR), authorisation must be obtained from SEPA for all new engineering works within inland surface waters. SEPA will expect all applications for new engineering to follow Good Practice, which is defined as:

"…the course of action that serves a demonstrated need, while minimising ecological harm, at a cost that is not disproportionately high."

SEPA will test all engineering applications to assess if they follow Good Practice. The tests are part of SEPA's duty under CAR to ensure licences represent efficient and sustainable use of the water environment. It is also part of SEPA's approach to managing capacity in the water environment to allow for future sustainable development.

SEPA have defined five tests to assess whether Good Practice has been followed (Fig 1)

1. Has the applicant demonstrated a need for the proposed activity?	Y/N
2. Has the applicant considered appropriate alternative approaches?	Y/N
3. Does the proposal represent the best environmental option?	Y/N
4. Is the activity designed appropriately?	Y/N
5. Have all necessary steps been taken to minimise the risk of pollution and damage to habitat, plants and animals during construction?	Y/N

Figure 1 Summary of SEPA Good Practice Tests

Each section of this document provides guidance on one or more of the above steps (see Figure 2). This information will aid selection of sustainable river engineering solutions and help applicants provide the information required in the CAR application form.

When SEPA deem that an activity fails to follow good practice, the application will be subject to a more thorough and detailed licence assessment. As part of this detailed assessment, the applicant will be required to provide additional information to justify their proposal. It is therefore always in the best interest of the applicant to consider thoroughly whether their proposal represents good practice prior to submitting an application to SEPA.

The document is not intended as a technical design manual, and it is important to recognise that any engineering works must be designed to suit site specific conditions. The document focuses on the environmental aspects that should be considered when undertaking a project. Using this document will help with the process of obtaining an authorisation for works under the Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR) (see sepa.org.uk/wfd for more information).[1]

1.1 What's included in this guide?

To help applicants through the process, the guidance is divided into four stages:

Section 2 Demonstrated need →	The first step when identifying a sustainable engineering solution is to determine whether new engineering work is necessary. This section will help applicants assess the need for new engineering.
Section 3.1 Identification of options →	There are often multiple solutions to a river engineering problem. This section provides information on relevant engineering options.
Section 3.2 Selecting best option →	This section provides guidance to help you select the most suitable and sustainable engineering option.
Section 4 Design and implementation →	Successful river engineering requires selection of a suitable option followed by appropriate design and implementation. This section provides guidance on design and implementation considerations.

Figure 2 Summary of key Sections with this guidance document

- Appendices

The final section is a series of appendices containing useful reference information.

This document uses colour coded text boxes to highlight important information:

Blue boxes provide details of other useful sources of information

Green boxes provide summaries of important points

Orange boxes provide summaries of regulatory information

[1] Under CAR, new engineering activities in Scotland's rivers, lochs and wetlands require and authorisation. Authorisations take various forms and more information is available in the CAR Practical Guide available from www.sepa.org.uk/wfd

2 Defining the problem

2.1 Bank erosion

Bank erosion is often caused by natural processes but it can also be due to by human activity, especially livestock management, vegetation management and river engineering. Bank erosion can result in a loss of land and can threaten property or structures. The deposition of eroded bank material further downstream can also cause damage, both to structures (e.g. sedimentation under bridges) and to the environment (e.g. smothering of spawning gravels by fine sediment).

Natural bank erosion fulfils several purposes (Figure 3): it renews ecological habitats; it is part of the natural balance of rivers (see 'river processes affecting erosion' below); and, crucially, as sediment is eroded, moved downstream and deposited, river energy is dissipated. Significant funds and effort are spent on engineering and maintenance to control and alleviate bank erosion. Halting erosion by using engineering has a negative impact on habitats, disrupts the natural balance of the river and, crucially, can make the original problem worse because the river has more energy. Also, some of the effort is ineffective because activities often treat the symptoms of erosion, without addressing the underlying cause. Bank erosion may then move elsewhere, making the original problem worse, adding to the economic burden, and causing further ecological damage.

In order to identify the best solution to erosion it is therefore critical to identify its **cause**, its **value** in terms of ecology and river function, and its **impact** on human activities, resources or health. **This document provides guidance on how to control river bank erosion by choosing and using appropriate and effective measures that are as beneficial as possible for natural processes and habitats.**

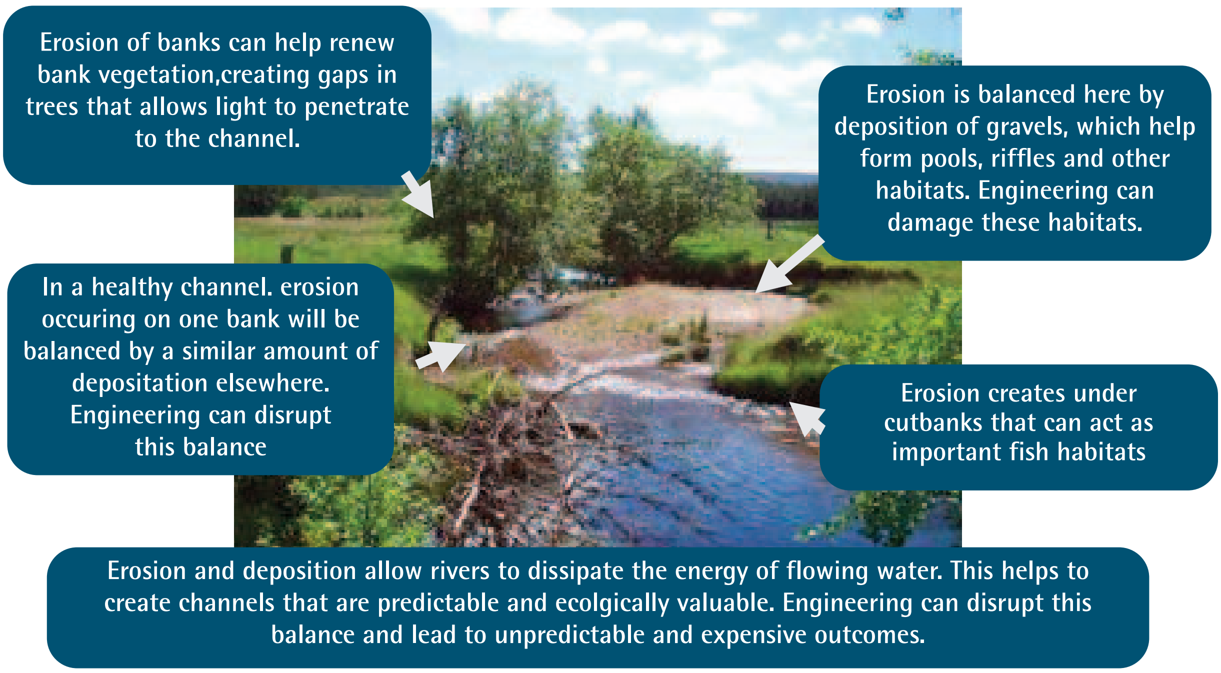


Figure 3 Examples of the importance role of bank erosion.

Stream bank zones

When considering bank erosion, it is useful to split the river into 3 zones (Figure 4):

Bank toe zone- The section below the water surface at normal flow conditions.

Upper bank zone- The section above the water surface at normal flow conditions

Riparian zone- the land running adjacent to the river channel – around 10 m wide. The character of this zone is important in maintaining a healthy river

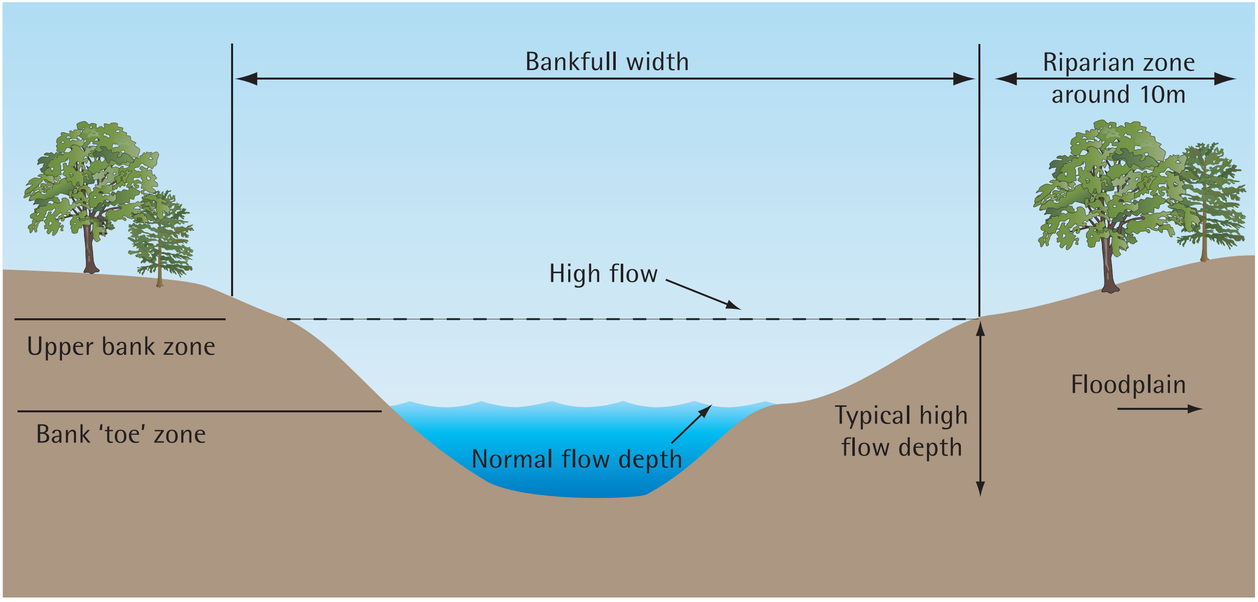


Figure 4 Summary of streambank zones

2.2 River processes affecting erosion

Rivers are the landscape's natural drainage system. They transport water and eroded materials from the land surface to the sea. The varied and complex habitats found in rivers are formed through the transport, deposition and organisation of sediment. Patterns of erosion and deposition are influenced by many factors, including the amount of rainfall, the local topography, rocks and vegetation.

When large changes in the amount of water occur (e.g. after the construction of a new dam, or due to changes in land-use and drainage) or when changes in the amount and type of sediment available to the river occur (e.g. after dredging or other major in channel engineering works) rivers will often adjust their shape (width and depth) to accommodate these new conditions. These adjustments in width and depth are often accompanied by changes in rates or patterns of erosion. Similarly, when the character of vegetation along the channel banks alters, e.g. replacement of trees and shrub with grassland, dramatic changes in erosion often follow. Finally, the introduction of structures into rivers (inc. bank protection) can redirect flow onto banks, causing erosion.

2.3 River type

Rivers are complex systems, and it can be useful to simplify rivers into distinct types (appendix 1) as these tend to display similar patterns of behaviour. Understanding the river type can be helpful in identifying both the cause of erosion and what response is appropriate.

3. Assessing risk and demonstrating need

3.1 Is there need for engineering?

The response to bank erosion should always be proportionate to the scale and significance of the erosion, both for people and the environment. For example, if a house or road is threatened by erosion, there is an obvious need to take action to prevent damage. At the other end of the scale there may be minor bank erosion that occurs infrequently and threatens land of little value, where the best response will be no action or simple management, such as planting a few trees. In between these extremes whether or not erosion becomes a problem depends on several factors: its cause, its extent, how fast it changes, the value and extent of the property (land or structures) impacted, and what ecological value the erosion provides. In some instances, for example where the ecological value is high, or the impacted land is worth less than the cost of the proposed works, engineering may be inappropriate. In order to identify these cases, you should consider whether there is a real need for engineering. There is a series of four steps that should be followed when making this assessment (Figure 5).

All applications should be supported with evidence to demonstrate the need for the works. This could take the form of photographs, historic maps, survey data, anecdotal evidence or expert opinion. The exact type of information will depend on the nature of the site and the scale of the problem, but the applicant should describe the problem, identify the cause, and describe why the activity is necessary. Box 1 provides guidance on these questions. This information should be supplied with the CAR application.

Box 1	
Describe the problem	• Is this a new or long term problem? • Have recent environmental factors (high flow events) caused/ exacerbated the problem? • Is there evidence that the problem will not disappear naturally? • Is there any survey data (inc photos) to aid description of the problem? • Has a similar problem occurred before (elsewhere) and how was this addressed?
Identify the cause of the problem	• Can a simple cause and effect be described? • Are there multiple causes? • Are there wider sediment problems within the catchment? • Are there other examples of this problem that can be referenced? • Is the problem related in any way to other engineering structures or management? • Have weather patterns (inc. unusual weather) had an effect? • Has a geomorphologist or other field scientist assessed the problem?
Describe why the bank protection is necessary	• What is at risk if the bank protection does not proceed? • Are there flooding issues? • Is infrastructure at risk? • Has an economic analysis being carried out? • How long is the solution expected to last? • Are there environmental benefits from the activity? • Can evidence be provided to support justification?

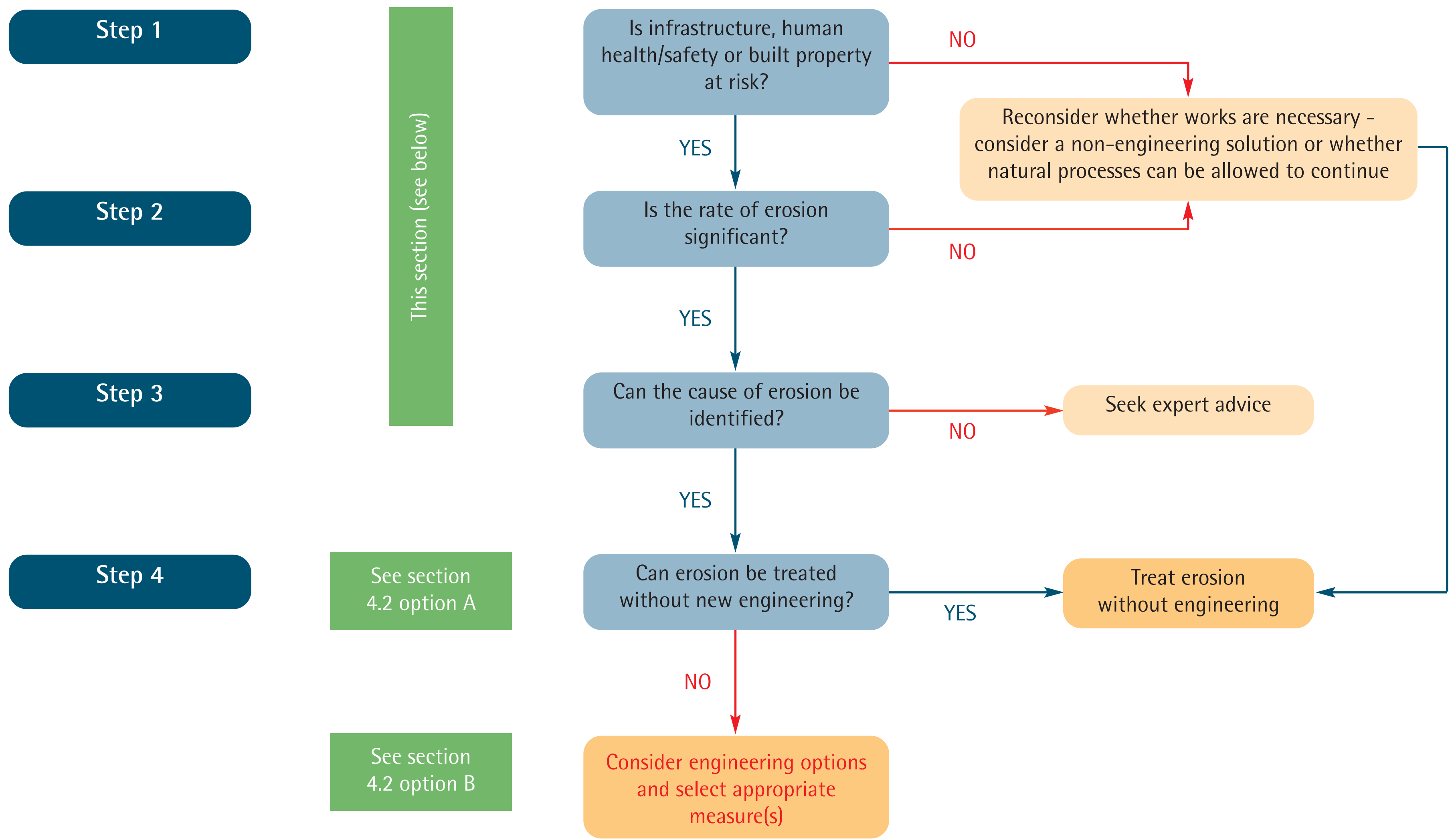


Figure 5 Steps to assess the need for new engineering

Step 1 – Is infrastructure, human health and safety or built property at risk?

Where infrastructure, human health and safety or built property is placed at direct risk from bank erosion (either naturally occurring or exacerbated by human activities), there will be a requirement to take steps to address the problem, either through erosion control or by redesigning or relocating a structure.

The option to redesign or relocate a structure is likely to be restricted to situations where previous experience has demonstrated severe difficulties using erosion control to manage the erosion, and where redesign or relocation is both a technically and economically feasible option.

Figure 6 Example of block stone being used to protect road from erosion

If there is no significant risk to infrastructure, human health and saftey, or built property, it will be necessary to re-consider whether engineering works are necessary. See 'Is the rate of erosion significant' (below) and GPG sheets 1 and 2 for more guidance.

Useful References for emergency works

WAT-PS-07_01 Position statement on emergency works, available at:

www.sepa.org.uk/wfd/guidance/engineering

Step 2 – Is the rate of erosion significant?

Where infrastructure, human health and safety or built property are not at risk, natural erosion processes should be allowed to continue (see GPG sheet 1). Where infrastructure, human health / safety or built property are at risk, the next step should be to identify the rate and the cause (see step 3).

Figure 7 Severe erosion

A good understanding of the rate and cause of erosion (i.e. how much bank is lost each year, and why) is a critical step in determining its significance and, therefore, whether bank protection is necessary. Erosion rates vary widely and they can suddenly accelerate naturally or due to human activity, so the rate of erosion should be assessed and Box 2 provides guidance on how to do this. It is also useful to know if the erosion is accelerating (Box 3) because this may provide a clue as to the cause and, therefore, the solution.

The decision over whether or not erosion is significant depends on the level of risk. This risk is site-specific, so it is only possible to provide very general guidance for when erosion becomes significant. Natural erosion rates vary widely within and between rivers, so whether the measured rate is significant or not depends on the context (including river type) and on the risk posed to infrastructure, human health and safety or built property. For example, an erosion rate of 0.5m per year on a stable, lowland river may be considered to be severe if the rest of the river is stable and a house is at risk. The same erosion rate in a remote, high-energy river, which changes position much more rapidly, may be seen as moderate or even low. It is therefore important to consider the context of your erosion and what is at risk when deciding whether or not erosion is significant. Where erosion control is necessary, the rate of erosion can also be a useful for guiding selection of an appropriate response (see Step 4 in Figure 5).

Box 2 Appropriate techniques to assess the rate of bank erosion

Rates of erosion can be determined from photographic surveys or from direct measurements. A fixed point of reference should be used to allow the rate of erosion to be tracked over time. As rates of erosion are linked to flow and weather conditions, erosion should ideally be tracked over a number of years or seasons.

Points to remember when assessing rates of erosion-

- Always identify a fixed reference point to track rates of erosion.

- If photographs are being used to track rates of erosion, ensure all photographs are adequately named and dated.

- Rates of erosion are often higher during and after high flow events. It is therefore important to assess erosion over a period that is long enough to measure rates of erosion over a range of flow conditions. If possible, try to assess the rate of erosion immediately after a high flow event, and note down the date and height of the flood.

- If possible, try and keep a record of flow or rainfall between each assessment, e.g. X number of high flow events, or 'uncharacteristically dry period'.

As a rough guide, if the erosion is happening more than one channel width from the object or activity at risk, or erosion is thought to be a few centimetres per year, you should first consider monitoring the rate of erosion rather than taking immediate action (see GPG sheet 1).

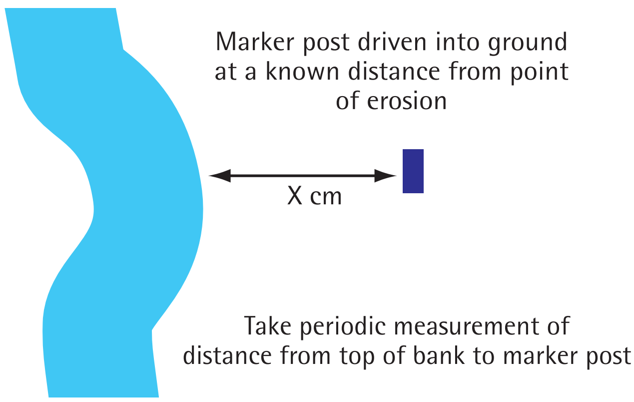


Figure 8 Using erosion markers

Using erosion markers

Fixed markers can be used to track rates of erosion. Typically makers are wooden or metal stakes driven into the ground adjacent to the river.

The marker should be placed at a known distance from the channel. Periodic measurements at sensible intervals of the distance from the marker to the top of the bank should then be made.

Remember to locate the marker at a distance that ensures it is not washed into the channel

Box 3 Assessing whether erosion is normal or accelerated

Some indicators of normal bank erosion

- Erosion on the outside of meander bends, perhaps with bank collapse
- Some vegetation establishing itself and / or growing on eroded faces
- Localised scour of finer sediments at the toe of the bank
- Scour around tree roots where the bank line has not retreated back from treeline;
- Evidence of historic bank collapse that has stabilised and re-vegetated

Where erosion is part of a naturally occurring cycle of river processes, efforts should be made to allow the erosion to continue (see GPG sheet 1).

Figure 9 Examples of natural erosion

Some indicators of accelerated bank erosion

- The erosion rate is significantly greater than that happening on comparable rivers
- A recent and sustained (for months or years) increase in the rate of erosion
- On eroded faces, vegetation is no longer establishing where it grew previously
- Opposite banks are eroding for long sections
- The channel is getting wider, or is already much wider than adjacent reaches
- There is evidence of the channel eroding it bed (cutting down vertically) e.g. a lack of gravels in the bed, exposure of underlying clay or bedrock, or undermined structures (e.g. bridge foundations).
- Lots of sediment has accumulated in the channel at the site of the eroded bank(s)

The cause(s) of accelerated erosion should be investigated. Where possible accelerated erosion should be allowed to continue if there is no risk to humans, infrastructure or valuable resources (see GPG sheet 1).

Step 3 – Identify the cause and type of erosion

Bank erosion can be caused naturally or by human activity. Natural erosion varies between river types, with the higher-energy upland and transitional type rivers most likely to have naturally-caused erosion. Also a variety of factors can trigger new erosion, or increase existing erosion rates ('accelerated erosion'; BOX 3). Natural causes like flooding, a meander cutoff or trees falling into the river can trigger dramatic and sudden changes in erosion. Human activity – such as changes in bankside vegetation or introduction of livestock on the banks or structures into the river – can also trigger or exacerbate erosion.

Figure 10 Erosion caused by livestock trampling

Figure 11 Erosion displaced to the end of a structure

Sometimes the resultant erosion is temporary; in other instances it may become prolonged. Therefore, diagnosing the cause(s) of erosion is critical in order to identify an appropriate solution. Some causes are easy to identify but in other instances there may be multiple interacting causes, and identifying which one(s) are most important can be difficult. Also, banks are often affected by more than one type of erosion. Identifying the types of erosion can help identify the causes. An understanding of the type of erosion can also aid selection of appropriate control measures. There are three broad types of bank erosion:

- Bank scour (typically at the bank toe);
- Whole bank collapse; or
- Direct impact

The type, characteristics and potential human causes of erosion are described in Figure 12. More detailed guidance on the type of erosion is provided in Appendix 2.

A field visit to investigate and record the erosion can be used to help identify what its extent, type and cause may be. For guidance on how to do this, see Appendix 3, which describes the structure of a simple field survey.

It may not be readily apparent what the type or cause of erosion is. In this case you should seek advice either from an experienced river geomorphologist, or from local conservation groups who may have background knowledge of the river.

Step 4 – Can erosion be treated without new engineering?

When infrastructure, human health / safety or built property are at risk, and the erosion rate is significant, and you have identified the type and likely cause of erosion, you will be able to identify what type of treatment is likely to be needed. Section 4 (below) provides guidance on whether or not new engineering is needed to treat the erosion.

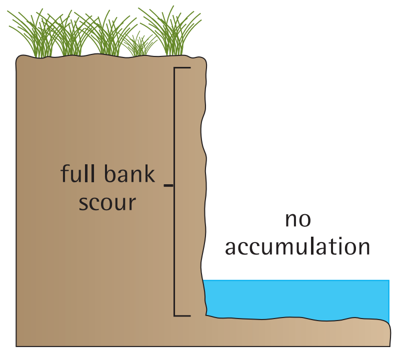
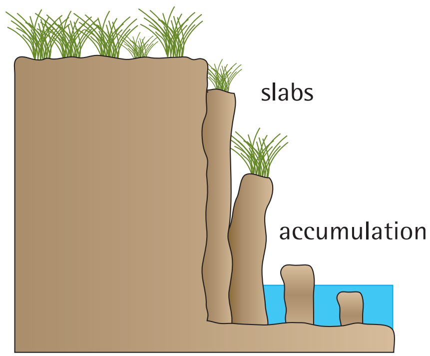
TYPE OF EROSION	NATURAL CAUSES AND CHARACTERISTICS	HUMAN FACTORS CONTRIBUTING TO EROSION
	• Bank material is removed directly by water • Most pronounced where banks are composed of loose material (sands, gravels). Natural scour is common on the outside of bends. • Rates of erosion typically increase during periods of higher flows, and then return to slower rates. • Anything that increases or directs flow into the banks can increase erosion, for instance trees falling into rivers can cause localised scouring. • Several sub-types (see appendix)	• Introduction of engineering structures can deflect flow onto and around structures, causing increased erosion. • May be caused by a loss of sediment supplied from upstream (e.g. due to bank protection) • Increased high flow events, caused by alterations to land drainage, flood control structures. • Wave action generated by boats or wind • Loss of natural riparian vegetation (reduces bank strength).
	• Blocks of material collapse under their own weight • Often caused by scour at the bank toe • Can also be caused by waves • Also caused by saturated banks (after rain or flood) • Most common on cohesive banks (i.e. rich in clay) • Exacerbated by high banks (from bed lowering or channel movement into terraces) • Exacerbated by freeze-thaw cycles. • Although bank failure can appear concerning, banks are often quick to re-stabilise. • Several sub-types (see appendix)	• Any human impact that increases toe scour • Change to the height of the stream bed (e.g. from dredging or gravel extraction) • Saturation of banks from off stream sources • Loss of natural riparian vegetation (reduces bank strength). • May be caused/ accelerated by boat wash
	• Bank material is eroded directly by other means • Includes cattle trampling, recreation, vehicle access, and burrowing.	• Livestock management • Vehicle access to the river and banks • Recreational access to river and banks

Figure 12 Common types of bank erosion. See Appendix 1 for more information

4. Making a decision

4.1 Introduction

The guidance provided in this section is applicable to situations where it is not possible to allow natural processes (do nothing) or to monitor the situation.

A basic principle of good practice is to consider a range of alternatives in addressing an identified problem or need. There are often multiple solutions to a river engineering problem or need. Without consideration of these alternatives it is not possible to determine if the approach represents the best practical environmental option. This section will provide information on relevant engineering options and will provide guidance to help applicants select the most suitable and sustainable type of bank protection.

4.2 Alternative approaches

There are two broad options for erosion protection:

Option A: use a solution that does not need engineering

Option B: use an engineering solution

Within each strategy there is a variety of approaches. The response to bank erosion may involve more than one strategy or approach, so the best response may involve combining engineering with other methods. For example, this may include using branch packing to restore a bank that was eroded by cattle poaching (an engineering activity) and then fencing it to create a riparian buffer strip and control cattle access (a non-engineering solution).

Option A: use a non-engineering solution

There are many good reasons to avoid un-necessary engineering (Box 4). Therefore, where there is a demonstrated need for erosion control, the first step is to assess whether this can be achieved without engineering. This can be done by managing the cause of the bank erosion (either controlling a particular activity, altering riparian management, or developing a catchment plan to address wider causes such as changes to discharge). Managing the cause is likely to be useful in combination with other options.

"Before pursuing an engineering activity, SEPA will expect applicants to consider options that do not require introduction of new engineering structures."

Engineering may NOT be needed to manage the following causes of erosion:

- Boat wash – control the activity
- Tree fall – manage trees appropriately
- Invasive species – remove and re-plant with appropriate species
- Livestock access (poaching) – control/ restrict access
- Burrowing – control animals
- Recreational use – control/ restrict access
- Scour around a redundant structure – remove

Figure 13 Cattle trampling causing erosion. Controlling Cattle access would be appropriate.

Box 4
Possible impacts of unnecessary bank protection works

- ✗ Failure of bank protection requiring further, potentially costly, works;
- ✗ Initiation of erosion downstream or on the opposite bank;
- ✗ Scouring of channel bed and undermining of bank protection;
- ✗ Habitat damage at an existing reach or downstream; and
- ✗ Loss of habitat and vegetation during construction works;

Benefits of seeking a non-engineering solution

- ✓ Normally no requirement to obtain SEPA license for works
- ✓ Often cheaper
- ✓ Often have greater aesthetic appeal
- ✓ Often better for river ecology
- ✓ Likely to be more sustainable and require less maintenance
- ✓ Grants may be available to undertake works

Having trouble determining whether a non-engineering solution can be adopted?

Seek advice form an experienced geomorphologist (Typical cost £400 per day). Alternatively, contact a local conservation group. **Remember** where a non-engineering solution is used, there will normally be no requirement to obtain a CAR license (except where structures are removed from the river – these licences are subject to discounted charges).

Option B: engineering solutions

Where there is a demonstrated need for protection, and controlling the cause of the erosion is not enough to solve the problem, engineering will be necessary. Remember that engineering and non-engineering solutions may provide the most effective erosion control. Combinations of options should therefore be considered.

STOP!

Have you considered a non-engineering solution? If not, see options A.

"The type of bank protection used should be appropriate and proportionate to the type, location and rate of erosion, as well as the property, infrastructure or resources at risk."

Erosion can be controlled with different engineering techniques. For example, where a road or footpath is threatened by bank erosion, the problem could be solved by:

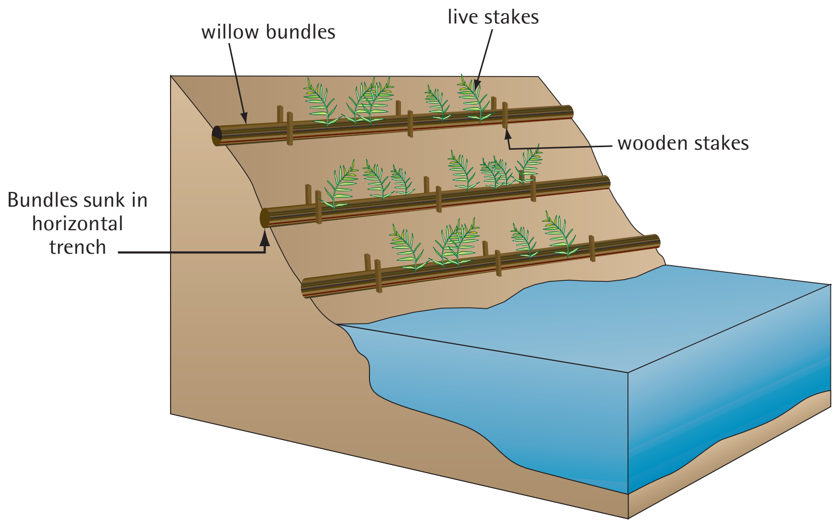
- hardening the bank-line to prevent future erosion,
- placing structures in the river to divert flow away from the bank-line, or
- moving the road or footpath away from the rivers edge, or in extreme cases;
- moving the river away from the road or footpath.

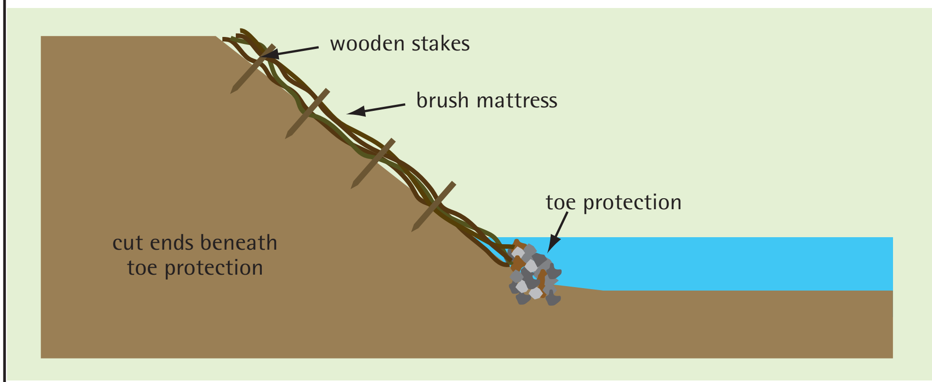
And within these approaches there are a number of ways the solution could be achieved; for example instead of using a concrete structure, it would be possible to re-profile the bank, stabilise it with biodegradable geotextiles, and plant to ensure long-term stability.

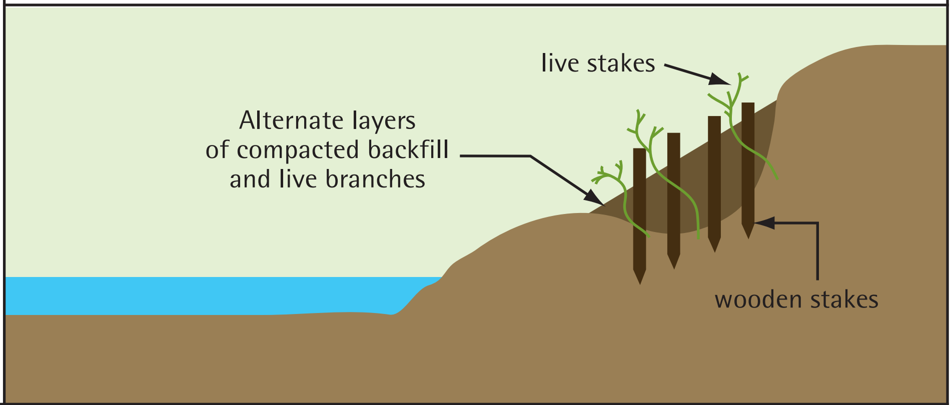
SEPA define two categories of engineering for bank protection: green and grey. Green options involve engineering with biodegradable or living materials or un-mortared rip-rap restricted to the bank toe only. Grey engineering involves major bank modification, often using artificial materials. Table 1 lists the most common types of bank protection.

The causes of bank erosion and the methods of protection are highly variable, and Table 1 and Figure 14 provide guidance on selecting appropriate bank erosion measures.

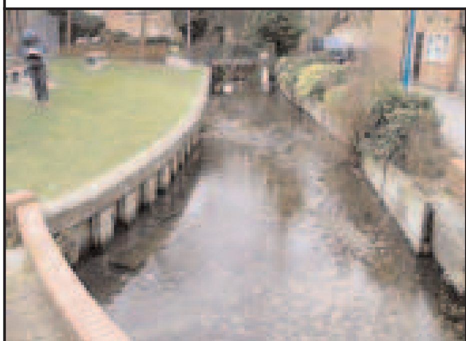
Table 1 Methods of bank protection using green and grey engineering and in-stream structures.

Green Bank Protection Techniques	
Technique	**Short description**
Brushwood bundles	Bundles of untreated brushwood are bound together and used to stabilise banks. The wood may be live (and likely to root, such as willow) or dead (often hazel or chestnut is used). The bundles are usually set into shallow trenches on the river bank, parallel to the direction of flow. The bundles slow the flow of water and trap silt and sediment. Coir rolls (see biodegradable geotextiles) may be used in place of brushwood bundles.
	
Woven stems	Woody stems woven into a vertical fence provide physical protection against fast-flowing water. These may be live or dead. If placed or constructed within the channel these form a type of temporary flow deflector.
	 *Photo courtesy of Salix RW* 
Biodegradable geotextiles	Biodegradable geotextiles are meshes or rolls of natural fibre that protect and stabilise the riverbank while allowing vegetation to grow through. Materials used for geotextiles vary, but coir is often used. Coir is the stiff fibre from the outside of coconuts. It can be woven and pressed into many shapes including rolls (which are usually compressed into a relatively solid matrix), and matting of various thicknesses. Biodegradable geotextiles are often used as a rooting base for marginal plants. They can be used in conjunction with re-vegetation schemes to aid rapid re-establishment and thereby to stabilise an eroding bank, and are also placed under hard revetment to prevent bank material being washed out (soil outwash). NB: Non-biodegradable geotextiles are classed by SEPA as grey engineering.

Green Bank Protection Techniques (cont'd)		
Biodegradable geo-textiles (cont'd)		Biodegradable geotextiles – matting and rolls before vegetation growth. Photo courtesy of Salix RW.
Brushwood layering	Brushwood layering can be used to stabilize a slope against shallow sliding. Cut branches are interspersed between layers of soil on either cut slopes or fill slopes. The branches may be live or dead.	
Brushwood mattresses	A thick layer of branch cuttings are installed to cover and physically protect stream banks. The mattresses are effective at trapping fine sediment during flooding, and work well on a wide range of steep banks and fast flowing streams. 	
Green Toe protection	Un-mortared rock, untreated timber or other green materials placed or anchored at the foot of the bank below the normal low-flow water level to protect against toe scour. Stone pitching (see grey techniques) are considered as green if they protect the toe only. See above for diagram.	
Reprofiling	Involves excavating and / or filling the raw eroded stream bank to a low gradient slope without either increasing the bank height or the channel width. Use of natural materials (locally sourced earth / vegetation / surface protection as above) only.	
Root wads	Tree trunks with the roots attached pushed into the bank (trunk first), with the roots exposed. The roots increase bank roughness and therefore dissipate the water energy, sheltering the bare banks. However, they could also create scour due to local turbulence.	

Root wads (cont'd)	  Root wads being installed (left) and after emplacement (right). *Photography courtesy of Salix RW*
Branch Packing	Technique in which alternate layers of compacted backfill and branches are used to fill holes in stream banks. The branches may be live or dead. 

Grey Bank Protection

Technique	Short Description
Retaining Walls	**Concrete** Concrete walls are usually massed structures reinforced with steel. Their durability depends on the composition (cement content and aggregate size/shape/grading) and design. The sharp edges found on many concrete structures (e.g. sides or toe) are prone to hydraulic scour. Concrete structures are significantly weakened if the internal reinforcement corrodes due to exposure to water and air. Concrete will last for decades under most circumstances but will need to be periodically checked for deterioration or undermining.  Gravity walls, masonry, concrete, timber and sheet piling in an urban setting **Masonry** This usually involves a vertical, hand-laid wall. Engineering bricks (resistant to sulphate attack) with strong lime-free mortar should be used.

Retaining walls (cont'd)	**Gabions** These are stone-filled mesh structures used to reduce water velocity through friction, which leads to the dissipation of erosive energy. Gabions, are square or rectangular wire cages filled with stone, which can be stacked vertically.
	Piling Sections of profiled interlocking metal (normally steel) or plastic or regular section sawn timber driven vertically into the bed of the river, creating an artificial bank surface. Piling normally acts as a support or retaining wall to riverbanks as well as providing protection against erosion.
	Timber walls Full face placement of timber pilings, stakes or boards placed along the bank. The woody material should be untreated.
Reinforced earth	Compacted soil sandwiched between folded layers of geotextile. The layers are usually pinned into place. These can be used to create steep, erosion-resistant banks that will become vegetated. Retaining walls can also be constructed using geotextile bags filled with soil and pinned together. Seed can be mixed into the soil before placing to encourage vegetation establishment.
Stone Revetments	**Rock armour ('rip-rap')** Large fragments of quarried rock placed on riverbanks. This is a durable technique that can be used for banks that are exposed to high water velocities. It can be designed to allow self-adjustment of the bank slope.
	 Rock armour
	Hand pitched stone A traditional technique using un-mortared stone to create a sloping wall. If the toe is not being scoured and undermined and the bank is stable (i.e. not washing out from behind the stone), pitching can last for decades. It is usually used at the bank toe, with trees to protect the upper bank.
	Grouted revetment Grouting individual blocks of stone or brick can be used to incresae the stability of the protection, leading to a more monolithic structure. It often reduces the permeability of the bank surface, so drainage must be considered to avoid undermining. Bricks and cement, if used, should be the same as for masonry.
	 Grouted (and failing) revetment on a loch shore.

	Gabion mattresses ('Reno mattresses') Gabion mattresses are shallow wire cages filled with stone that are thin enough to make a structure that can be laid on a shallow bank or at the bank toe.
	Gabion tubes ('Rock rolls') Flexible gabions are rock-filled tubes or bags of various shapes. The tubes or bags are usually made from a non-biodegradable metallic mesh sometimes coated with plastic.
	
	Gabion tubes filled with rock – *photograph courtesy of Salix RW*
Concrete Revetment	Concrete revetments come in a variety of forms and can even be used to mimic the shape of natural materials such as cobbles or boulders. Massed concrete structures are often reinforced internally with steel. The durability of concrete depends on its composition (cement content and aggregate size/shape/grading). Concrete structures are significantly weakened if the internal reinforcement corrodes due to exposure to water and air. Concrete will last for decades under most circumstances but will need to be periodically checked for deterioration or undermining.
Non biodegradable geotextiles	Meshes, fabrics and mats made from synthetic material that are designed to stabilise soils. They come in various forms. Those with larger voids are designed to allow vegetation to colonise the exposed surface.
	 Non biodegradable geo textiles. *Photo courtesy of Salix RW.*
Other Techniques	
Current Deflectors	Current deflectors deflect the main flow path in the channel away from the eroding bank. This has two potential advantages. Firstly the erosive power of the flow should be deflected. This leaves a lower energy area behind the deflector where sediment may accumulate, which further reduces flow velocities at the bank.

4.3 Selecting options

Once all the alternatives have been evaluated the best practical environmental option should be chosen. This does not always mean adopting a soft engineering approach. The best practical environmental option means choosing the approach that effectively addresses the problem or need and minimises negative environmental impact as far as practical. It also has to be cost effective (see box 5) and achievable. This section will guide you in making this choice, but each site is different so it is necessary to undertake an appropriate assessment of the site characteristics before deciding on a solution. If there is uncertainty about the site, the cause, or what solution is appropriate, get advice from an expert (experienced river geomorphologist and/or hydraulic engineer).

Box 5 Proportionate cost

The most cost effective solution should be sought; this is the one that minimises environmental harm or maximises environmental benefit at a proportionate cost. Large absolute cost in itself does not constitute disproportionate cost. For example: Incurring significant costs to prevent significant environmental harm or achieve significant gain would be considered proportionate; however incurring significant cost for minor environmental gain would be considered disproportionate and not cost effective.

Figure 14 can be used to guide you to a decision on what type of erosion protection to use. Remember that there may be more than one option, and it is important to consider all of these. This may involve comparing the suitability of multiple options and/or combinations of options. For instance, the best way to control erosion could be to use toe protection on the bank toe zone and geotextile matting on the upper bank zone. Also, in some instances, a non-engineering solution could be coupled with one of the engineering solutions described in Table 1, for instance toe protection and vegetation management. Using non-engineering solutions where possible will make the process faster and less expensive, as well as providing environmental benefits.

Box 6 Useful points to consider when choosing bank protection:

Consider Maintenance – How often will a structure have to be replaced, or how often will an activity need to be repeated? Projects that work against natural processes often result in high maintenance. Has this cost been built into consideration of alternatives? A project which takes account of natural processes such as sediment movement could avoid or reduce these costs.

Respect Channel Form – Natural, un-modified channels are a particular shape for a good reason. They represent a long-term balance between the forces of water flowing downhill and resistance caused by sediment and vegetation. Any project that significantly alters channel form (i.e. width, depth, slope, planform) will affect the natural balance in the river with consequences for erosion and deposition of sediment. Always encourage options that accommodate natural river form.

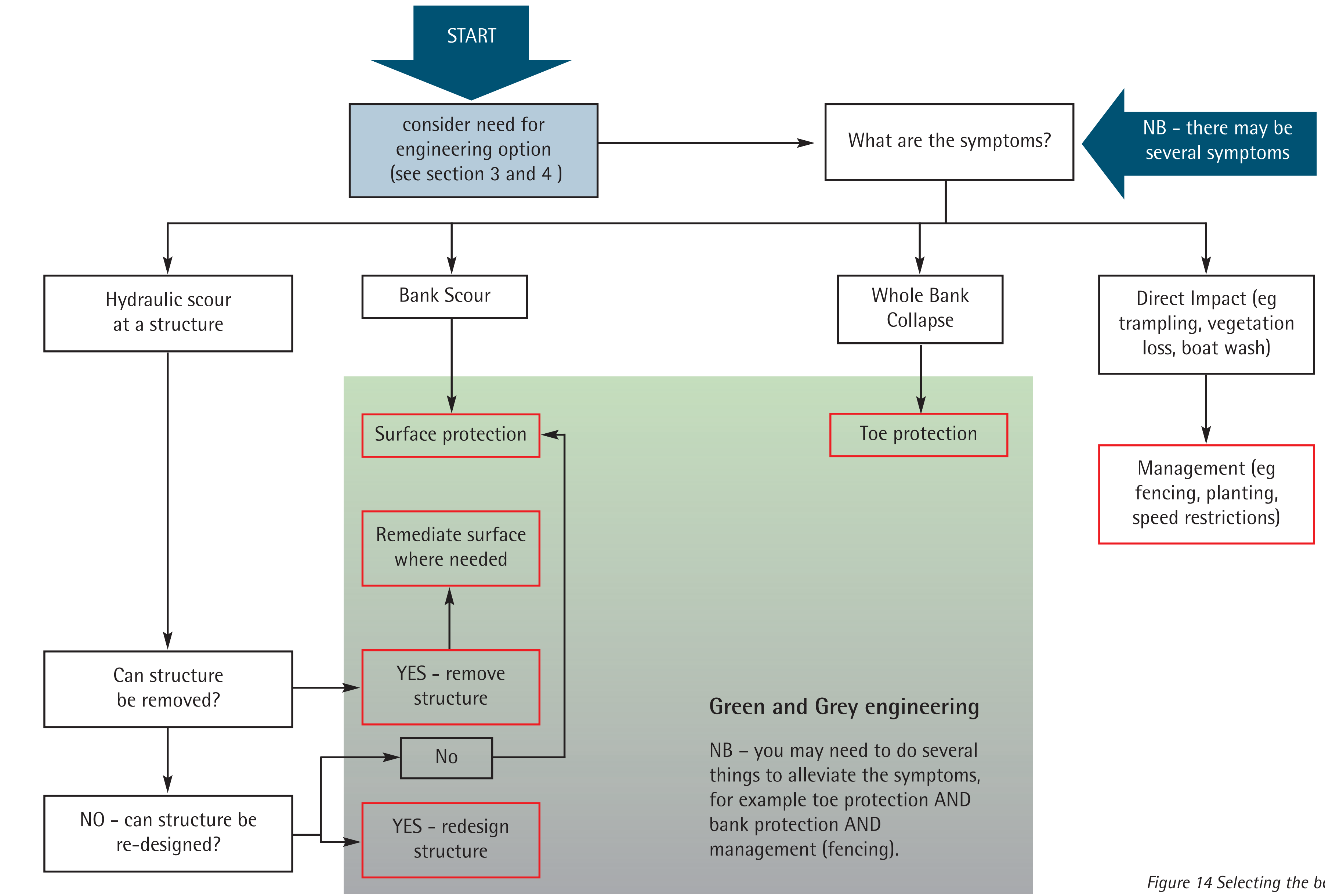


Figure 14 Selecting the best option

5. Design, implementation and monitoring

5.1 Introduction

Design, implementation and monitoring are the key to getting a solution to bank erosion that is the best practical environmental option. Engineering should only be undertaken when (a) there is a demonstrated need, based on a clear and sound understanding of the type and cause of erosion; and (b) appropriate knowledge and expertise is being employed. Each site and technique is different so the principles within the following sheets should be used as a guide, not a detailed design manual.

5.2 Good Practice Sheets

The following Good Practice Sheets provide guidance on when and how to remedy common causes of bank erosion, with and without the introduction of new engineering. The sheets should be used in combination with the information provided in Section 4 and the following situations are covered:

GP sheet	Option type
1 – Allow processes to continue	Allow natural processes / do nothing
2 – Riparian buffers and management	A - Non-engineering solution
3 – Structure removal	B - Engineering solution
4 – Green bank protection	B - Engineering solution
5 – Grey bank protection	B - Engineering solution

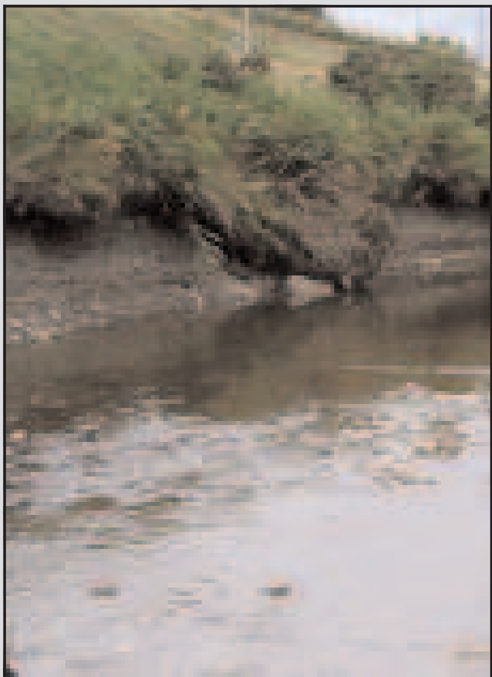
Good practice guide to construction methods

For more information on good construction practice, please see WAT-SG-29 Good Practice Guide to Construction Methods.

Good Practice Sheet: 1 – Allowing natural processes

Rationale

Allowing natural processes to happen gives the river room to move, and allows natural adjustment. In some cases this means doing nothing for existing erosion, which means no capital or maintenance costs. In other cases, the approach of allowing natural processes may follow the removal of an existing structure.



natural erosion

Key Features

- By allowing natural processes to continue, the river is given room to move
- Allows the natural development of habitats for flora and fauna
- Should be used where the cause of erosion is natural, or where the river is recovering from some form of past management.
- Unlikely to be appropriate where the river has de-stabilised very significantly, for example where the river is very incised and this incision is working upstream.
- This approach should be adopted if putting in structures to prevent erosion are likely to make the original problem worse
- If the rate of erosion is high, it should continue to be monitored
- It does not threaten human health, infrastructure or valuable resources

Benefits	Potential impacts/problems
• Best environmental option • Working with nature – most sustainable • Least expensive option	• Erosion is often seen as a negative process, so riparian owners may be resistant to the principle of letting it continue • May result in loss of land • Not appropriate where erosion is threatening human health, infrastructure or valuable resources

Further Reading

- Environment Agency Waterways Bank Protection Guide (R & D Publication 11) Version no. 1.
- Integrated Streambank Protection Guidelines 2003 – Washington State Aquatic Habitat Guidelines Program. Washington State Department of Fish and Wildlife (WDFW).

Good Practice: 2 – Riparian management

Rationale

Changing riparian management and use can reduce or solve erosion without using new engineering.

Riparian management

Various forms of riparian management can help control erosion. Fencing or hedging the bank creates a riparian buffer strip. This helps prevent direct bank erosion through cattle trampling or human access. Vegetation may establish naturally or it may need to be planted. Mature vegetation also stabilises banks and prevents erosion. Buried fencing can also help to reduce the erosion caused by burrowing (e.g. of rabbits). Other forms of management may involve re-planting the bank with grasses, shrubs or trees, removing invasive species, or management of trees or fallen timber.

Fencing used to manage access

Installation

- Buffer strips should be wide enough to allow for natural channel adjustment. This will depend on channel type and activity. As a minimum, on a loch or on stable parts of a river the boundary or fence should be set back from the top of the bank approximately the same distance as the height of the bank. On more active parts of a river the boundary should be set back further.
- The type of boundary should be related to its purpose, i.e. dependant on the type of livestock, vehicles or recreational use that is being restricted.
- Fences or hedges should be installed parallel to the flow direction where possible. Where boundaries cross the river, they should be designed to allow movement of debris and sediment. Crossings should therefore be made on stable, straight sections of river if possible. To allow the downstream flow of debris and sediment, a simple swing gate may be needed.
- Planting of appropriate native vegetation may be necessary – this may include grasses, shrubs and trees. Removal of invasive species, such as Japanese Knotweed, may also be needed.

Key Features

- Riparian buffers restrict access and therefore reduce direct erosion (e.g. by recreational access or by poaching).
- Planting or encouraging the growth of other natural riparian vegetation may be necessary, and fencing is likely to be needed for good growth
- Mature riparian vegetation can significantly stabilise and protect eroding banks from scour, reducing bank erosion.
- Mature riparian vegetation can act as filters, reducing the amount of sediment that gets into the river from surrounding land
- Tree removal can help some problems such as erosion from tree fall, but should be kept to a minimum
- Coppicing can stimulate root growth, significantly strengthening the bank
- Removal of invasive species and replacement with native species is likely to increase bank strength and reduce erosion
- Allowing timber from mature trees to fall into the river can help

Maintenance

Fencing and hedging will require maintenance visits. Short term-management may be intensive, but this should decrease in the long term. The rate of bank erosion should be monitored to assess effectiveness.

Design Life

A typical timber post and wire riverside fence can last between 10-20 years if maintained properly. A well-established hedge and buffer strip can last for hundreds of years.

Costing

Fencing: around £10 per m, not including installation. Higher costs if electric fencing is used.

Good Practice Sheet 2: – Riparian management (cont'd)

Benefits	Potential impacts/problems
• A well-managed, mature buffer strip can provide significant natural bank protection. • Involves minimal disturbance and reduces future disturbance of bankside habitat. • A well developed riparian buffer strip will promote sediment storage and facilitate filtering of pollutants from overland flow. • May contribute to improved health and safety conditions for livestock. • Timber fall from the established riparian zone can improve in-channel habit. • Plant cover increases hydraulic roughness on channel banks and floodplains, slowing flow velocity and reducing scour. • Provides good habitat	• If placed too close to an eroding bank, fencing may be undermined. • Fencing materials may be costly and are labour intensive to install. • Riparian vegetation may not readily colonise sandy/gravel banks. • Where invasive species are present, they are likely to colonise the fenced off bank and benefit from reduced grazing pressure. • A management plan and regular maintenance is likely to be needed, but this should decrease as hedges and buffer strips reach maturity.

Further Reading

- Environment Agency Waterways Bank Protection Guide (R & D Publication 11) Version no. 1.
- Integrated Streambank Protection Guidelines 2003 – Washington State Aquatic Habitat Guidelines Program. Washington State Department of Fish and Wildlife (WDFW).
- SEPA Riparian Vegetation Management Good Practice Guide

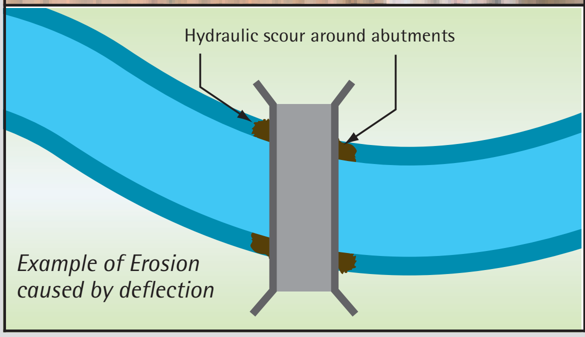
Good Practice Sheet: 3 – Structure removal and re-design

Rationale

Some structures cause scour of the bed or banks. Removing or re-designing them to a more appropriate form may cost the same as, or less than, new bank protection engineering.

Erosion downstream of bank protection

In this example, there is scour at the end of bank protection. The main issue with this stream is that it has excess energy to scour the banks. Protecting a section of bank will therefore move the problem elsewhere. It may instead be better either to remove this structure and allow monitored erosion to see if the channel becomes stable, or to re-design the structure so that it dissipates more energy.



Erosion caused by scour at a Structure

Structures built on the banks of rivers (for instance bridges, or existing protection) can be prone to local scour around their foundations. Local scour is the removal of sediment around the base of a structure caused by the erosive action of flowing water on the bank/bed material.

Situations where a structure could be removed	Situations where a structure should not be removed
• Where the structure can easily be removed and the impacts of doing so will be less than leaving it in place • The structure is causing erosion or deposition • The structure is derelict or is in a state of disrepair, for instance old bank protection works or croys • The structure no longer serves a purpose • The structure is not meeting its intended purpose • The costs would not be prohibitive • The damage caused during or after removal can be adequately mitigated.	• If the structure is embedded in the bed or banks and would cause greater disruption than the proposed bank protection • If the structure controls the bed level (shown by a significant change in channel bed level (water level) upstream and downstream) • If the structure has an existing function that cannot be removed or changed • Prohibitive cost • The structure is required and redesign would be technically unacceptable; and • Removal would involve in-channel works which could cause longer term damage.
Situations where a structure could be re-designed	**Situations where a structure should not be re-designed**
• The structure is needed but it is causing a negative environmental impact • The re-design minimises negative environmental impact • The cost of re-design is the same as, or less than, the cost of new works.	• The re-designed structure will still cause erosion (e.g. of adjacent channel bed) • The new design has not been made by an appropriately qualified individual.

Good Practice Sheet: 3 – Structure removal & re-design (cont'd)

Important considerations

When considering the removal of a structure it is important to assess the function of that structure and what impacts could occur if the structure were removed. A river system may have adjusted "dynamic equilibrium" due to the introduction of the structure. Removal of the structure may once again upset the equilibrium causing erosion or deposition problems which did not previously exist. Whenever removing or re-designing a structure, expert advice should always be sought (suitably experienced geomorphologist and/or civil/hydraulic engineer)

Benefits	**Potential impacts/problems**
• Removing the cause removes the problem • Removal is likely to benefit river ecology • A licence fee may not be required (see box below) • Potentially cheaper than other options (e.g. adding concrete walls to the edges of abutments)	• Structures should not be removed where they serve a particular purpose • Fresh sandy / gravely bank surfaces are unstable and may not be colonised quickly • Where invasive species are present, they are likely to colonise the new bank surface first • Care should be taken to ensure minimal bed and bank disturbance during removal works • Manifestation of erosion or deposition problems which did not previously exist.

Further Reading

- Environment Agency Waterways Bank Protection Guide (R&D Publication 11) Version no. 1.
- Integrated Streambank Protection Guidelines 2003 – Washington State Aquatic Habitat Guidelines Program. Washington State Department of Fish and Wildlife (WDFW).

CAR and Regulating the removal or alteration of structures

Although SEPA are required to issue a license for all engineering activities, including significant alterations to existing structures, there will be no license fee for activities that are considered an environment service. In many instances, rectifying or removing poorly designed structures, or altering river management practices would be considered by SEPA as an environmental service, and would not incur a license fee. Furthermore, grants may be available in the future to assist with activities that are deemed an environmental service.

Good Practice Sheet: 4 – Green bank protection

Rationale

Environmental impact can be minimised by using bank protection that covers the toe of the bank, or is made from natural and / or biodegradable materials.

Green bank protection

This includes techniques that are sympathetic to the environment, such as protecting the toe only, use of natural materials (e.g., brushwood mattresses), bank re-profiling (where the bank height is not increased) and biodegradable textiles. There are a wide variety of green bank protection methods, and new types are being developed, so the following is a general guide.

Green bank protection

Types of protection

- Surface protection (e.g. woven branches or brush; brush mattresses; rolls of living or dead brush; coir rolls or matting; re-vegetation using biodegradable geotextiles)
- Toe protection (woven branches; rock, logs or other materials resistant to erosive flows placed at the bank toe)
- Bank modification using soft methods (re-profiling without raising the bank height; filling holes with layers of branches, brush and compacted earth; increasing bank strength using root-wads)
- Channel modification using soft methods (temporary current deflectors to narrow the channel and promote sedimentation at the toe of the bank; emplacement of wood jams).

Installation

- Specialists will normally be needed to advise on materials and appropriate methods because each type of protection has subtle but important differences. For example, dead branches that are woven together should lie below the low-flow level, because they will rapidly break down in the air.
- Some of these methods are highly specialised – using root wads, for example, needs considerable expertise and equipment.

Maintenance

Variable, dependent on type. If vegetation is established as part of the protection, this may need infrequent management, such as thinning or pruning.

Design Life

Variable but typically more than 10 years

Costing

Variable: between £150 - £450 per metre, depending on type. Typically cheaper than hard engineering alternatives.

Good Practice Sheet: 4 – Green bank protection (cont'd)

Benefits	**Potential impacts/problems**
• Greater environmental benefit / less negative environmental impact than grey bank protection • Often cheaper than grey protection • Can be used in some high-energy environments • May provide a more sustainable solution than grey bank protection	• Specialists often needed for installation • Needs to be installed with due consideration for river type and energy, particularly if used in higher energy environments • For live branches or planting, a 'bedding-in' period is needed before vegetation is fully established. During this time the works are more susceptible to large floods • Not appropriate in some circumstances (e.g. where eroding banks are appropriate and natural, and protecting the banks may lead to bed scour) • May need maintenance (e.g. vegetation thinning) • More susceptible than some forms of grey engineering to damage / failure in high-energy environments

Further Reading

- Watershed Science Institute. Stream Bank Protection and Restoration. www.wsi.nrcs.usda.gov/products/urbanbmps/stream.html
- Riparian Vegetation and Fluvial Geomorphology (Bennett S.J. and Simon A., 2004).
- Hoey, T, Smart, D, Pender G and Metcalf, I (1995). Alternative Methods of River Management for Scottish Rivers. SNH
- RSPB, NRA and RSNC (1994) The New Rivers and Wildlife Handbook. RSPB, Sandy.
- Rootwad Composites for Streambank Erosion Control and Fish Habitat Enhancement. Traci Sylte and Craig Fischenich, May 2000. (http://el.erdc.usace.army.mil/elpubs/pdf/sr21.pdf)
- A rehabilitation Manual for Australian streams (Cooperative Research Centre for Catchment Hydrology and Land and Water Resources, 2000).
- Waterways Bank Protection Guide (R & D Publication 11) Version no. 1.
- BTCV (1987) Waterways and Wetland – A Practical Conservation Handbook. British Trust for Conservation Volunteers, Oxon

Good Practice Sheet: 5 – Grey bank protection

Rationale

Grey bank protection may be required where human health, infrastructure or valuable resources are at risk. It usually represents a strong engineering structure that solidly defends a particular section of river bank. However, this strength often means significant environmental impact – either directly, through loss of natural banks, or indirectly, as this type of protection interferes the most with natural river processes.

Grey bank protection

This includes any type of full bank protection made of artificial or non – biodegradable materials. This includes geotextiles made of plastic or other non-biodegradable materials. Installing grey bank protection often requires specialist knowledge, and appropriately experienced individuals should undertake the work (e.g. civil or environmental engineers).

Types of protection

- Vertical structures
- Revetments
- Flow deflectors.

left: Grey bank protection for bridge abutments

Installation

By specialists (e.g. civil engineering contractors).

Design Life

Variable, depending on circumstances, but often long-life (several decades).

Costing

Variable, but typically more expensive than other methods.

Maintenance

Variable depending on the structure. Will usually need maintenance in the long term (decades) to ensure structural integrity.

Should be designed to have minimal impact on sediment movement to minimise ecological damage and sediment maintenance.

Good Practice Sheet 5 – Grey bank protection (cont'd)

Benefits	**Potential impacts/problems**
• Most robust type of bank protection • Can be used in confined spaces.	• Major direct environmental impact – loss of bank habitat, disturbance to and loss of bed habitats; disturbance to hydraulic habitats; loss of bank vegetation; potential for scour at the edges (base and sides) of the structure • Major indirect negative environmental impacts: may starve downstream reaches of sediment or deflect flow to another area (e.g. channel bed or opposite bank); may cause unnecessary or unusual sedimentation, disrupting habitat dynamics • May de-stabilise the channel leading to major impacts elsewhere • Generally more expensive than other types of bank protection.

Further Reading

- R W Hemphill & M E Bramley, CIRIA (1989), Protection of River and Canal Banks
- Environment Agency (1999) Waterway bank protection guide, Environment Agency, Bristol.
- Hoey, T, Smart, D, Pender G and Metcalf, I (1995). Alternative Methods of River Management for Scottish Rivers. SNH

5.3 Post project appraisal

After the engineering is installed, you should undertake post-project appraisal and, if necessary, site management (Boxes 7-9). This will help identify if there are any problems that can be investigated and addressed at an early stage.

Box 7 Post project appraisal and site management

Frequent inspection and maintenance of project sites is required to ensure that damage that occurs can be repaired before it progresses to major failure. The following points summarise the suggested appraisal methods:

- All projects should be inspected at reasonable intervals and at least annually. New projects should be inspected after the first major high flow or series of high flows.
- Ground photos should be taken periodically at established points. Photos should be taken at least twice a year, ideally in the spring and autumn. To allow comparisons among repeated photographs, they should be taken during low water periods and at corresponding water levels. If it is safe to do so, you may wish to take extra photographs during higher flows in order to record the performance of the engineering.

Box 8 Post project appraisal after planting

The development of the vegetation should be monitored and correlated, at least visually, to the degree of or lack of erosion occurring on the treated streambank.

Plantings are assumed to be effective if the vegetation is growing well in all bank areas, and ground reconnaissance suggests erosion is not occurring. The frequency of monitoring should be a minimum of once per growing season (preferably near the end of summer) for at least three consecutive years.

Box 9 Post project appraisal at bank protection structures

Most conventional bank protection structures fail because of undermining or washout of soil behind the structure. Care should be taken during design to present this happening e.g. bury the toe well below the bed and use geotextile to prevent washout. Careful inspection of the toe area can also help prevent failures by identifying damage before it progresses to failure.

Inspection of the toe zone should occur during low water periods, when the toe is more likely to be visible. Areas below the normal high water mark should be inspected for evidence of sediment movement along the toe or streambank erosion that could undermine the toe. The bank behind the struture should also be inspected for depressions which may indicate ground subisdence due to washout.

The following conditions may suggest a need for repairs:

- Areas of bare soil within the toe zone;
- Displacement of rocks or sections of rock within the toe zone;
- Scour along the toe that results in loss of support to the upper bank;
- Evidence of bed degradation (lowereing), or scour holes that might undermine the toe;
- Movement or loss of large rock protecting the foundation of walls, or movement (settling, tilt, or horizontal displacement) of the structure;
- Movement or deformity of the structure.

6. Sources of Further Information

6.1 Publications

Bennett S.J. and Simon A., (2004). Riparian Vegetation and Fluvial Geomorphology.

CIRIA (2002) Manual on Scour and Bridges and Other Hydraulic Structures. CIRIA, London

Environment Agency (1999) Waterway Bank Protection: a guide to erosion assessment and management. Environment Agency, Bristol.

Hemphill, R.W. and Bramley, M.E. (1989). Protection of river and canal banks. CIRIA, London.

Hoey T.B., Smart D.W. and Pender G., (1998) Engineering Methods for Scottish Gravel Bed Rivers.

Hudson, H.R., and Harding, J.S., (2004) Drainage Management in New Zealand: A Review of Existing Activities and Alternative Management Practices. Dept of Conservation, New Zealand.

Laing, S. (2003) Investigating the application and long-term performance of 'soft' riverbank protection techniques; 30 case studies from the Thames Region.

Morgan, R.P.C., Collins, A.J. and Hann, M.J. (1999) Waterway Bank Protection: a field manual. Environment Agency R & D Publication.

River Restoration Centre (1999) Manual of River Restoration Techniques.

Scottish Native Woodlands (2000) Restoring and managing riparian woodlands. Scottish Native Woods: Aberfeldy.

SEPA, SNH and WWF Scotland (2000) Farming and watercourse management - A good practice handbook, Written and produced by V. Wood-Gee, Hay Nisbet Press

Thorne C.R., Seed S. and Doornkamp J.C., (1996), A Procedure for Assessing River Bank Erosion Problems and Solutions.

Washington State Department of Fish and Wildlife (2003) Integrated Streambank Protection Guidelines 2003. Washington State Aquatic Habitat Guidelines Program. (WDFW).

Werritty, A., and McEwan, L.J. (1997) Fluvial Landforms and Processes in Scotland. In: Gregory, K.J. and Hooke, J.M (eds) Fluvial Geomorphology of Great Britain. Chapman and Hall, London.

6.2 Websites

Adopt-a-Stream Foundation
Habitat Assessment and Culvert Analysis
www.streamkeeper.org/habitat/Assessment.htm

BTCV (British Trust for Conservation Volunteers)
Online Handbooks, Waterways and Wetland
http://handbooks.btcv.org.uk/handbooks/index/book/87

International Focus Group on Rural Road Engineering
Causeways Information Note
www.ifgworld.org/subsites/documents/document_view.asp?title=Causeways&siteid=1&id=91

Ohio Department of Natural Resources
Division of Water Stream Management Guidance
www.dnr.state.oh.us/water/planing/streams/aboutstrm.htm

Stream Systems Technology Centre
Culvert Case Studies
www.stream.fs.fed.us/fishxing/case/Mynot/

Watershed Science Institute
Stream Bank Protection and Restoration
www.wsi.nrcs.usda.gov/products/urbanbmps/stream.html

7 Glossary

Alluvial	Sediment deposited by a river.
Biodiversity	Biological richness, including species, genetic and ecosystem variety.
Boulder	Particle of diameter > 256mm, "head" size and above.
Buffer strip/zone	Area adjacent to the watercourse, left uncultivated - often fenced off.
Catchment	The total area of land that drains into any given river.
Channel	The course of a river including the bed and banks.
Clay	Particle of diameter < 0.002mm.
Coarse sediment	Sediment of grain diameter greater than 2mm.
Cobble	Particle of diameter 64mm to 256mm, approximately "fist" sized.
Competence	The ability of the river to pick up and transport sediment downstream.
Culvert	Artificial structure, often concrete, for carrying water underground or under bridges.
Debris	Dam coarse woody debris blocking the channel and causing water to pond back.
Deflector	A structure projecting out into the channel to deflect the current.
Emergent	Vegetation plants rooted below water or along the water's edge.
Embankment	Artificial flood bank built for flood defence purposes, which can be flush with the channel or set back on the floodplain.
Fine sediment	Sediment of grain diameter finer than 2mm.
Fluvial geomorphology	Is the study of landforms associated with river channels and the processes that form them. It considers the process of sediment transfer – erosion, transport and deposition – in river channels and also the relationship between channel forms and processes.
Fluvial erosion	Hydraulic processes which detach, entrain and transport individual particles or assemblages of particles away from the face or toe of the channel bank.
Floodplain	Area of land over which a watercourse will spill in spate, i.e. periodically inundated part of a river valley floor.
Geomorphology	Is the study of features and processes operating upon the surface of the Earth.
Gabion	(Basket) wire baskets filled with rocks, used to form bank protection structures.
Geotechnical failure	Failure of channel banks including a variety of mechanisms such as slumping, translational failure and rotational failure.
Glide	A narrow section of smooth flowing water.
Gravel	Particle of diameter from 2mm to 64mm.
Groyne	A protective structure of stone or concrete; extends from bank into the channel to prevent a erosion.
'Hard' engineering/ techniques	Involving heavy engineering and use of non-vegetative materials.
Holistic approach	Considering the river system as a whole. Management is conducted on a catchment scale, rather than site specific.
Imbrication	Clusters of coarse particles aligned in the direction of flow (not necessarily a continuous coverage).

Incised	Channel where the riverbed is well below the floodplain due to downwards erosion.
In-stream	That part of the channel covered by water in normal flow conditions.
Lateral adjustment	Of a river across the floodplain through bank erosion and deposition.
Meander	A bend in the river formed by natural river processes e.g. erosion and deposition.
Mid-channel bars	Gravel or other shallow deposits in the middle of straight sections of watercourse.
Poaching	Trampling by livestock.
Point sediment supply / storage	Where sediment supply or storage can be attributed to a specific point on the river bank.
Point bar	Gravel or other shallow sediment deposition on the inside of bends.
Pool	Discrete areas of deep water, typically formed on the outside of meanders.
Proportionality	Applying an extent of investigation, implementation, or monitoring to reflect the size (physically and/or in relation to the importance, risks, or functional consequence) of the project/plan/site in question.
Reach	A length of an individual river which shows broadly similar physical characteristics.
Realignment	Alteration of the planform channel (often by straightening) to speed up flows and reduce flood risk.
Reprofiling	Reshaping a bank to improve its stability and potential habitat value (usually by reducing the slope and making the shape asymmetric).
Resectioning	Alteration of the cross-sectional profile of a channel, often to speed up flows and reduce flood risk.
Revetment	Bank strengthening.
Riffle	A shallow, fast flowing section of water with a distinctly disturbed surface forming upstream-facing unbroken standing waves, usually over a gravel substrate.
Riparian	On the banks of a river.
Rip rap	Angular stone placed to protect eroding banks.
River corridor	Land to either side of the main river channel, including associated floodplain(s).
Salmonid	The family of fish species that includes the salmon, trout and char.
Sand	Particle of diameter between 0.063mm to 2mm.
Side bars	Gravel or other shallow deposits along the edges of straight sections of river channels.
Silt	Particle of diameter between 0.002mm and 0.063mm.
'Soft' (engineering/revetment)	Environmentally friendly, often using vegetation.
Submerged Vane	A submerged structure used to deflect the current

Appendix 1: River typologies

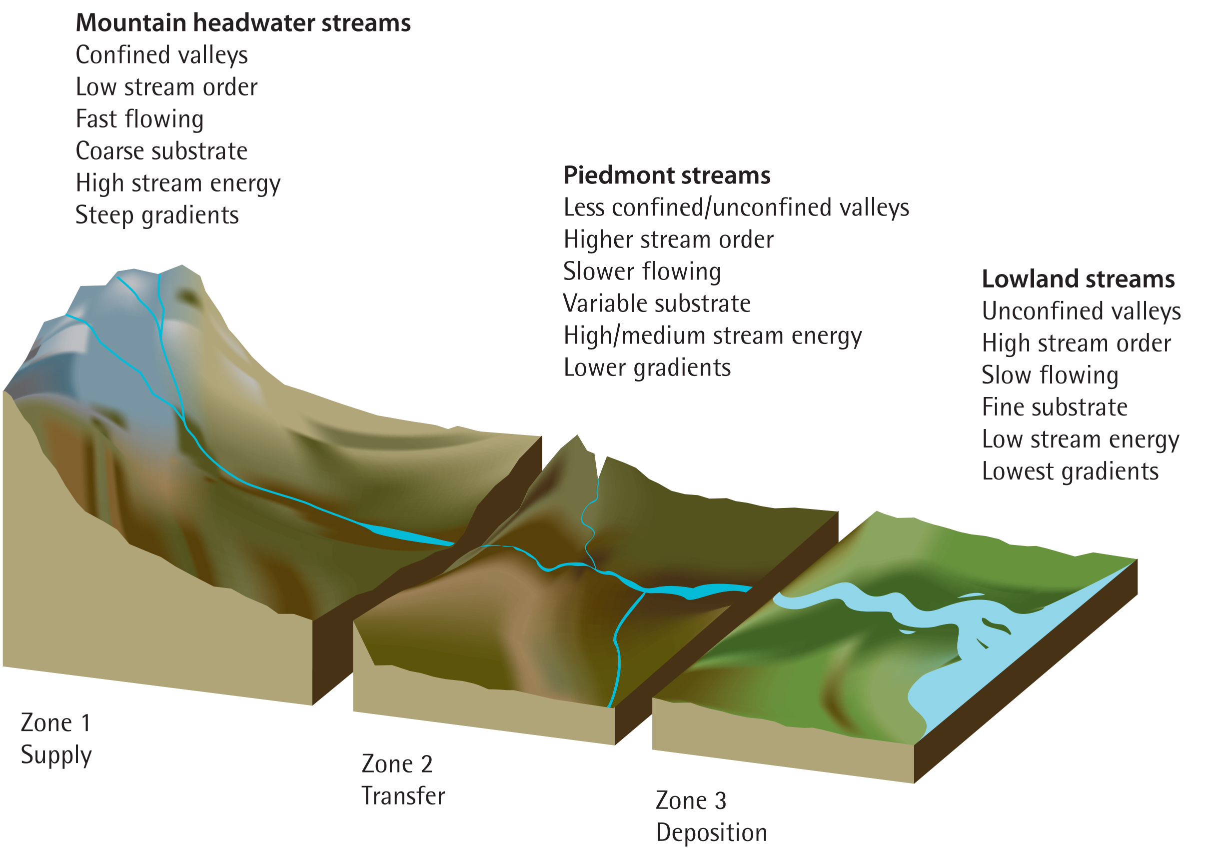
River typologies have become a valuable tool for geomorphologists for identifying and interpreting river characteristics.

Different rivers (or sections of channel within a river) display distinct characteristics that can influence the considerations that need to be taken into account for bank erosion. For instance, as flow speed increases, the erosive power of flowing water also increases, increasing the risk and intensity of bank erosion and channel migration. For the purposes of this guidance, rivers and streams have been divided into three categories upland, transitional (piedmont) and lowland (fig 1.1). Please note that the different types of environment can be found throughout the catchment, fig 1.1 gives a generalised overview of the different areas with a catchment.

For the purposes of this guidance, rivers and streams have been divided into three categories as shown in Figure A1 and outlined below:

- upland;
- transitional (piedmont);
- lowland.

Figure A1.1 Generalised diagram of different types of environment within the river catchment



River Slope

One of the most important factors in influencing river type is slope. If you do not know the slope, it can be determined by looking at the contour lines on an Ordinance Survey map. Look at how many metres a river falls over a kilometre e.g. a river falls 5 metres over 1 kilometre. To convert this to a percent, divide the number of metres fallen over the distance and multiply by 100.

- Number of metres fallen / distance x 100 = % slope

For the example above the slope in % is worked out as follows:

- 5 / 1000 x 100 = 0.5%

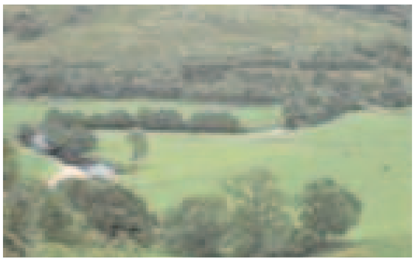
Upland - Upland streams are generally fast, shallow, high-energy streams. Generally have a slope of more than 1%. They are formed in steep environments and are capable of mobilising and carrying large particles such as cobbles during floods. The sides of the channel tend to be steep, with little if any flood plain development, and tend to be relatively stable i.e. they do not tend to migrate. Straight channels with coarse (gravel, cobble substrate) and erratically placed larger boulders should, for the purposes of this guidance, also be considered as upland-type channels.



Transitional (piedmont) - The transfer zone receives much of the eroded material from the uplands and often has coarse bed and bank material. Additional sediment enters the channel through channel migration and associated bank erosion. Slope is generally from 0.1 – 3%. These zones usually have a well-developed flood plain, and are often highly active, so the channel pattern can be quite variable: transitional streams may have pool-riffle sequences, active channel migration (channel meandering) or braided channels (multiple channels).



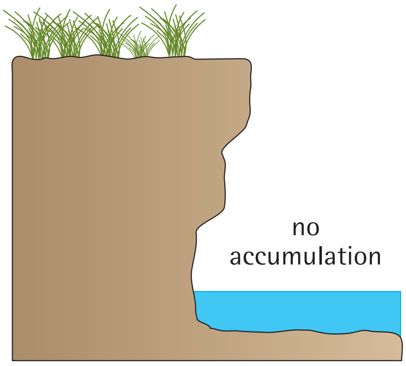
Lowland - Lowland rivers are the main depositional zone with well-developed flood plains. They are typically low energy environments where the bank material size is generally a lot smaller than that in upland and transitional streams (e.g. sand and silt). Nevertheless these streams often retain a gravel bed. Slope is generally less than 0.1%. The planform is likely to be sinuous and the channel is usually fairly stable, but there may be short sections of more active erosion and channel movement, particularly if there is a steep section of the valley. Also included in this category are man made, or modified (e.g. straightened) rivers.

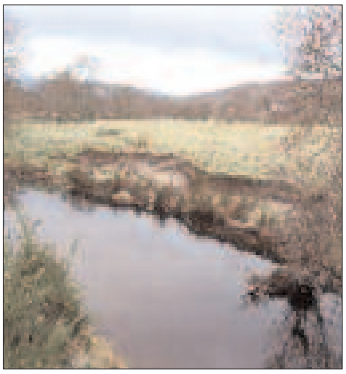


Appendix 2: Types of bank erosion

1. Basal Bank Scour

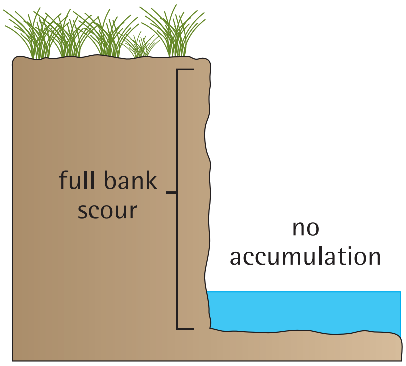
Scour at the base of the bank near the water level

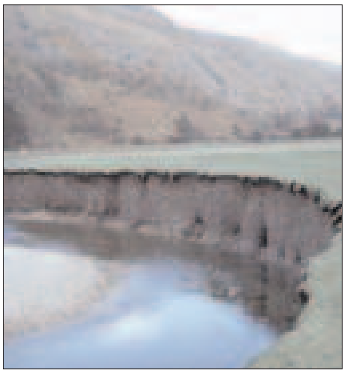




2. Full Bank Scour

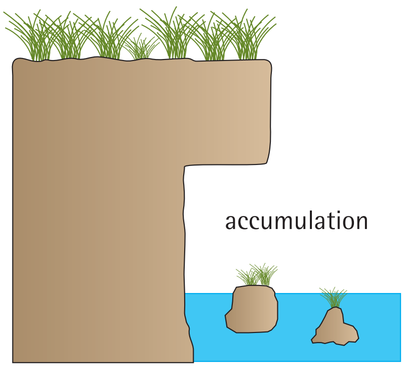
Scour that extends up the entire height of the bank

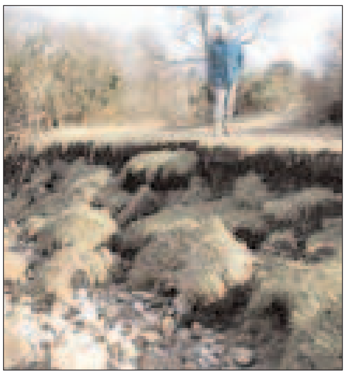


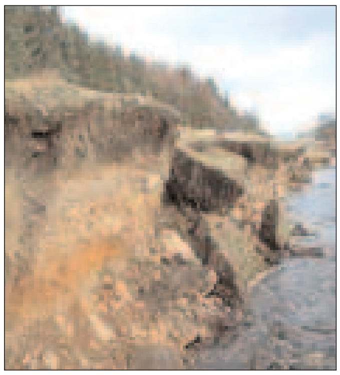


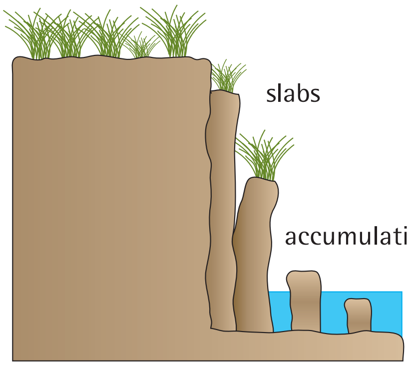
3. Cantilever

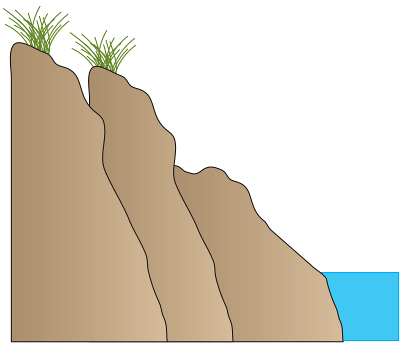
The failure of large portions of the upper bank through basal scouring. The debris accumulates on the edge of the channel

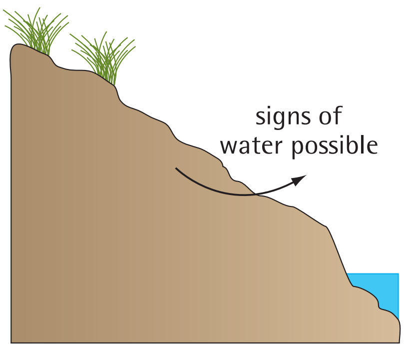






4. Slabs	Failure of entire bank sections along a vertical line. Large portions of the bank may break away and collect as debris on the edge of the channel.
	

5. Slide	Failure of entire sections of the bank along a slope line. May occur where there is a change in lithology. This failure may be a slow process with little evidence of accumulation at the base near the water level
	 

6. Flow	Erosion of the bank via sub-surface washout
	

Appendix 3: Field survey checklist

You may wish to use the list below to undertake a simple site survey. This information may also be useful as supporting evidence if you need to apply for an engineering licence. A survey is of little use if you can't remember exactly when, where or by who it was done, so a note of the following will help:

1. Date, river and name of surveyor

2. Location and grid ref (e.g. NS 3345 1973; 250 m upstream of Byres Bridge)

3. Weather (e.g. dry at time of survey; recent light rain; floods 2 weeks ago)

4. Photographs and descriptions (e.g. 1 – erosion viewed from upstream)

5. A sketch map of the section in question, showing

   - the river (including flow direction and any features of interest e.g. gravel bars, fallen trees, existing bank protection)
   - the erosion (location, type (if you know what type it is) and extent)
   - any important or relevant features (e.g. landuse, areas of sediment deposition, or buildings or roads)
   - the location of any photographs taken as a number and arrow, e.g 1
   - a sketch of the channel cross-section at the erosion site
   - your notes on the type and cause of erosion (Appendix 2, above, lists the type of erosion and possible causes)

Box A3-1 (over) provides a few rules of thumb that may be useful when considering the type of protection that may be required.

Box A3-1 'Rule of thumb' guide to selecting bank protection works

General rules

- Look at other bank protection in the area to see what works and what doesn't work
- Look at other, similar rivers, to see what might work
- Talk to other land owners who have used bank protection
- Seek guidance from local conservation groups.

Situations were green protection might be more suited

- lowland (low energy) environments
- Environments where the bed and banks are composed of cohesive materials (e.g clays)
- Environments where tree and shrub riparian vegetation is present
- Rural areas, where there is less likelihood of impacts to infrastructure
- Sections of straight channel
- To accompany non-engineering solutions.

Situations where grey protection might be more suited

- Upland (high energy) environments where infrastructure or built property is at risk
- Environments where the banks (and bed) are composed of larger stones and rocks
- Urban and/or semi urban settings
- Channels where rates of erosion can be measured in metres per year.

Situation where toe protection might be more suited

- Straight section of channel
- Lowland (low energy) environments
- Upland (high energy) environments where infrastructure or built property is not at risk
- Outside of meander bends.

Situations where set-back protection might be more suited

- Where erosion has been identified, and infrastructure could be put at risk at a future date.

Appendix 4: Bank protection costings

	Technique	Approximate Cost Guide
Green protection	Grass and Reed Planting	£100 – 200 m^2 per run
	Live Woody Revetment	£115 – 125m
	Faggots	£50 – 120/m
	Tree and Shrub Planting	-
	Temporary Current Deflectors	-
	Geotextile	£160/m
	Bank Reprofiling	£3000 (based on a reach of 40m by 9m)
Grey protection	Non-live Timber Revetment	£100 – 350m^2
	Low Level Piling	£200-500 m^2
	Sheet piling	£80-200 m^2
	Toe protection	Varies according to material – Log toe for example typically costs between £140 - 180/m
	Concrete Revetment	Blockstone ~ £250/m
	Gabions	Rock Gabions £50 – 70m2 (including preparation and excluding anchoring)
	Riprap	£60 – 150m^2
	Gravity Walls	£300 – 500m^2
	Permanent Current Deflectors	£800 – 1500 (based on 2-4m river width)
	Sheet piling	Approximately £580/m

Appendix 5: Feedback form – Good Practice Guide WAT-SG-23

SEPA is committed to ensuring our Good Practice Guides are useful and relevant to those carrying out engineering activities in Scotland's rivers and lochs.

We welcome any comments you have on this Good Practice Guide so that we can improve future editions.

After completing the short questionnaire, please detach it and post to the address below or fax it to 01355 574 688.

SEPA
WFD Administration Officer
5 Redwood Crescent
Peel Park
East Kilbride
G74 5PP

The aim of this Good Practice Guide is to set out the environmental aspects that should be considered when undertaking engineering works and to help applicants choose sustainable engineering solutions that reduce environmental impacts. This will also help them obtain an authorisation for works under the Water Environment (Controlled Activities) (Scotland) Regulations 2005.

1. Which of the following do you think describes how well the Guide meets these aims?

Excellent	☐	Good	☐	Average	☐	Poor	☐

2. How relevant was the content of the Guide to your activity?

Very relevant	☐	Sometimes relevant	☐	Not relevant	☐

3. What elements of the guidance did you find most useful?

4. What elements of the guidance did you find least useful?

5. Did you find the Guide clear and easy to follow?

Yes	☐	Sometimes	☐	No	☐

If there were areas that could be clearer, please let us know in the box below

7. Were there issues you felt should have been covered, omitted or dealt with differently in the Guide?

Please use the box below for other comments or suggestions on the Guide (continue on a new sheet if required).