H20-DS Hillslopes to Oceans:

Decision Support System for sustainable drainage management

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Work in Progress

This guideline is a work in progress, reflecting best practice in a rapidly evolving field at the time of writing. Any comments and additional information that could help other drainage managers in New Zealand are most welcome and can be directed to NZWERF.

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The information is provided as a starting point for professionals and advisors in land and water management. The information supplied is a synthesis and interpretation of published material. Any misinterpretations are unintentional.

Users are warned that the implementation of some management strategies and recommendations require prior authorisation (i.e. resource consent). The advice of Regional and District Councils should be sought before embarking on the management strategies and recommendations from this report.

Summary

This decision support system has been developed to assist waterway management decisions by providing a series of critical Best Management Practices (BMPs), specifically focused on practical drainage management. These BMPs are supported by an analysis of environmental issues within a decision-making framework that encourages that both effects and causes be considered. It has been written to assist landowners, contractors and drain managers. While focusing on environmental benefits it recognises the operational need for maintaining drainage outfall and minimising long term costs.

Management practices are based on the best available science identified in the review of national and international practices. In some cases practices are transposed to New Zealand without local verification, in the belief that the practices have been proven overseas, and that they will be tested locally and refined as necessary.

In these guidelines waterway management problems are identified, causes of these problems are discussed, and management options are reviewed. An operational decision making framework to identify problems and select management measures is presented.

There are a broad range of issues that drainage managers face; some of which are political in nature, such as who pays for maintenance and access and land ownership issues. These issues are not addressed here. Nor do we directly address the issue of overall network efficiency, which is complicated by ownership. The focus is on physical issues related to drainage maintenance, specifically:

- Sedimentation - the loss of outfall due to sediment build up
- Vegetation - loss of outfall due to aquatic weeds and bank vegetation
- Water quality - waterways collect, store and transfer contaminants leading to a deterioration of water quality in receiving waters
- Biodiversity - adverse effects on aquatic, marginal and terrestrial flora and fauna, mahinga kai, cultural and amenity values

While the specific details of many waterway problems can be complicated (e.g. variable causes of excessive sediment supply and poor water quality), the range of management measures used to address these problems is surprisingly small. Based on national and international experience a broad range of problems are addressed with the following measures:

1) Control the generation of sediment and contaminants in the first instance.
2) Control stock access to waterways.
3) Use knowledge of plants to determine an appropriate weed management strategy.
4) Construct or leave a vegetated buffer between cultivated areas and waterways.

5) Provide habitat, food, and shade with streamside planting, and at the same time reduce the need for weed control in small streams.

6) Stabilise eroding stream banks with vegetative control measures, bank re-grading and structural measures.

7) Trap and treat sediment and contaminants in wetlands that are positioned at major sources of contaminants, at tile drain outfalls, and in the stream channel.

8) Provide a corridor for drainage channels and incorporate natural channel features when maintaining or constructing these channels.

9) Identify important flora and fauna and minimise or avoid disturbance of sensitive places at sensitive times (e.g. fish spawning).

It is generally accepted that there is no single ‘silver bullet’ best management option. A system of management practices must be employed. A decision support framework is provided to guide the selection of BMPs. For each BMP the complexity, effectiveness and costs are rated. It is expected that these BMPs will be refined over time, and more practices will be added.

The title of this decision support system “Hillslopes to Oceans” (H20) is intended to convey the message that drainage management can not be sustainably undertaken in isolation:

- Drains are a source, a sink, and a conduit of water, sediment and contaminants
- Events or actions in one part of a catchment might have effects elsewhere
- Local actions are not necessarily enough to solve catchment scale problems.

Outline

This Decision Support System (DSS) was developed to assist drain owners, maintenance managers, engineers and contractors by providing a comprehensive review of the context through to the implementation of best management practices (BMPs) to address common drainage management problems. While readers are encouraged to become familiar with the whole system, it is expected that some sections will be of more interest than others.

Part 1: Introduction

The present Part describes emerging issues in waterway management, the phased development of the system and supporting documents, the systematic approach required, and principles of use, and outlines the structure.

Part 2: Management Context

The Management Context discusses the intent of drainage, defines the types of waterways of interest, and outlines risk management, management principles and processes, and maintenance objectives. Legislation to link the operational decisions to the legal responsibilities of governments and communities is also reviewed.

This information sets the scope for the Manual and establishes/recommends how maintenance operations need to be designed and carried out.

Part 3: Problems and Solutions

Part 3 is an overview of common problems and of the science behind measures to address these problems. This provides information for the professional managers and advisers to assist non-technical persons operating at the local waterway scale to design and implement best management practices.

The Manual augments and complements other sources of information and provides sufficient technical information so that users can understand underlying principles, and select and adapt practices as required to meet particular objectives in a local setting.

The information is set out in stand-alone sections that can be extracted to be used alongside the appropriate Best Management Practices. The Chapters are:

1. Sediment.

3. Water quality.

2. Vegetation.

4. Biodiversity.

Part 4: Best Management Practices

Individual Best Management Practices (BMP) explain the why, what, where, how, when, and so what? Each technique is supported by a section explaining the science and justification for the recommended practice.

The BMPs are a standalone procedures guide with a target audience of the farm advisor, land management specialist, and ultimately the person undertaking the work.

The procedures will be updated as required (e.g. on the basis of field trial results); and additional procedures will be developed.

Streamside Planting Guide

To assist operational decisions for riparian management, a Streamside planting guide is presented as a subsection of mitigation measures under Biodiversity.

Plants are selected based on the purpose of the planting (e.g. erosion control; contaminant trapping), the bank shape (profiles) and how frequently the zones are flooded. This ranges from the "margins" that are continuously wet (they intercept the groundwater table and are flooded by streamflow), to frequently wet lower bank zones; to stopbanks and upland fringe zones that are flooded infrequently. Wetlands are flooded for extended periods or have high water tables.

References

Glossary

Contents

1 Introduction to sustainable drainage management

1.1 Intent

This Decision Support System (DSS) was developed to assist drain owners, maintenance managers, engineers and contractors by providing a comprehensive review of the context through to the implementation of best management practices (BMPs) to address common drainage management problems. While readers are encouraged to become familiar with the whole system, it is expected that some sections will be of more interest than others.

1.2 Emerging challenges

Many waterways are actively managed in New Zealand. The primary purposes are to remove surface water from land to enhance productivity and access, to alleviate flooding, and to control channel erosion. Managed waterways span the range from constructed headwater drains to natural streams and rivers draining into the ocean (See Part 2-2 Waterway Types). They are often significant resources in their own right in terms of aquatic and streamside habitat, amenity and cultural values. The necessity for drainage management will continue, but the expectation is that different approaches will be required in some circumstances to address multiple needs.

Expectations for more sustainable approaches to drainage management are driven by several factors including:

- The desire for cost effective management and/or environmental improvement by many landowners and other interest groups
- The recognition that local actions alone are not enough to solve catchment (watershed) scale problems such as habitat degradation, flow modification and water quality degradation
- Legislation, such as the Resource Management Act and Regional Council water plans
- Trade implications including the potential for imposition of non-tariff trade barriers by competing countries that are already operating under stricter environmental regulatory controls than New Zealand

A major challenge is to find the best solution for the immediate drainage management issues, while considering the possible effects of these solutions on other interests/values in the waterway. Whatever the main interest, the long-term solution sought is preferably sustainable with respect to appropriate hydraulic performance, reduced costs, and multi-uses.

The approach emphasised here challenges the user to respond to the causes rather than effects. For example a loss of outfall should be treated as an excess sediment supply problem, rather than simply a problem of local sediment deposition. While it is recognised that the immediate problem must be repaired (e.g. remove sediment to unblock a drain), the causes (e.g. bank erosion; farm land erosion) should not be neglected when a long term sustainable solution is more appropriate.

The focus of this DSS is on agricultural waterways. While the DSS does not specifically refer to urban or forested catchments, the principles are the same and the system is likely to have some applicability to these situations.

1.3 Building blocks

Different aspects of the problems addressed here have been reviewed (e.g. Collier *et al.* 1995; Hicks 1995; MfE 2001; Hudson & Harding 2004) and there are guides on managing waterways in New Zealand (e.g. Bay of Plenty draft environmental code of practice for rivers and drainage activities -Crabbe & Ngapo 2000; Marlborough landscape guidelines - Lucas Associates 2002; Managing waterways on farms - MfE 2001; the Clean Streams booklets for managing waterways on farms - Environment Waikato 2002; Environment Bay of Plenty 2004 and others; and numerous fact sheets by various councils and organisations). Dexcel provides a search tool (www.envirodirect.co.nz) that links various sources of information for New Zealand including the Dexcel fact sheets for dairy farmers (www.dexcel.co.nz/farmfacts).

Available reviews and guidelines illustrate there is no shortage of good ideas; but these are in multiple sources, and presented in numerous formats with varying degrees of comprehensiveness and scientific foundation.

The point of difference here is that this Decision Support System provides a place to encapsulate the rapidly expanding body of knowledge related to waterway management; it provides a process to select appropriate management measures; and provides detailed procedures to manage waterways. The objective is to create a one stop reference for comprehensive drainage management that evolves as knowledge and experience is gained.

Efficiencies should be gained by reducing the replication of research and guideline documents, promoting a common, comprehensive format for best management practices (BMPs) to ensure future research and guidelines address user needs, and by eliminating contradictory or incorrect advice.

1.4 Adaptive approach

For many waterway problems a system of BMPs is often required. For these problems the decision support framework identifies a range of management measures and associated BMPs. The effectiveness of individual BMPs varies for particular problems. The decision support system evaluates the effectiveness for the identified problems.

While these guidelines are based on best available national and international science, such research cannot be simply transposed without local verification. It is expected that the knowledge base will develop, and the BMPs will be refined over time, and more practices will be added.

Several principles are promoted as part of an adaptive management approach:

1) Co-operative management is required. Decision making should be shared among all legitimate interests.
2) Management approaches must be sensitive to local conditions.
3) Flexibility must be built in to allow for changes in management practices based on experiences.
4) Systematic learning is required. Activities should be treated as experiments using appropriate experimental designs, monitoring, and assessment and reporting.
5) Specialist expertise will be required to advance the science and practice.
6) Experiences, both successes and failures, should be shared.

We encourage users to supplement this document with new literature, and regionally or locally specific information including case studies.

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2 Drainage management context

2.1 Intent of drainage

Large-scale surface and sub-surface drainage of swamps and flood prone areas has occurred throughout New Zealand, with the purpose of enhancing agricultural production, and making land less flood-prone and more suitable for building or development (Hudson & Harding 2004). Surface drainage is designed to minimise crop and pasture damage resulting from ponding for excessive periods on the soil surface, to allow equipment and livestock access, and to control runoff to prevent soil erosion. Sub-surface drainage is designed to remove excess water from the plant root zone by artificially lowering the water table level.

Drainage networks were initially designed to remove excess water as efficiently as possible. While land drainage substantially changed the natural landscape, with significant losses of wetland habitat, the drainage network is often important habitat in its own right. Consequently drainage management is evolving to include consideration of the effects on water quality, and effects on aquatic and marginal terrestrial flora and fauna, mahinga kai, cultural and amenity values.

In addition, as upgrading and extension of the drainage network is occurring and as community expectations for improved flood management are increasing, cost effective and sustainable practices are needed. Land, channel margin and instream management is required, otherwise constant waterways maintenance is necessary, which may not be sustainable. It is within this broader context that drainage management is now, or will be, undertaken in New Zealand.

2.2 Waterway types

2.2.1 Definitions

Drains are often though of as artificial watercourses (a “constructed channel”) that were made and maintained strictly for removing surface water and lowering water tables (i.e. hydraulic efficiency). A broader view is taken here in that artificial watercourses are considered part of a greater drainage network that requires integrated management.

Various types of waterways drain the land and carry water, sediment and contaminants from hill slopes to oceans. A typical drainage network consists of natural or constructed depressions and wetlands that collect runoff, which in turn flow into a drain or stream channel. These drains and streams often converge with other drains and streams to form rivers which ultimately flow to the ocean. Management of drainage outfall might involve all or part of the waterway system; and these waterways have different physical characteristics and actual or potential habitat sensitivities and values.

Where the depression or channel is above the ground water table, the stream flow is ephemeral, occurring only after rainfall or snowmelt. Intermittent streams flow during wet periods (e.g. during the winter), and may intercept the water table. Following rainfall or snowmelt, as the ground water levels drop, the flow stops in intermittent streams. Perennial streams flow most of the time and are sustained by groundwater during dry periods.

Drains are constructed (artificial) channels designed to remove excess surface water from depressions, wetlands, and surface runoff; and to lower the groundwater table (e.g. by providing outfall to tile drains). They are characterised by one or more of the following:

- Channels are usually excavated with a uniform bottom and steep side slopes
- Channels are typically straight for long reaches, and often flow along property or field boundaries, with tight bends (90°)
- They may show signs of natural channel processes (e.g. meandering, pool-riffle development; erosion and slumping of banks)
- “Dry drains” are ephemeral or intermittent and flow some of the time. These drains typically do not support aquatic vegetation or aquatic invertebrates and fish. However, there may be some exceptions (e.g. Canterbury mudfish)
- “Wet drains” are perennial and have standing water or flow almost all the time. They are likely to have aquatic vegetation growth and support aquatic invertebrates and fish

A stream is characterised by water flowing in a definite natural channel (other terms include creek, burn and river). Flow may be intermittent, ephemeral or perennial. Streams have various degrees of modification. There are few lowland streams in New Zealand, particularly in agricultural areas, which are unmodified with native vegetation cover and no channel alteration (Day & Hudson 2001). There is some ambiguity between artificial (constructed) and natural streams and in some circumstances constructed drains may be classified as a stream or river (See An overview of environmental policies-legislation).

In agricultural areas existing streams have often been channelised and relocated. Channelised streams are characterised by one or more of the following:

- Channels are usually excavated with a flat bottom and steep side slopes
- Channels have long straight reaches which may show some signs of natural channel processes (e.g. meandering, pool-riffle development)
- Relocated streams typically flow along property or field boundaries
- Flow may be ephemeral, intermittent, or perennial
- They are an integral component of natural drainage, often with a network of surface and subsurface drains

- Perennial streams are likely to have aquatic vegetation growth on the bed and banks and support aquatic invertebrates and fish

Natural streams are defined as being characterised by one or more of the following:

- They do not appear to be channelised or relocated
- Channels are typically meandering; with an asymmetric cross section (e.g. deep outer bend, shallow inner bend); and undulating long profile (e.g. shallow riffles and deep pools)
- Flow may be ephemeral, intermittent or perennial.
- Perennial streams usually support submergent and emergent aquatic vegetation and have streamside vegetative cover.
- Woody debris in the channel and along the banks
- Support aquatic invertebrates and often have good actual or potential fish habitat

In New Zealand waterways often flow to the sea via various types of mouths (estuaries, lagoons, deltas and adjacent wetlands of the "Estuaries" category of Cowardin *et al.* 1979). River mouths may be managed (e.g. Wairau River, Marlborough) or structurally controlled (e.g. floodgates). Estuaries and lagoons are influenced by tides and have distinctive characteristics (Kirk & Lauder 2000). Estuaries have tidal circulation, but this is not necessarily the case in river mouth lagoons. These waters, which may be brackish, shelter and feed marine and/or freshwater life, birds and wildlife.

Consideration must also be given to the stream corridor which consists of the streamside (riparian) vegetation, and floodplain features such as wetlands, oxbow lakes, backwaters, islands and adjacent land uses (e.g. forest, pasture) along the stream margin (FISRWG 1998). The stream corridor may be contained within embankments.

2.2.2 Channel classification

Streams and drains look and behave differently because of regional differences in geology, landforms, soils, vegetation, climate, hydrology and land use. This variation is reflected in stream channel morphology, habitat, water chemistry, runoff patterns, aquatic flora and fauna, and riparian conditions. It is recognised that the physical conditions are not static and that there are numerous and complex interconnections at various scales that determine stream form and processes. In turn the physical environment exerts a strong control on stream ecology, but the effects can be indirect and mediated through complex interactions.

One of the challenges of sustainable management is to recognise these differences, and develop and apply plans and policies, and undertake management activities, which are appropriate for these inherent differences. For example, gravel bed, spring fed, waterways in Canterbury are distinctly different in form, processes, and ecological potential, to soft sedimentary streams, or peat bog drains, in the Waikato. Management activities would be sensitive to trout spawning in the gravel bed streams but not in the mud bed streams.

It is generally accepted that there is a hierarchical arrangement of physical features within stream systems and that processes operating on higher scales act to constrain processes operating on lower scales (e.g. Frissell *et al.* 1986). Physical features can be described on a number of scales ranging from catchments, to zones, segments, reaches, individual habitat units and microhabitats. In turn the physical structure of a stream provides a habitat templet or matrix within which biophysical processes and communities are structured (e.g. Southwood 1977; Townsend & Hildrew 1994).

There are numerous classification schemes, designed for various ecologic, geomorphologic, or planning purposes (e.g. Gordon *et al.* 1992). In New Zealand the River environment classification (REC) is being developed with the intent of providing a framework for river management (Snelder *et al.* 1999, 2000, 2004). The Land Environments of New Zealand (LENZ) classification has a primary focus of land management (Leathwick *et al.* 2003). Information from both is required for some applications (e.g. denitrification potential of streamside vegetation is classified by soil characteristics reported in LENZ, but soils are not included in REC – Quinn 2003).

While classification schemes can provide a context for planning and policy, the formal delineation of management units has not in the past been a prerequisite for operational management. One of the major benefits of a uniformly applied classification scheme is the ability to provide a mechanism to extrapolate site specific information derived from one area to other areas with similar characteristics. For example, if the stream characteristics are similar, it is likely that successful management procedures developed in the Central Dry Lowlands around Gisborne could be applied to similar LENZ classified areas in the Waikato, Marlborough and North Canterbury.

Operational decisions are usually based on site specific conditions; but a broader perspective may help determine priorities. For example, in his Riparian Management Classification (RMC) Quinn (1999, 2003) classified valley landform on site rather than with REC, which classed valley form based on slope down the valley not the valley cross section (Snelder *et al.* 2003). Quinn (2003) also measured stream bank characteristics and channel widths. Goals for reach and farm scale riparian management were defined for each farmer/landowner; and riparian microhabitat-based native species planting requirements were determined based on the local channel profiles and zones and an assessment of potential relative importance of different riparian functions.

To assist operational decisions for riparian management, a streamside planting guide for native plants is presented. Plants are selected based on the bank shape (profiles) and how frequently the zones are flooded. This ranges from the “margins” that are continuously wet (they intercept the groundwater table and are flooded by streamflow), to frequently wet lower bank zones; to stopbanks and upland fringe zones that are flooded infrequently. Wetlands are flooded for extended periods or have high water tables. The idealised sequence illustrated in the planting guide occurs with gentle side slopes and may be disrupted by stopbanks or steep side slopes.

In the tidal zone, three planting zones were identified by Meurk (Landcare Research, written comm.): the lower marsh which is flooded on every tide; the upper marsh which is flooded only on spring tides; and the banks and levees which are seldom if ever flooded.

The effectiveness of streamside planting, and other forms of bed or bank stabilisation, depends on the channel characteristics and flow regime. The required attributes are measured in the field, and the observations can be classified to provide a means to extrapolate site specific data to other stream reaches having similar characteristics. They can also be used to provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties.

Caution is required in using the River Environment Classification. "The classification uses discriminating variables that can be obtained from a GIS database, although these are not necessarily the optimal ones… the characterisation of channel morphology usually includes variables that are measured or observed in the field, in addition to some which can be measured from large-scale topographic maps or aerial photographs. The type of GIS data available in the present study are at a relatively coarse scale, or are simply not able to provide relevant information (e.g. on channel width, depth, roughness, stream power, etc)." (Mosley 1999). For example, in REC bed materials are inferred from the three valley-landform classes and geology (e.g. hard sedimentary – cobble, gravel and sand; soft sedimentary – silt and mud). Many gravel bed streams on the Canterbury plains are inferred to have silty/sandy bed materials (Snelder *et al*. 2003) by virtue of their "low elevation" classification.

Various classification schemes have been developed to facilitate transfer of information; and many of the attributes are similar (e.g. Australian River Assessment System Physical Assessment Protocol - Parsons *et al.* 2002). The Rosgen river classification, based on streams in North America and New Zealand, describes 7 major stream types that differ in entrenchment, gradient, width/depth ratio, and sinuosity, in various landforms (e.g. steep, entrenched mountain streams; meandering channels in broad floodplains; multi channel delta streams) (Rosgen 1996). Within each major category are up to six additional types delineated by dominant channel materials (1- bedrock, 2- boulder; 3- cobble; 4- gravel; 5- sand; 6- silt/clay) for a total of 41 stream types. There are a large number of refinements when other attributes, such as flow regime (e.g. snowmelt dominated, spring fed, tidal influence, regulated), are considered.

For each stream type the sensitivity to disturbance, recovery potential, sediment supply, vegetation controlling influence and streambank erosion potential are described based on extensive field observations; and these interpretations can be used for potential impact assessment, risk analysis, and management direction by stream type (Rosgen 1996). Level 3 classifications describe the existing condition of the stream as it relates to its stability, response potential, and function. Stream condition variables include riparian vegetation, width and depth, channel features, flow regime, channel stability, and bank erosion potential. Potential condition can be assessed.

Rosgen's (1996) stream classification and analysis criterion can be applied to particular waterway management problems; in essence to predict a stream's behaviour from its appearance and to facilitate the transfer of information on stream management from overseas and within New Zealand.

2.3 Maintenance issues

Without adequate drainage large areas would be unproductive or inaccessible, and would suffer long-term reductions in productivity. Therefore the primary objective of drainage management must be maintenance of drainage outfall. The secondary, but increasingly important management issue is to manage the channel capacity objectives while maintaining and conserving, and in some cases improving, aquatic habitat and water quality. It must be emphasised that the actual and potential habitat values of the drainage network is highly variable, and management objectives should vary to reflect these differences.

There are a broad range of issues that drainage managers face; some of which are political in nature, such as distribution of costs of land drainage, access and land ownership. These issues are not addressed here. Nor do we directly address the issue of overall network efficiency, which is compounded by integration of private and community drains. The specific focus is on physical issues related to drainage maintenance:

- Loss of outfall due to sediment build up and other obstructions
- Loss of outfall due to aquatic weeds and bank vegetation
- Deterioration of water quality as waterways collect, store and transfer sediments and contaminants
- Adverse effects on aquatic and marginal terrestrial flora and fauna, mahinga kai, cultural and amenity values.

In the future it is proposed to develop guidelines for naturalising waterways, which would be pertinent to addressing the issue of changing expectations of waterway management and changing catchment conditions requiring drainage rehabilitation-improvement. The effectiveness of the drainage network, particularly where there is a mix of community and landowner drains, would be addressed on a case-by-case basis.

A three-step process to develop an operational plan is recommended:

1) Preliminary activity
    - Establish principles
    - Establish commitment to the process
    - Agree on the framework and scope

- Define problems-issues and information requirements

2) Manage risks
   - Consider threats
   - Identify values of the receiving environments
   - Develop risk management strategies

3) Develop an operational plan
   - Identify the causes of the problems
   - Establish the performance objectives
   - Prioritise issues and options
   - Evaluate options
   - Recommend management measures and implement BMPs based on cost effectiveness, capabilities, and opportunity
   - Establish responsibility, costs, monitoring and review

2.4 Management principles and process

Waterways management is best integrated into an overall catchment management plan, with management based on the following principles:

- Preserve existing valuable habitats (e.g. physical protection such as managing stock access; planning controls – preserve stream assets by giving them a particular status in regional plans)
- Avoid threats to the target reach (e.g. control sediment inputs from upstream; prevent headward erosion from over-excavation downstream)
- Control the flow of water and sediment in the reach (e.g. prevent undercutting of banks)

In addition, consideration should be given to:

- Environmentally sensitive landscaping: The physical appearance of the best management practice is important. Some BMP's can enhance the appearance of a site, while others detract from it
- Habitat: Opportunities to enhance the landscape should be taken (e.g. create a wetland suitable for wildlife rather than a detention pond of limited wildlife value)
- Maintenance: BMPs will require maintenance, but some more frequently than others. An objective should be that control measures should be as self-sustaining as possible over the long term (e.g. periodic spraying of pest vegetation is all that is required to maintain a permanent wetland). Access to maintain drainage outfall is a statutory requirement
- Safety and integrity: BMP's must not jeopardise public safety or infrastructure integrity (e.g. bridges, bank protection)
- Pollution prevention and clean up: Although not discussed further, a fundamental aspect of good management is good house keeping

(e.g. refuel in areas where spills can be contained and cleaned up; correctly dispose of rubbish such as old tyres). For more specific information refer to the On-Site Stormwater Management Guideline (NZWERF 2004)

These principles can be used as the framework to achieve the performance based objectives of regional water plans.

The framework and scope of drainage management is established in New Zealand. In most cases local or regional authorities are responsible for community drains, and individual landowners for local drains. Community drain management is funded through specific taxes on landowners (“rates”), with the scope of annual work determined in consultation between the managing authority and the community. Activities such as riparian planting are undertaken in consultation with landowners often with some support from Regional and District Councils. Private drains are managed by the individual landowners.

Historically drainage maintenance was undertaken with a focus on maximising hydraulic efficiency with routine cleaning. With the shift to specific rates for drainage maintenance, the focus has shifted toward performance based management. This has required a more specific determination of drainage problems. Information requirements have increased as the management objectives have been broadened to include environmental effects.

2.5 Risk management

Rarely in the natural world is one action independent from another. Any decision taken to address a maintenance problem must be made within the broader context of adjacent and upstream/downstream impacts to the waterway and its surrounding land. There are both physical and biological impacts to be considered.

No waterway serves only one purpose, no matter what its origins. For example drains become part of the aquatic environment, as natural waterways always were. The challenge herein is to find the best approach to meet the range of needs of a site, and it is likely, if not normal that a combination of maintenance treatments be required.

Taking a risk management approach means assessing the risk or likelihood of losing significant values in receiving environments. The risk of those values being lost or compromised depends on:

- Scale or severity of the activity
- Frequency of the activity and
- Sensitivity of the environment in which the activity takes place

In terms of problems, maintenance activities and extension of the drainage network can release large quantities of sediment into drains and receiving waters, with significant adverse impacts. Well-managed drains can reduce sediment problems and improve water quality and amenity value, by reducing the frequency and severity of maintenance activities.

Regarding environmental sensitivity, particular regard must be paid to avoiding damage to the few remaining lowland wetlands and significant areas of native vegetation. As well, drainage management can be planned to avoid sensitive times and places (e.g. inanga spawning along the high tide line in lowland streams).

2.6 Maintenance performance objectives

2.6.1 Hydraulic efficiency

The objective of drainage maintenance is to maintain drainage outfall as cost effectively as possible. However, this is rarely quantified. While the ability to predict hydraulic efficiency in relatively straight constructed channels is good, the effects of natural complexity, instream weeds, and streamside vegetation is less readily predicted (Fisher 2001). It is clear that plant growth, bank collapse, sediment infilling and debris accumulation can all significantly reduce the hydraulic capacity of waterways by changing the streambed roughness, cross sectional area and/or slope of a waterway. Although substantial reductions in water level are often apparent after the removal or cutting of weeds; and the removal of obstructions (e.g. sediment and debris), there is surprisingly little information on the hydraulic effects of either the problems or treatments (Hudson & Harding 2004). As a result the effectiveness of maintenance is reported as a process measure (how much drain is cleaned) rather than a performance measure (how has drainage efficiency increased).

Hydraulic efficiency of problems and treatment measures should be evaluated. For example, experiments on vegetation clearing show effects vary between plant types and timing of treatment, with varying periods of increased hydraulic efficiency following treatment (e.g. Smailes 1996).

In addition, a broader view of cost effectiveness of treatments should be considered. Costs are reported in terms of the price of treatment of effects (e.g. weed clearing or sediment removal), rather than of the long term cost of alternative management measures such as controlling sediment inputs into a waterway (e.g. riparian planting and stock exclusion).

2.6.2 Agricultural productivity

The clear objective of drainage system design is to remove excessive water (e.g. Heretaunga Plains, Hawke’s Bay - Olsen *et al.* 1999). Yet, the effectiveness of drain maintenance in terms of flow, and consequently agricultural productivity and accessibility (e.g. for tillage) are rarely assessed. Again the focus is on the process (how much drain was maintained) rather than on performance (what gain in agricultural productivity resulted from maintenance).

The danger of not linking drainage maintenance to hydraulic efficiency, and to agricultural productivity, is that drains are cleaned too frequently or not frequently enough, and that the value and effectiveness of drain maintenance is assumed, but not actually known. Explicit relationships should be made between water levels (hence outfall maintenance), weather conditions, soil types and field drainage conditions. Water table heights should be compared with those required for crop growth and access (e.g. tillage of soils). Productivity and economic returns with and without outfall maintenance should be predicted and the value of maintenance ascertained.

Performance based management recommendations can be developed by combining the approach of Barker and others (1996), Dall'Armellina and others (1996), Dundedale and Morris (1996) and Evan, Gilliam and Skaggs (1996).

2.6.3 Environment

Environmental performance objectives will be set in regional water plans, including sediment and water quality standards. Objectives should be sensitive to regional differences (see Waterway types). In terms of sediment, objectives will probably include effects on water clarity, and deposition of sediment in the bed and receiving waters. Water quality objectives will probably include stream temperature, faecal material, nutrient levels, and pesticide levels in water.

The overall goals are to eliminate or reduce agriculture and industrial impacts (e.g. decrease off-farm soil and nutrient losses, maintain or enhance water quality, and to comply with the environmental expectations associated with international trade); and to restore, create and manage waterways for multiple purposes where appropriate (e.g. to improve water quality, provide habitat etc.).

An additional component of the environmental objectives is to avoid damage to terrestrial vegetation and wildlife. Special areas may be designated in various plans, but it is often a requirement to avoid damaging native vegetation and to re-habilitate disturbed lands.

2.7 Operational decision-making

From an operational perspective the immediate priority is to address the problem at hand. For example, if sediment deposition causes high water levels and flooding, then the operational priority is to remove the sediment. Treating the effects is a necessity in the short term, but the long term solution should involve management measures to treat the causes of the problem.

While the specific details of many waterways problems can be complex, the range of management measures used to address these problems is often surprisingly small (see Summary). However, there may be problems implementing a sustainable solution because the treatment of the causes of problems may be outside the immediate authority of drainage managers, or local problems may be caused from upstream sources beyond the control of the local authority or landowner.

An integrated management approach is required involving co-ordination and co-operation between landowners and various levels and groups in Councils. In terms of operational management:

- For a long term sustaining solution a high priority should be to control the source of the problem (e.g. bank erosion; soil erosion- Hicks 1997)
- Management measures should first occur at critical areas that contribute, or control, the largest proportion of the sediment or contaminant
- It may be impractical to control all the diffuse sources of sediment or contaminants so various practices are required to mitigate influx into waterways (e.g. BMP’s to retard sediment and contaminant movement to a waterway such as buffer strips and wetlands)
- As well, it may be necessary to trap and treat sediment and contaminants in waterways to reduce downstream impacts (e.g. sediment traps; treatment wetlands)

Rarely is there a “silver bullet” solution to a sediment or contaminant problem (EPA 1993). A system of BMPs is normally required. Gale *et al.* (1993) and NRCS (1994) list the key points for successful implementation BMPs:

- Systems of BMPs can be designed to reduce the amount of sediment eroded or contaminants generated, retard the transport of the sediment or contaminant, or remediate impacts, whereas individual BMPs can only affect one of these three mitigation mechanisms
- A BMP system is two or more individual BMPs that are used to control sediment or contaminants from the same critical source (e.g. bank erosion)
- If the sources of the sediment are different, BMP systems must be designed for each source (e.g. grassing bare banks to control surface erosion; re-shaping and planting deep rooted vegetation to stabilise an undercut bank)
- Appropriate combinations of BMPs should be determined based on local conditions, sensitivity of the site and experience
- The effectiveness of systems of BMPs can be evaluated
- To aid in the selection process of BMPs a matrix of problems, management measures and BMPs is presented for the major waterway management problems. Where information is available the performance of individual BMPs for particular purposes is presented.

2.8 An overview of environmental policies-legislation

2.8.1 Introduction

Various Acts, policies and plans are relevant to drainage management. These include, but are not limited to:

- Land Drainage Act 1908
- Soil Conservation and Rivers Control Act 1941
- Local Government Act (1974)
- Resource Management Act 1991
- Other policies and plans

Selected excerpts are presented. For further information consult Regional and District Council staff.

2.8.2 Land Drainage Act 1908

An Act to consolidate certain enactments of the General Assembly relating to the drainage of land.

“Drain” includes every passage, natural watercourse, or channel on or under ground through which water flows continuously or otherwise, except a navigable river, but does not include a water race as defined in section 58 hereof:”

Section 17. To construct and maintain drains and watercourses -

(a) Cleanse, repair, or otherwise maintain in a due state of efficiency any existing watercourse or outfall for water, either within or beyond the district, or any existing bank or defence against water.

(b) Deepen, widen, straighten, divert, or otherwise improve any existing watercourse or outfall for water, either within or beyond the district, or remove obstructions to watercourses or outfalls for water, or raise, widen, or otherwise alter any existing defence against water.

(c) Make any new watercourse or new outfall for water, or erect any new defence against water …

(j) In the making, widening, deepening, cleansing, or repairing of any drain or ditch, remove the soil thereof, and place it on the bank on either side of such drain or ditch.

(k) Fill up or obstruct any drain.

Section 25. Watercourses not allowed to become a nuisance –

(1) Every Board shall cause all watercourses and drains vested in it or under its management to be so constructed and kept as not to be a nuisance or injurious to health, and to be properly cleared and cleansed, and maintained in proper order.

Section 62. Local authority may order removal of obstruction from watercourse or drain-

(1) Where there is any watercourse or drain … and its obstruction, in the opinion of the local authority, is likely to cause damage to any property … the local authority may order the occupier … (or … the owner) … to remove from such watercourse or drain, and from the banks of such watercourse or drain to a distance not exceeding [[3 metres]] from the nearest margin of the watercourse or drain, all obstructions of any kind calculated to impede the free flow of water in such watercourse or drain.

(1A) For all the purposes of this section-

(a) ``Obstructions'' includes earth, stone, timber, and material of all kinds, and trees, plants, weeds, and growths of all kinds.

(b) The occupier or owner of land adjoining a road shall be deemed to be the occupier or owner of land on the banks of any watercourse or drain running upon such road where such road fronts the land of such occupier or owner, unless such watercourse or drain has been artificially constructed by the local authority for the purpose only of draining the surface of such road.

(c) ``Remove'', in relation to any obstruction consisting of trees, plants, weeds, or growths, includes, if the local authority so specifies, burning, poisoning, cutting, or treating, whether with or without the removal of the burnt, poisoned, cut, or treated portions.

(2) Every occupier or owner who fails to … complete the work within the time specified … is liable to a fine … and a further sum equal to the cost incurred by the local authority in removing any such obstruction….

(3) The local authority, for the purpose of removing any obstruction from a watercourse or drain, either within or beyond the limits of the district of its jurisdiction, shall by its servants have the free rights of ingress, egress, and regress on any land on the banks of any such watercourse or through which any such drain runs.

Section 63. Power to compel local authority to order removal of weeds and obstructions-

In summary, ratepayers can request the local authority to order a specified occupier or owner of land to remove weeds and other growth or refuse and obstructions from drains. If the local authority does not act, then a complaint can be laid to a District Court Judge who will rule on the action required.

Section 76. Power of applicants to clear drains-

(1) After drains have been opened or improvements in drains made under this Part of this Act, it shall be lawful for the applicant, and his successors in title for ever thereafter, from time to time, as it becomes necessary, to enter upon the lands through which such drains have been opened or improvements in drains made, for the purpose of clearing out, scouring, and otherwise maintaining the same in a due state of efficiency.

(2) If such drains or improvements in drains are not kept so cleared, scoured, or maintained in a due state of efficiency, the owners or

occupiers for the time being of the lands through, on, or between which such drains or improvements in drains are made may, after giving 7 clear days' notice of their intention so to do, clear out, scour, and otherwise maintain the same in a due state of efficiency, and recover in a summary manner from the applicant, or his successors in title, a fair and equitable proportion of the expenses incurred by them in so doing.

Section 78. Obstructing or injuring drains-

Every person who wilfully obstructs any person making any drain or improvements in drains under this Part of this Act, or who wilfully dams up, obstructs, or in any way injures any drains or improvements in drains so opened or made, is liable for each offence to a fine not exceeding [$100].

2.8.3 Soil Conservation and Rivers Control Act 1941

This Act has the following objectives: promote soil conservation; prevent and mitigate soil erosion; and prevent flood damage. ``Watercourse'' includes every river, stream, passage, and channel on or under the ground, whether natural or not, through which water flows, whether continuously or intermittently. Drainage functions were repealed in 1991.

2.8.4 Local Government Act 1974

This Act allows Councils to purchase, or make and maintain, or enlarge, and from time to time alter, extend, or repair, any drainage channel or land drainage works constructed under the Act. “Land drainage works”' means works of any sort for the drainage of land in the district (being works vested in the council or acquired or constructed or operated by or under the control of the council under this Part of this Act), including drainage channels for receiving water in its natural flow on or from any hills or other lands, and works diverting or damming the same to prevent its overflow on to any other lands at a lower level, as well as drainage channels for carrying of water from any land. Councils may direct landowners to provide drainage where required and to maintain vegetation to prevent obstructions to drains. Many of the drainage related functions were repealed in 1991.

2.8.5 Resource Management Act 1991

New Zealand’s key environmental laws, including the Resource Management Act 1991 (RMA), are explicitly based on the ethic of sustainability with the obligation to sustain the natural environment not just of current use, but for its ecological functions, its intrinsic value and its potential to future generations (Day & Hudson 2001). “… under this ethic, the environment is no longer the economy’s servant but its host, and extinction’s and environmental degradation are no longer acceptable prices to pay in the pursuit of economic growth” (MfE 1997, page 1.3). In reality, the Act requires ecosystem management in its broad sense (GAO 1994).

The RMA represents the most recent step in the evolution of water management in New Zealand (Day & Hudson 2001). The Land Drainage Act 1908 facilitated the drainage of land. The passage of the Soil Conservation and Rivers Control Act in 1941 reflected the need to contain flooding of communities and agricultural lands so important to the country's agrarian growth. As the country developed, the degradation of natural waterways led to another legislative step, the Water and Soil Conservation Act (1967), and a new centralised agency, the Ministry of Works and Development, to service the Act.

As development interests, such as hydroelectric power and irrigation schemes, continued public interest in conservation and environmental management grew. The resulting conflict directly led to the Resource Management Act and its expectations of a balanced, ecological approach.

With respect to waterway management the RMA is important because:

1) It establishes a holistic context for management decisions.
2) It is effects based.
3) It assigns the river and land management role to local government.
4) It sets out the steps local government must follow to legally implement the RMA.

While another Act may give council's or territorial authorities the power to undertake certain functions, these must be undertaken in a manner that is conducive to Part II of the Act - Purposes and Principles. Consent may still be needed to do so under the RMA. Regional and District Council plans and policies will vary, but must be consistent with the Act.

Section 5 requires that the use, development and protection of natural and physical resources be used in a way or a rate which safeguards the life-supporting capacity of water and ecosystems.

Section 6 considers matters of national importance: S6(a) "preservation of natural character of … lakes rivers and their margins and protection of them from inappropriate use and development"; S6(e): Relationship of Maori and their culture and traditions with ancestral lands, water.

Matters of relevance in section 7 are: S7(c): Maintenance and enhancement of amenity values; S7(d): Intrinsic values of ecosystems; S7(f): Maintenance and enhancement of the quality of the environment; and S7(h): Protection of the habitat of trout and salmon.

Section 30(1)(c)(iv) of the Resource Management Act lists functions of regional councils under the act:

> the control of the use of land for the purpose of:-
>
> Soil conservation;
>
> The maintenance and enhancement of the quality of water in water bodies and coastal water;
>
> The maintenance of the quantity of water in water bodies and coastal water;

> The avoidance or mitigation of natural hazards;
>
> The prevention or mitigation of any adverse effects of the storage, use, disposal, or transportation of hazardous substances:

where natural hazard is defined as:

> any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment.

Section 30(1)(e) & (f) may also be relevant to drainage work:

> The control of the taking, use, damming, and diversion of water, and the control of the quantity, level, and flow of water in any water body, including-
>
> The setting of any maximum or minimum levels or flows of water;
>
> The control of the range, or rate of change, of levels or flows of water;
>
> The control of the taking or use of geothermal energy;
>
> The control of discharges of contaminants into or onto land, air, or water and discharges of water into water:

where contaminant is defined as:

> “Contaminant" includes any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy, or heat-
>
> (a) When discharged into water, changes or is likely to change the physical, chemical, or biological condition of water; or
>
> (b) When discharged onto or into land or into air, changes or is likely to change the physical, chemical, or biological condition of the land or air onto or into which it is discharged: (s2 Resource Management Act 1991).

Section 70 (Rules about discharges) and 107 (Restrictions on grant of certain discharge permits) specify narrative water quality standards (i.e. the intent of the legislation is provided without specifying numerical criteria). The sections specify that there shall be no “conspicuous change in colour or visual clarity” and no “significant adverse effects on aquatic life” following the discharge of contaminants into receiving waters (after reasonable mixing). MfE (1994) noted “conspicuous change” is not defined in law.

For farm drains (“canals”) the generality of RMA Section 17 (avoid, remedy, mitigate …) and the specifics of dumping drain spoil on land (Section 9) would logically apply. Section 9 relates to rules in District Plans or Proposed District Plans. Therefore it will be necessary to consult the transitional and any proposed District Plans or Regional Plans.

Numerous sections of the RMA relate to rivers and river and lake beds. However these sections may not apply to drainage ditches. “River” means a continually or intermittently flowing body of fresh water, and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal): (RMA Section 2).

An “artificial watercourse” was not defined in the RMA. In case law an “artificial watercourse” was determined in B.N. Johnston & E.E. Brown v Dunedin City Council (C64/94). This case concerned the Silverstream in the Taieri Plains - Otago. The judges asserted that the Silverstream is a river as defined in the Act. The original Silverstream had been diverted through an artificial channel. The judges accepted that it is a common practice to divert rivers for drainage purposes but that does not mean that they cease to be rivers or that the course that they then follow, becomes an artificial watercourse. The waters within that channel or diversion remain part of the continually or intermittently flowing body of fresh water. Therefore where a river has been diverted into a drainage channel it remains a river and not an artificial watercourse.

In the “Proposed Waikato Regional Plan as Amended by Decisions and the Environment Court” (updated January 2004) an artificial watercourse was defined as “A watercourse that contains no natural portions from its confluence with a river or stream to its headwaters and includes irrigation canals, water supply races, canals for the supply of water for electricity power generation and farm drainage canals.” A modified watercourse was defined as “An artificial or modified channel that may or may not be on the original watercourse alignment and which has a natural channel at its headwaters.” A river was defined as “A continually or intermittently flowing body of fresh water, and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal).”

The Environment Court determined that the Cust Main Drain, a 10 km straight channel dug about 100 years ago to drain the Rangiora swamp, was not an “artificial watercourse” but a “river” for the purposes of setting a residual streamflow. (The Press, July 26, 2002).

2.8.6 Other acts, policies and plans

These Acts are described in detail in national and regional policy statements and proposed or operational plans. The plans and policy statements are not repeated here – advice should be sought from the regional councils. But in general, regional policy statements and water plans identify beneficial uses of waterways including:

- Intrinsic values of aquatic ecosystems
- Recreational values/ability to safely swim

- Natural character/amenity/landscape values
- Cultural/spiritual values and
- Human use values.

Section 418 of the RMA provides temporary exemptions from various restrictions in Section 13(1) of the RMA. Section 418(3B) basically states that if an activity did not require any authorisation, and it was lawfully being carried out before 1 October 1991, then it can continue to be undertaken until a regional plan says otherwise.

An area not traditionally considered in river engineering and waterway maintenance is Part 5 of the Biosecurity Act (1993) that provides for the management of pests already established in New Zealand. National Pest Management Strategies have been developed for various plants by Ministry of Agriculture and Fisheries (MAF) including three aquatic species (salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*)). Regional Pest Management Strategies target more aquatic plants (e.g. ccc.govt.nz/ parks/ TheEnvironment/ weed-guide_status.asp; and envbop.govt.nz/land/media/pdf/Pp1300.pdf).

Consult with the appropriate local authorities and obtain resource consents where required before proceeding with drainage management activities.

Citation:
Hudson, H.R. 2005. Drainage management context. Pages 2.1-2.18 in Hudson, H.R., editor. H20-DSS: Hillslopes to Oceans Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington. Available online at www.nzwerf.org.nz

3 Drainage problems and solutions: introduction

Waterway managers face a broad range of issues, such as network efficiency, and costs of land drainage (see Management context), but the focus here is on physical issues related to drainage maintenance, specifically:

- Sedimentation - loss of outfall due to sediment build up
- Vegetation - loss of outfall due to aquatic weeds and bank vegetation
- Water quality - drainage systems collect and transfer contaminants leading to a deterioration of water quality in receiving waterways
- Biodiversity - adverse effects on aquatic and marginal terrestrial flora and fauna, mahinga kai, cultural and amenity values

Each of these chapters is divided into four sections that describe problems (including performance objectives), causes, management measures and an overview of appropriate best management practices (BMPs). Before embarking on the implementation of BMPs several steps were recommended in the section on Management Context:

1) Establish the management principles and processes.
2) Assess risks.
3) Define agricultural, environmental and hydraulic performance objectives:
4) Review the key question in decision making.
5) Prioritise what management measures will be undertaken and where.
6) Select a combination of BMPs to address problems.

Regarding performance objectives, several tenets underpin the decision support system and field guide:

1) Drainage networks have multiple functions: they should act as efficient, cost-effective channels for removing excess water, while still providing sustainable habitats for flora and fauna.
2) Adopting effective and sustainable drainage network maintenance practices requires understanding of the hydraulic, geomorphologic and ecologic effects of these practices:
3) Waterway behaviour is complex and intervention may result in unexpected adverse effects, so management needs careful judgement
4) A clear understanding of the problem or issue to be addressed, and the underlying causes, is required
5) Take a broad view of the problem, considering the site in relation to the overall catchment

Key questions in decision making

1) What is the problem? A clear identification of the particular problem(s) is a prerequisite to any management intervention.
2) What are the causes? There may be multiple causes of a particular problem. The sources, and magnitude and frequency of contribution to the problem must be identified to prioritise actions. Management should always try to address the causes of a problem. Treatment of effects without addressing the causes may result in expensive, repetitive actions that are unsustainable and unsuccessful.
3) What is the objective? Have a clear idea of what you have to achieve both locally (e.g. removing sediment) and at a reach (e.g. general channel instability) or perhaps catchment scale (e.g. changing land use). Check if these objectives are realistic and will bring a demonstrable benefit.
4) Is intervention required? In some cases indirect actions may solve the problem. E.g. local bank failures may stabilise and the blockage may be naturally removed by streamflow if livestock grazing on the banks is controlled.
5) What are the most appropriate methods to relieve effects and to achieve a long term solution? The choice of management practices and the location and timing of operations will determine the success of the project and likely impacts. The decision support system will help select practices.
6) Is consultation and resource consent required? Early and extensive consultation with relevant regulatory authorities, interest groups and individuals is crucial. Obtain the required authorisations.
7) Are there negative local impacts? Think what other activities might be indirectly or inadvertently affected. E.g. riparian planting may prevent access for future drainage management; using heavy equipment to clear a channel may cause land disturbance and loss of farm productivity.
8) What effects might the works have elsewhere? Actions in part of a waterway may have impacts upstream (e.g. erosion with channel excavation), downstream (e.g. sediment plumes) or laterally (e.g. de-watering wetlands).
9) When is the best time to undertake work? Some emergency works have to be undertaken immediately. For routine maintenance consideration should always be given to sensitive times and places for fish and wildlife; and to the most effective timing for weed management (which is often not when weed growth is at a maximum). Flood or erosion risk should also be considered.
10) What are the chances of success and risks of failure of the proposed actions?
11) What are the risks of no intervention?
12) Is help or consultation required? Even if activities are permitted under council plans, it may be beneficial to consult with others to deal with particular problems.

6) Causes of problems must be controlled to achieve a sustainable solution
7) Long-term solutions, although perhaps more expensive at the time, are often more cost-effective than repeated short-term approaches
8) Look for environmentally beneficial options to reduce costs and minimise disturbance; including not intervening at all
9) Drainage networks are a part of, and intimately linked to, larger freshwater systems
10) Consult with others to assess the potential for a broader based solution involving upstream, downstream and adjacent landowners
11) Consult with the appropriate local authorities and obtain resource consents where required before proceeding with drainage management activities.

Citation:
Hudson, H.R. 2005. Drainage problems and solutions: introduction. Pages 3.1-3.3 in Hudson, H.R., editor. H20-DSS: Hillslopes to Oceans Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington. Available online at www.nzwerf.org.nz

4 Drainage problems and solutions: sedimentation

4.1 Sedimentation problems

Sedimentation includes the processes of erosion, transport and deposition of sediment, in this case by the action of wind and water.

Sediment loads in New Zealand streams are naturally high primarily because of rainfall patterns, and because of catchment geology and land use characteristics (Hicks & Griffiths 1992). In drainage management areas rates of erosion may be accelerated by land use change and channel instability caused by increased runoff or modification to channels.

Suspended sediment loads

In New Zealand about 400 million tonnes of sediment per year is transported from the land to the oceans, with a considerable variation in time and space.
Quoting various sources, Hicks & Griffiths (1992) report flood flow concentrations ranging from a few hundred to a few thousand mg/L for small and undisturbed catchments in low hill country; to peaks of ~12,000 mg/L for large east coast South Island rivers.
Extremely high concentrations (40,000-60,000 mg/L) are not uncommon in East Cape, North Island, Papa mudstone catchments. High concentrations (on the order of 30,000 mg/L) have been measured in small catchments disturbed by earth-moving machinery, such as during forest harvesting or urbanisation.

A common problem in drainage management in New Zealand was loss of outfall caused by sediment deposition (Hudson & Harding 2004). Sediment deposition occurs because the water velocity decreases to the point where sediment motion in the water column or along the bed can no longer be maintained. Sediment deposition can obstruct the channel, and may increase hydraulic roughness, resulting in elevated water levels and possibly flooding.

The correct immediate management response is to excavate channels to restore the required outfall, but unless the sources of sediment are controlled, frequent sediment removal may be required. Effective sediment control will reduce costs by reducing the frequency or eliminating the need to remove sediment from waterways. As well as benefits to land productivity by controlling erosion, there are instream environmental benefits from controlling excessive sediment. In addition, there are sediment related water quality guidelines that must be adhered to.

Taking a more holistic view, several aspects of the sedimentation problem are addressed:

- Environmental effects
- Sediment guidelines
- Causes of sedimentation

    - Upland erosion
    - Channel erosion
    - Bank erosion
- Management measures
- Best management practices (BMPs).

4.2 Environmental effects

While turbid or 'muddy' water is natural, particularly during storm runoff, excessive sediment can adversely affect freshwater ecosystems. The issue facing drainage managers is the effect of temporary increases in suspended particulate matter, and the effect of sediment deposition, resulting from drainage management. Reviews by Bjornn & Reiser (1991), Ryan (1991) Waters (1995) and ANZECC (2000) report the following sediment related problems; many of which have been documented in New Zealand.

- Reduced light penetration reducing primary productivity (Davis-Colley *et al.* 1992)
- Abrasion of periphyton (Biggs *et al.* 1999)
- Smothering of aquatic plants or propagules (Dugdale *et al.* 2001)
- Impairment of feeding or feeding behaviour changes of native fish and trout (Rowe *et al.* 2002, 2003); snails and mayfly (Broekhuizen *et al.* 2001)
- Abrasion of benthic invertebrates by suspended sediment
- Smothering of benthic organisms and their habitat (Quinn *et al.* 1992)
- Increased invertebrate drift with sediment deposition (Suren & Jowett 2001; cf. Bond & Downes 2003)
- Impairments to migration of native fish (Boubée *et al.* 1997; Richardson *et al.* 2001)
- Avoidance of streams with high sediment loads by fish (Rowe *et al.* 2000; Richardson & Jowett 2002)
- Mortality of fish (e.g. through gill abrasion) (Rowe *et al.* 2004)
- Smothering of fish eggs buried in the bed
- Prevention of the emergence of small fish from gravel beds
- Loss of streambed shelter for native fish with fine sediment deposition (Jowett & Boustead 2001)

Increased runoff and sediment can contribute high nutrient loadings and toxic substances attached to sediment particles can significantly degrade receiving water quality and habitats (USEPA 1999). If the sediment is highly organic in nature, there may be an additional oxygen demand (ANZECC 2000).

As well as a loss of productive capabilities of land from erosion or deposition, there can be a wide range of downstream physical impacts such as loss of reservoir capacity, infilling of estuaries and lagoons; with impacts on plants and fish (ANZECC 2000), and shellfish such as mussels and pipi's (Hancock & Hewitt 2004).

While the impacts of sediment on stream systems have been the subject of numerous studies, there is little published information overseas or in New Zealand on the sediment related effects of maintenance activities (e.g. bank protection works; channel excavations) (Hudson & Harding 2004). Brookes (1988) reported significant deposition following channel clearing in Wallop Brook in England, while in the River Wylye sediment deposition was negligible when cleaning operations coincided with a period of high flow. Wilcock *et al.* (1998) reported short term increases in turbidity (~3 h) with clearing of a Waikato drain, New Zealand. The removal of weeds and sediment had a direct affect on macro invertebrates, particularly snails.

Without information on the impacts of maintenance activities on waterways there is a concern that in some circumstances "… aesthetic reactions to suspended sediment may be of more concern than biological ones." (Ryan 1991). Conversely, there may be significant undetected environmental effects. Critical issues regarding sediment release during maintenance activities include how much, how persistent, what are the effects, and can adverse effects be avoided or mitigated?

4.3 Sediment Guidelines

There are problems with existing sediment guidelines. Earlier ANZECC (1992) guidelines recommended that increases in SPM should be limited such that the optical guidelines are maintained and that the seasonal mean nephelometric turbidity (NTU) does not change by more than 10%. Present ANZECC guidelines vary regionally within Australia. New Zealand default trigger values are presented for water clarity and turbidity for unmodified or slightly disturbed ecosystems. Interim values for upland rivers are 0.6 m^{-1} clarity and 4.1 NTU turbidity; and 0.8 m^{-1} clarity and 5.6 NTU turbidity for lowland rivers (ANZECC 2000).

- These values are far lower than the turbidity affecting primary productivity, macroinvertebrates, and migration and feeding of fish found in New Zealand streams
- These values do not recognise inherent differences in background levels which are extremely variable in New Zealand
- These values do not appear to consider research showing that aquatic biota respond to both the concentration of suspended sediments and the duration of exposure (e.g. Newcombe & MacDonald 1991; Shaw & Richardson 2001)

ANZECC (2000) guidelines are based on a model relating primary productivity to turbidity (Lloyd *et al.* 1987). The model suggested a 5 NTU increase in a clear, shallow stream would decrease gross primary productivity by 3-13%; and an increase of 25 NTU would decrease gross primary productivity by 13-50%. Davies-Colley *et al.* (1992) found that a 25

NTU increase in a previously clear New Zealand stream resulted in a 50% reduction in plant production.

Quinn *et al.* (1992) reported that turbidity increases of 7-154 NTU over several months resulted in a decreased invertebrate density of 9-45%. Growth rates of the Hydrobiid snail *Potamopyrgus antipodarum*,, dominant in macroinvertebrate communities in low-order pasture streams, was highest at intermediate levels of sediment contamination and lowest in the treatment with no sediment added (Broekhuizen *et al.* 2001). At high sediment concentrations growth rates were lower and mortality high. The mayfly *Deleatidium* sp., which is abundant in clean water streams, is unable at least in the short term to compensate for the 'dilution' of its food with sediment by increasing the efficiency with which it assimilates organic material.

In laboratory experiments juvenile native fish have been shown to avoid dirty water. For banded kokopu, 50% avoidance was observed at 25 NTU; for koaro and inanga 50% avoidance occurred at 420 NTU (Boubée *et al.* 1997). There was no avoidance by shortfinned and longfined eel elvers and redfinned bullies at the highest turbidity (1100 NTU). A limit of 15 NTU in otherwise clear waterways was recommended to ensure that upstream migration would not be affected. In a stream setting neither the migration rate nor the migration direction of banded kokopu were affected at turbidity <25 NTU (Richardson *et al.* 2001).

Feeding rates of adult inanga and riverine smelt in laboratory tanks did not reduce at turbidity levels up to 160 NTU (Rowe *et al.* 2002). Juvenile trout feeding rates on limnetic and benthic prey in laboratory tanks were not reduced by turbidities up to 160 NTU (Rowe *et al.* (2003). Although trout were strongly size-selective for both large chironomid and *Deleatidium* larvae in clear water; turbidities over 20 and 160 NTU reduced size-selection. The ability to detect and capture prey when turbidities are high and when light levels are low is expected to offset any reduction in visual feeding caused by increased turbidity and helps explain the increased emphasis on epibenthic feeding by trout in turbid waters.

Fatal levels of sediment for salmonids show highly variable results (Waters 1995). Concentrations of suspended sediment that have been determined to kill fish over a period of hours typically range from hundreds to hundreds of thousands of milligrams of sediment per litre. Concentrations that may harm fish but not kill them directly (sublethal effects) are often in the ten to hundreds of milligrams of sediment per litre range.

New Zealand rivers can be extremely turbid for several days at a time during floods and native fish appear to be able to cope with such short spells of high turbidity (Rowe *et al.* 2004). Both red-finned bullies and banded kokopu can tolerate extreme turbidity, with lethal levels exceeding 38,000 NTU - a value that would not occur in most rivers. Turbidity producing 50% mortality over 24 hours ranged from 1700 to 3000 NTU for smelt and 17,500 to 21,000 NTU for inanga. It was recommend that maximum turbidities should not exceed 3,000 NTU for more than 24 hours in rivers and streams of the Auckland region (or 1,500 NTU if oxygen concentrations and pH are also low).

In setting sediment standards for the protection of fish and their habitat, DFO (2000) recognised that sediment and its associated effect on water clarity is an inherent and variable component of aquatic ecosystems. The adopted standards recognise there is an increased risk to the survival and well being of aquatic organisms when sediment levels exceed background values for a particular duration (Canadian Council of Resource and Environment Ministers CCREM guidelines). However:

- Laboratory based measures, such as suspended particulate matter, are impractical to address in real-time compliance monitoring - the turn around time for samples is too long, and analytical costs are relatively high
- Turbidity is a relative index of light scattering, with highly variable results between instruments, and it has no intrinsic environmental relevance unless calibrated to suspended solids or visual clarity. Calibration is required for each site because there is no universal relationship (Smith & Davies-Colley 2002)

CCREM (1999) guidelines

Suspended Sediments

Clear flow: Maximum increase of 25 mg-L^{-1} from background levels for short term (e.g. <24 h) exposures, and a maximum average increase of 5 mg-L^{-1} from background for longer term exposure (e.g. 24 hours to 30 days).
High flow: Maximum increase of 25 mg-L^{-1}from background levels at any time when background levels are between 25 mg-L^{-1} and 250mg-L^{-1}. Should not increase more than 10% of background levels when background levels are >250 mg-L^{-1}.

Turbidity

Clear flow: Maximum increase of 8 NTUs from background levels for short term (e.g. <24 h) exposures, and a maximum average increase of 2 NTUs from background for longer-term exposures (e.g. 24 hours to 30 days).
High flow or turbid water: Maximum increase of 8 NTUs from background levels at any time when background levels are between 8 NTUs and 80 NTUs. Turbidity should not increase more than 10% of background levels when background levels are >80 NTUs.

Clarity is easily perceived and measured by black disc or beam attenuation and is relevant to aesthetic quality of water and habitat. Therefore clarity is a preferred measure (Smith & Davies-Colley 2002)

In terms of practical guidelines, the recommendation for the Tasman District general river works resource consent conditions stated: “The consent holder shall ensure that, as a result of carrying out any river works authorised by this consent, the clarity of any receiving water shall not be decreased by more than 50% instantaneously, or 30% over a 24 hour period, when measured by the black disc method. The point of measurement shall be approximately 200 metres downstream of the work site, but not less than seven channel widths downstream. Clarity shall be compared with the stream clarity immediately upstream of the work site.” (Hudson 2001). (The guideline is used in conjunction with a guideline on sediment deposition):

- The 50% instantaneous decrease in clarity recognises that short duration activities (e.g. uprooting a tree, or placing rock along a bank) will cause a short duration plume of highly discoloured water. However, as long as this is almost instantaneous, this will not have significant adverse effect (particularly given the resource consent condition related to deposition on the bed - embeddedness). (MfE 1994 indicate that there is widespread use by regional councils of turbidity increases ranging from 50% to 100%, which implies that these values have public acceptance and are appropriate for general waters. These turbidity changes correspond approximately to visual clarity changes of 33% to 50%. For Class A waters, where visual clarity is an important characteristic of the waterbody, a visual clarity change of <20% was recommended)
- The 30% decrease in clarity over background levels would be perceptible to most observers (MfE 1994); hence the restriction on protracted discolouration
- The resource consent conditions recognise that visible discolouration from some activities will occur over a period of hours, but that if this were protracted and deposition was excessive, then special measures would be required to control sediment (e.g. bund the work site, divert flow)

Smothering of the streambed with fine material was recognised as having a significant impact on aquatic life, but MfE (1994) and ANZECC (2000) do not provide guidelines. Overseas measures of embeddedness are often used because there is a well defined relation between salmonid spawning success and embeddedness (e.g. Bjornn & Reiser 1991; MacDonald *et al.* 1991; Bain 1999). Jellyman (pers. comm.) has suggested that embeddedness is an important determinant of habitat suitability for small eels in New Zealand streams. Experiments by Jowett & Boustead (2001) show that "When sufficient fine sediment was added to fill the spaces under the cobbles, bully numbers reduced by more than 60%....when cobbles were raised above the fine sediment, the numbers of bullies remaining in the channels was similar to the number of bullies remaining with cobbles and no sediment."

In developing consent conditions for general river works for the Tasman District, embeddedness was included: "The consent holder shall ensure that, as a result of carrying out any river works authorised by this consent, that deposition of fine sediment (i.e. < 2mm diameter: sand, silt, and clay) does not increase the embeddedness of runs and riffles by more than 10% over a 24-hour period." (Hudson 2001). A standard measure of embeddedness was recommended (Bain & Stevenson 1999).

Further research is required:

1) To evaluate how much sediment is derived from drainage management activities.
2) To evaluate if the proposed sediment guidelines are appropriate from a management and environmental perspective.

4.4 Causes of sedimentation

Suspended particulate matter (SPM) is derived from point sources such as sewage outfalls, storm water drains and construction sites; and from diffuse sources such as soil erosion and stream bank erosion. Point sources are expected to be controlled by resource consent conditions. Here we are concerned with diffuse sources, particularly upland erosion, channel erosion and bank erosion.

4.4.1 Upland erosion

Upland erosion, often referred to as “soil erosion” is caused by surface wash processes (e.g. rain-splash and surface runoff over exposed soil), concentrated flow (e.g. rilling, gullying), wind, and mass movements (e.g. slumps and slides).

Detachment occurs when water splashes onto the soil surface and dislodges soil particles, or when water or wind reaches sufficient velocity to dislodge soil particles on the surface. Sediment transport is reduced by crop residues and vegetative cover. Vegetation slows runoff, increases infiltration, reduces wind velocity, and traps sediment. Reductions in slope length and steepness (e.g. by contouring land; and diversion embankments and channels) reduce runoff velocity, thereby reducing sediment carrying capacity.

In terms of a sensitivity analysis of the revised universal soil loss equation, rates of soil erosion are largely governed by land management practices, particularly the vegetative cover (Renard *et al.* 1997). Topography is of secondary importance. If slopes are very gentle, surface wash processes will not remove significant amounts of soil, even with exposed ground (but wind erosion may be very important). If there is a dense protective vegetation cover, minimal soil erosion will occur on steep land with long slopes. Rainfall energetics and soil erodibility have a smaller influence. In the revised universal soil loss equation the topographic factor can vary by a factor of over 100, rainfall energetics vary by a factor of about 20 (across Washington and Oregon); and the soil erodibility factor varies by factor of about 6 globally. Hence the prime focus of runoff and erosion control is appropriate land management. The amount of material generated from upland areas will determine the size and effectiveness of mitigation measures which control the movement of sediment (and associated contaminants) to the stream.

4.4.2 Channel bed erosion

Streams are inherently unstable - they are subject to the forces of flowing water in the channel, and seepage flows and other forces acting on the banks. Additionally, surface runoff from surrounding land may flow erode stream banks; and stock may trample stream banks and re-suspend sediment on the bed (e.g. Williamson *et al.* 1992).

Degradation or local scour of the channel occurs when the force of water is excessive relative to the erosion resistance of the stream bed. This may be attributed to increased flow (e.g. with more efficient drainage increasing flood peaks); change in channel characteristics (e.g. steepened channels by removing meanders; changing the cross sectional form to a trapezoid or U shape); changing the erosion resistance of the bed (e.g. removal of protective material such as logs; or disturbance of the bed armour); over excavation of a channel inducing headward scour (e.g. Mataura and Oreti rivers – Day & Hudson 2000); sediment starvation ("hungry water" below dams – Kondolf 1997; or with reduced supplies of bed material with bank protection - Ashburton River, Hudson 2000).

4.4.3 Bank erosion

While evidence of bank erosion is readily apparent, there are various causes that require different management measures. Bank erosion can be grouped into three categories: scour of the lower bank; sub-aerial erosion of the upper bank; and mass failure. Process dominance is not well understood (Lawler 1992).

With scour the base (toe) of the bank is removed and the bank is undercut and collapses. Erosion occurs when the erosive force of flowing water exceeds the resistance of the bank, material is washed away from the toe of the bank, an overhang may develop, and the bank collapses (Fig. 4.1).

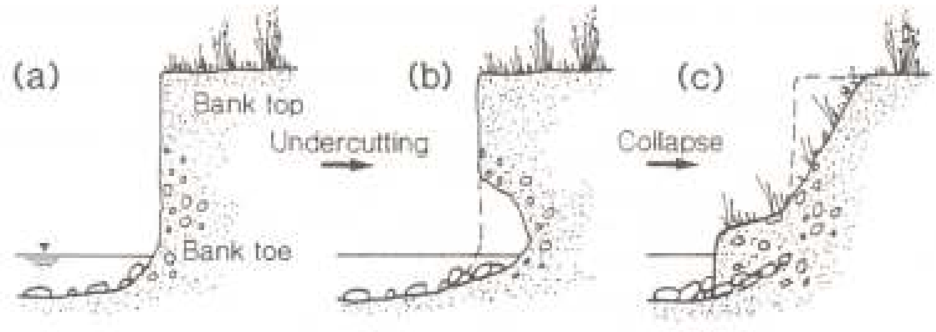

Fig. 4.1. Bank scour sequence. The collapse can be relatively stable in low energy or well vegetated bank situations, or the cycle of undercut and collapse can be repeated (adapted from Collier et al. 1995).

The resistance of stream banks to erosive forces is highly dependent on several factors (based on Rosgen 1996):

- Height of the streambank relative to flow levels
- Rooting depth of streamside vegetation relative to streambank height
- Density and strength of roots
- Composition (types of sediment) and stratigraphy (layering) of streambank materials
- Slope of the streambank

- Bank surface protection from debris and vegetation
- Geometry and type of river channel

Loosening of the bank material by sub-aerial processes may be an important factor (Lawler 1992). Sub-aerial erosion occurs on the exposed list erosion of exposed banks above the normal low flow margins that are continuously wet (Rutherford *et al.* 1999):

- Windthrow: Shallow rooted streamside trees are blown over and pull bank material into the stream. Erosion of the bank may occur as water flows around the tree
- Freeze-thaw: As temperature fluctuates, ice crystals grow and dislodge bank material. Soil particles are disaggregated and are easily washed away
- Desiccation: Banks that have dried out and cracked are more easily eroded
- Slaking: Soil aggregates disintegrate because of trapped air as banks are rapidly submerged
- Surface wash: Exposed soil is directly eroded by rainsplash and water running down the bank
- Stock trampling: Unrestricted stock access directly breaks down banks and moves soil into the stream and exposes soil to surface wash

Mass failures cause blocks of soil to slide or topple into the river (Rutherford *et al.* 1999) (Fig. 4.2):

- Shallow slip: Failure occurs almost parallel to the bank surface usually when the bank is saturated. Failure normally occurs at the contact of an organic rich layer draped over stiffer clay on the bank face
- Slab failure: On steep banks (generally $>60^o$) blocks of soil topple into the stream. Tension cracks are often evident before the failure
- Rotational slump: Often caused by saturation on less steep banks (generally $<60^o$). The failure block is back-tilted away from the channel. The failure may be due to undercutting of the toe or base of the bank, or occur further up the bank. Tension cracks are often evident before the failure
- Cantilever failure: Failure occurs when undercutting leaves a block of unsupported material on the bank top, which then slides or falls into the stream

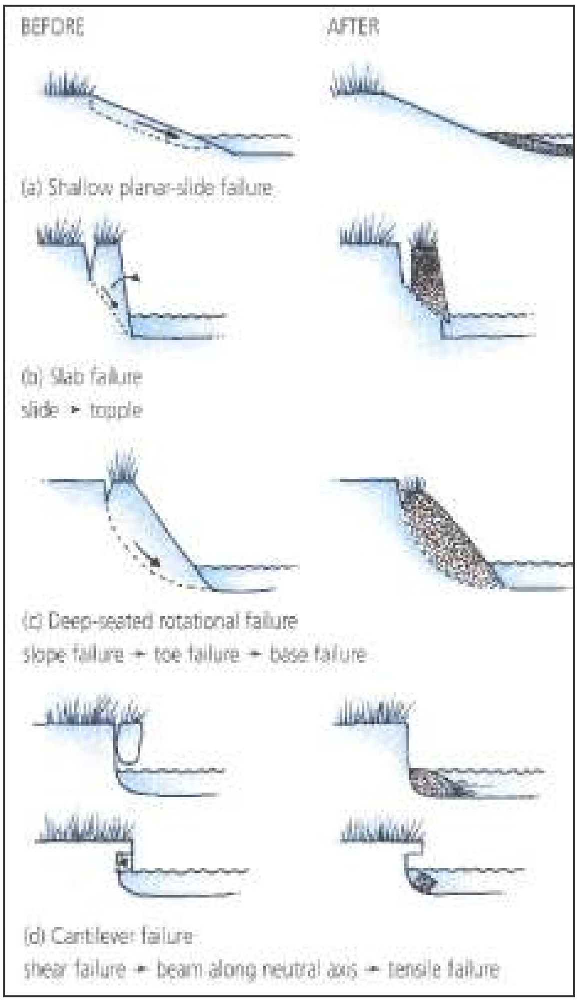

Fig. 4.2. Types of mass failure of river banks (based on Hemphill and Bramley (1989) in Rutherfurd et al. (1999).

4.5 Management measures and practices

In most drainage management programmes, nationally and internationally, little or no emphasis is placed on sediment management (Moore *et al.* 2001; Hudson & Harding 2004). Maintenance is normally reactive - sediment is removed when it becomes a problem. Unless the sources of sediment are controlled, frequent removal, rather than occasional removal, may be required.

It is generally accepted that the most effective method to reduce sedimentation in waterways is to control runoff and erosion. Controlling the transfer of sediment to waterways, and controlling sediment in waterways, should be considered as second lines of defence.

In this section the following are discussed:

- Sediment control objectives
- Sediment removal

- Upland erosion control
- Channel erosion control
- Bank erosion control

4.5.1 Sediment control objectives

Sediment control is focused on upland sources of sediment, transfer of sediment to streams, and instream sediment control. Management objectives can be cast as six rules of sediment management:

- Reduce runoff and soil erosion (and associated contaminants) through land management practices (e.g. excessive stocking rates leading to soil pugging and surface runoff)
- Retain sediments (and contaminants) on the land before they get into the drainage network, either by reducing runoff or through chemical or biological transformation (e.g. using filter strips, grassed waterways, and stream side buffers to trap sediment and contaminants)
- Retard stream flow velocities to protect the channel bed and banks (e.g. using vegetation or riprap); and retard movement downstream by sediment trapping (e.g. instream sediment retention wetlands)
- Repair erosion of the drain (e.g. reshape slumped or eroded banks and protect banks from future erosion)
- Remove stock from the stream bed and stream banks to prevent bank collapse, bank erosion, and concentration of overland runoff into the drain along stock tracks
- Remediate sediment in the drains (and improve water quality) directly (e.g. filtering and utilizing nutrients in channels (Moore *et al.* 2001) or in wetlands (Petersen *et al.* 1992)

4.5.2 Sediment removal

Excavation is often required to remove sediment and other obstructions to restore outfall. Hydraulic excavators are frequently used, but there are some draglines. BMPs for normal maintenance are limited to:

- Work windows: Using work windows, where appropriate, to avoid adverse effects on fish and wildlife by avoiding sensitive places at particular times. Work windows are discussed under Biodiversity
- Channel excavation: To restore the hydraulic capacity of channels that are obstructed by sediment deposits and weeds by excavating excess bed material and weeds. Hydraulic excavators with conventional buckets or weed rakes are used, normally from one bank, with spoil carted from the site or deposited along the edge of the channel.

A more proactive approach to sediment deposition can be undertaken – to trap sediment at preferred locations so as to limit the reach in which excavation is required. These traps can be constructed to trap and treat sediment and contaminants.

- Coarse sediment traps: Sediment traps are relatively wide, short and deep excavations in the bed. Trapped sediment does not progress downstream where deposition would reduce channel capacity. The trap itself has to be episodically excavated (after major storms) rather than a much greater length of the stream. Sediment traps confine sediment deposition to a small reach of channel and reduce excavation costs. They are used as the upstream control in sediment detention wetlands for fine sediment trapping
- Sediment detention wetlands: A wetland constructed for the primary purpose of trapping fine sediment and filtering nutrients and contaminants; with the secondary benefit of providing habitat diversity. Used with an upstream coarse sediment trap

In future developments channel excavations for the maintenance of hydraulic capacity will be modified to incorporate concepts of naturalising channels (e.g. asymmetrical rather than trapezoidal cross sections to produce deep water habitat and maintain a weed free zone - Hudson & Harding 2004).

4.5.3 Upland erosion

There are two general strategies regarding upland erosion. The first, and most desirable, strategy is to implement practices on the field to minimise soil detachment, erosion, and transport of sediment from the field. Effective practices include those that maintain crop residue or vegetative cover on the soil; improve soil properties; reduce slope length, steepness, or unsheltered distance; and reduce effective water and/or wind velocities (USEPA 2003). Hicks (1995) reviewed farmland soil erosion impacts and management options in New Zealand. The major focus of the control of soil erosion on farmland is on maintenance of ground cover:

- Crop residues (e.g. straw) or living vegetative cover (e.g. grasses) on the soil surface protect against detachment by intercepting and/or dissipating the energy of falling raindrops and flowing water

Control of soil erosion on farmland

Hicks (1995) summarised the impact of erosion on New Zealand agriculture, and farm management practices which counteract it. Practices which control erosion include:

- Maintenance of ground cover in arable land:
- Minimum tillage
- Stubble mulching
- Contour ploughing
- Windbreaks
- Grassed waterways

Maintenance of ground cover in pastures:

- Avoid overgrazing
- Oversow and fertilise to improve pasture

Various management practices are accessible through www.envirodirect.co.nz

- A layer of plant material also creates a thick layer of still air next to the soil to buffer against wind erosion

The management measures described in Hicks (1995) are effective for wind and water erosion. Reduced tillage systems are promoted by a large number of groups in the United States because they are both profitable and effective in controlling erosion. Although reduced tillage system results are site specific, erosion reductions in excess of 90% are reported (USEPA 2003).

Additional practices that are particularly effective include:

- Field strip-cropping: Growing crops in a systematic arrangement of strips across the general slope (not on the contour) to reduce water erosion. The crops are arranged so that a strip of grass or a close-growing crop is alternated with a clean-tilled crop or fallow. Effectiveness is rated as low to medium (Nokes & Ward 1992); with an average effectiveness in reducing erosion of 65% (USEPA 2003)
- Terracing: An earthen embankment, a channel, or combination ridge and channel constructed across the slope to reduce soil erosion and retain runoff for moisture conservation. An average effectiveness in reducing erosion of 85% has been reported (USEPA 2003). Effectiveness is rated as medium to high (Nokes & Ward 1992)
- Critical area planting: Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, in critically eroding areas such as gullies (does not include tree planting mainly for wood products)

The second strategy, which can be used in combination with the control of soil erosion, is to divert, filter, trap, or settle soil particles in surface runoff between the source and the channel. BMPs include:

- Interceptor drains (diversions): Small channels with a minor ridge along one edge that collect and direct surface water to a desired location such as a stable outlet or sedimentation pond. The drains and bunds can either have a natural grass lining or, depending on slope and design velocity, a protective lining, or gravel bed. They protect sensitive areas or work areas from upslope runoff and erosion; ensure that sediment-laden stormwater will not leave the site without treatment (e.g. diversion to a sedimentation pond); and divert water. Effectiveness is rated as low to medium for sediment control (Nokes & Ward 1992)
- Water and sediment control basin: An earthen embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin to reduce erosion, trap sediment and reduce and manage onsite and downstream runoff. Effectiveness is rated as medium to high for sediment control (Nokes & Ward 1992)
- Grassed waterways: Broad, shallow, natural or constructed channel that is grassed so as to move surface storm water across land

without causing soil erosion (e.g. rills, gullies). Effectiveness is rated as low to medium for sediment control (Nokes & Ward 1992)

- Field border: A strip of perennial vegetation established at the edge of a field by planting or by converting it from trees to grasses or shrubs. Effectiveness is rated as low to medium for sediment control (Nokes & Ward 1992)
- Filter strip: A strip of vegetation along a waterway margin that intercepts sediment, organics, nutrients, pesticides, and other contaminants from shallow surface flow. Effectiveness is rated as low to medium for sediment control (Nokes & Ward 1992); but this is highly dependent on the volume of sediment generated, topography, and cover conditions. Highly efficient trapping (>90%) is possible (Karssies & Prosser 1999)

An average effectiveness in reducing erosion of the various vegetative control methods (filter strips, field border and grassed water) of 65% has been reported (USEPA 2003).

Erosion control practices such as terracing and grassed waterways are generally successful in temperate areas but may be overwhelmed by torrential rains. Practices that conserve the soil, such as mulch farming, reduced tillage, mixed cropping with multi-storey canopy structure, and strip-cropping with perennial sod crops are more likely to be successful (e.g. Troeh *et al.* 1980; Lal 1983).

4.5.4 Streambed erosion

Stream bed degradation (general lowering of the bed) is normally controlled by structural measures installed in the channel to prevent further erosion, arrest the upstream migration of a knick-point or headcut, or promote aggradation:

- Grade control structures: Rock, wood, earth, and other material structures placed across the channel and anchored in the streambank to provide a “hard point” in the streambed that resists the erosion forces of the degradational zone, and/or to reduce the upstream energy slope to prevent bed scour. These structures can be installed with the invert at bed level (sills), to emulate a natural riffle, or as a higher check dam. Normally a series of structures are required to stabilise a degrading reach
- Boulder clusters: Groups of boulders placed in the base flow channel to provide cover, create scour holes and areas of reduced velocity
- Channel re-grading: Modification of the channel slope and bed profile to increase flow velocity (to limit sediment deposition) or reduce flow velocity (to limit erosion)
- Channel re-profiling: Modifications to the form of the channel (see Multi-stage channels) and shape of the banks (see Bank re-shaping) to increase hydraulic capacity and stabilise banks

Historically, high failure rates of instream structures suggests that better criteria are required for locating, designing and constructing instream structures (Rosgen 1996; Miles 1998). Examples of geomorphologically sensitive approaches to streambed stabilisation are provided by Newbury & Gaboury (1993); Brookes & Shields (1996); FISRWG (1998); Nijland & Cals (2000); RRC (2002); and Sears *et al.* (2003).

4.5.5 Streambank erosion

Stream bank erosion is normally controlled by a mix of structural measures and non-structural measures (Brookes 1989). Structures include flow deflectors, riprap, groynes, retards and anchored trees. Anchored trees are widely used in New Zealand as a revetment and are classed as a non-structural bioengineering (Eubanks & Meadows 2002). Non-structural measures include increasing the capacity and hydraulic efficiency of a channel (by straightening, deepening, shaping or widening the channel and constructing new channels); and by stabilising banks with vegetation. There is an increasing emphasis on non-structural measures, particularly use of tree revetments, re-profiling channels and stabilising banks with vegetation (Eubanks & Meadows 2002).

Structural practices can provide a hard point to protect stream banks from the force of flowing water, deflect flowing water away from the stream bank and retain eroding bank material. Often structural bank protection is required to protect banks, particularly the outside of bends during high flows and to allow the establishment of bank vegetation (Eubanks & Meadows 2002). Major types of structural practices include riprap, deflectors and revetments (USEPA 1993):

- Riprap: Rock dumped or placed along a streambank to armour the bank against the force of flowing water. The toe of the bank is often excavated to provide a footing for the riprap
- Streamflow deflectors: Sills, bars, or groins of logs, rock, or concrete projecting out from the bank into the stream to redirect the streamflow away from an eroding bank
- Revetments: Structures such as timber cribbing backfilled with gravel, anchored trees, gabions, or bulkheads applied to the streambank to hold back eroding material as well as to protect from flowing water.

Significant increases in channel capacity can be achieved by multi-stage (compound) channel designs in unconfined streams (Brookes 1989; Brookes *et al.* 1996: RRC 2002) and in restricted corridors in urban areas (Ellis & House 1994). Increasing the high flow channel width increases channel capacity, while retaining a low flow channel. Works can be undertaken on the floodplain with minimal disturbance to the existing low flow channel (Brookes 1989). Similarly, bank reshaping can be used in increase channel capacity and to increase channel stability and suitability for vegetation control.

- Multi-stage (compound) channels: Benches are cut into the banks to increase the width of the flood channel. The low flow channel supports aquatic life; and the shallow marginal bench accommodates flood flows and supports emergent and wetland plants in addition to providing locations for small linear ponds for habitat diversity and contaminant filtering (Fig. 4.3)

- Bank reshaping: Banks are excavated to remove steep drops and unstable materials, and to lower the bank to allow roots to extend through potential failure planes and into the lower bank where there is potential for scour. Channel capacity may be increased by bank reshaping (Fig. 4.3) and marginal vegetation may filter contaminants and reduce flow velocities

Bank reshaping (Fig. 4.3) is often required to facilitate vegetative bank stabilisation (FISRWG 1998 – Fig. 4.4). The requirements for reshaping are largely related to the bank height relative to the rooting depth of stabilizing vegetation. If the rooting depth is less than the bank height the streamside vegetation will provide little protection from bank scour.

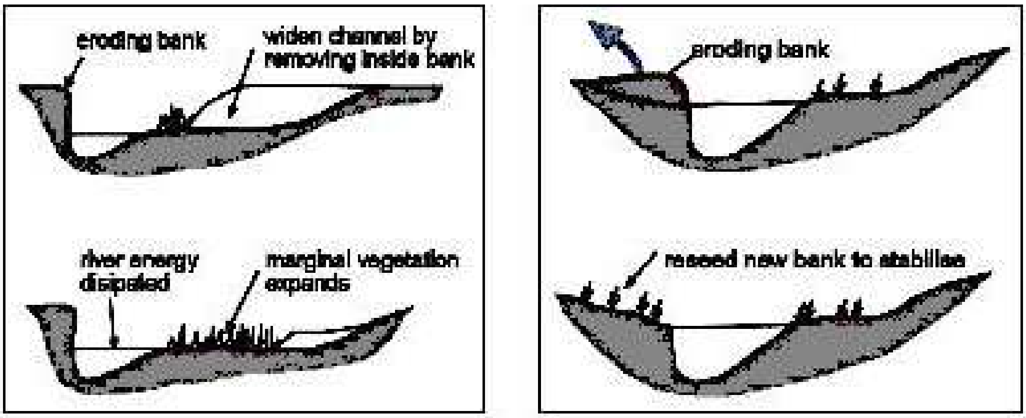

Fig. 4.3. Compound channel (left) and bank re-shaping (right) (based on WWF 2002).

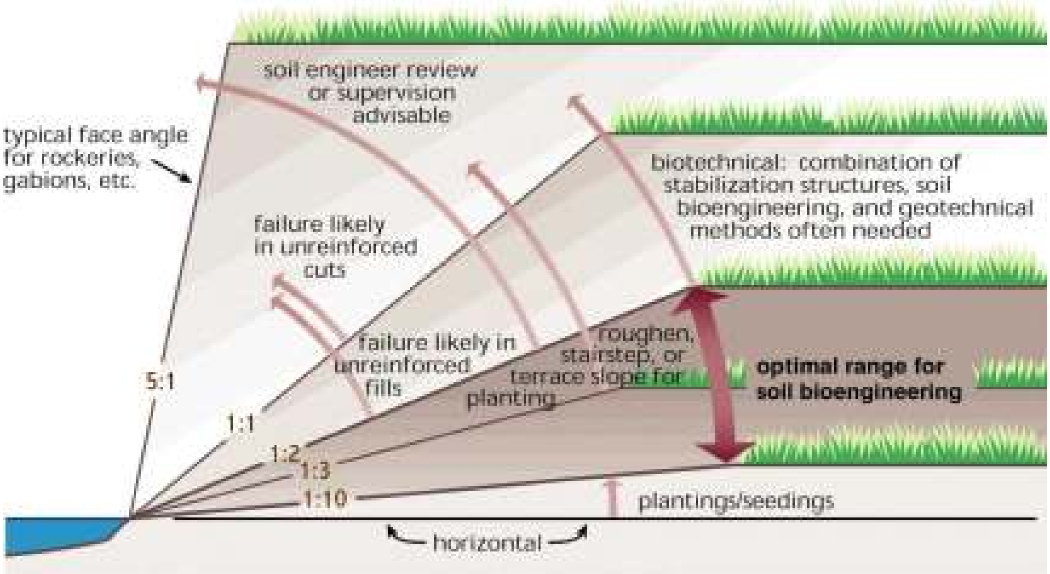

Fig. 4.4. Slope (rise/run), and bank height relative to rooting depth, are important factors in determining appropriate bank protection measures (adapted from FISRWG 1998).

Rutherfurd *et al.* (2000) report some broad guidelines for root system protection:

- Ground cover such as grasses, shrubs, sedges and forbs provide reinforcement to the top c. 0.3 m
- Understory trees, typically 1-5 m high, have roots extending to the drip line, with penetration to c. 1.0 m depth
- Large trees have effecting rooting depths of up to c. 3 m and a lateral extent equal to about that of the crown. The mass of roots are contained in a “rootball” (or “rootplate” in some species or where growing depth is restricted by a high watertable) which is generally about five times the diameter of the trunk. Beyond the rootball root density decreases rapidly and most of these roots are in the upper 0.5 to 1.0 m of soil. Some undercutting of the rootplate is common and does not diminish stability

Aquatic and bank vegetation affects the erosive forces exerted on the bed and banks by slowing down flows and the increases the resistance to erosion by mechanical root binding (Thorne & Furbish 1995). Most well rooted vegetation, including pasture grasses, is likely to be a benefit for bank protection. A wide range of native plants are also appropriate for planting in various zones from the channel margin to upland areas (See Biodiversity: land retirement and streamside planting).

Emergent macrophytes such as sedges, rushes and reeds that grow along stream margins can reduce scour and induce near sediment deposition (Hemphill & Bramley 1989; Pitlo & Dawson 1990). Low lying grasses and shrubs retard near bank velocities (e.g. Kouwen *et al.* 1969) and resist erosion (Table 4.1). Experience in Southland suggests that relatively short vegetation cover provided bank protection, but taller vegetation was prone to erosion.

Bank Material	**Tractive Stress** (N/m^2)
Bare banks	1 to 10
Grass (turf)	15
Dense native vegetation	~50
Willow revetement	70
Rockfill bank protection (400 mm diameter)	150

Table 4.1. Tractive stress ratings for bank vegetation (Hader in Rutherfurd et al. 1999).

Trees have to be closely spaced to avoid local scour (Thorne 1990). Willows (Hathaway 1986) and some native trees (Pollock 1986) offer a high degree of bank protection. Manuka can grow in wet areas and has a dense root mat such as that found with willows (Rutherfurd *et al.* 2000). It is often difficult to establish vegetation to counter toe erosion and bank failure in a section of bank below baseflow levels and in coarse gravel.

Vegetation plays an important role in sub-aerial erosion (Rutherfurd *et al.* 2000). Vegetation provides some insulation value reducing freeze thaw particle heave. Vegetation reduces the drying and cracking of soil by reducing bank moisture fluctuations. Slacking is reduced because vegetation maintains a porous bank material structure and aggregate bonding. Surface wash is reduced because vegetation intercepts raindrops, and surface runoff is reduced by promoting infiltration and reducing water velocity.

Mass failure of streambanks is reduced by vegetation acting in several ways (Rutherfurd *et al.* 2000). The most direct effect is the increase in bank material strength with root reinforcement. For this to be effective roots must cross the failure plane. Trees may act as buttresses and directly support upslope material; and may protect the toe against shear failure. Banks are kept drier and more stable because vegetation intercepts precipitation, uses water in transpiration, and promotes soil drainage.

Shallow-rooted streamside trees may be blown over and deliver sediment into the channel. The uprooted tree may redirect flow into the bank resulting in scour. Single rows of trees lining a channel are particularly prone to wind-throw. Most streamside planting guides promote a range of tree heights in a belt along the stream. Wind loading may be an issue, but Rutherfurd *et al.* (2000) argue that the weight of trees added to the streambank (“surcharging”) is likely to be a problem only for steep (>45^0) shallow slide-type failures where the roots are enclosed in the top layer of the slide.

- Streamside planting: Plants are established or encouraged to grow along the channel margin, on the banks, floodplain and berms along the stream to provide erosion protection, habitat, food supplies, amenity and cultural values and to enhance water quality by reducing light and temperature and filtering and absorbing sediment and contaminants. Desirable species may suppress weeds in the channel and on the banks. (See Biodiversity: land retirement and streamside planting)

While streamside planting can be very effective in its own right, particularly in areas with low rates of erosion, planting may have to be combined with structural measures in other situations (e.g. eroding bends). When used alone for bank protection it must be recognised that time is required for the plants to grow to become effective. In some cases a sacrifice zone is established, with planting set back to protect the bank from erosion some years in the future.

Improper livestock grazing affects banks and shores, water column, channel morphology, and aquatic and bordering vegetation (Platts 1990). Stock trampling can result in soil compaction and damage to plants. This promotes surface wash processes with high delivery rates of sediment into streams. Stock movement along the waters edge re-suspends sediment resulting in plumes of turbid water; and pugs the bed at the toe of the bank making it more prone to erosion. Stream crossing points are often a focal point of erosion (Trimble 1994). The impacts of stock grazing can be highly variable and dependent on site conditions and the type of livestock

(Williamson et al. 1990). For example, deer wallow in shallow pools while sheep generally avoid water.

The overall benefit of excluding livestock from waterways is usually high (e.g. Osmond *et al.* 1997); but is site specific. There was little impact of grazing on northern Southland streambanks (Williamson *et al.* 1992) whereas Environment Waikato (2000) found that drains with stock excluded needed clearing less frequently. They attributed this to reduced inputs of effluent and sediment. Drain cleaning has shifted from a 2-3 year cycle to a 10-15 year cycle (Guy Russell pers. comm.). A livestock control BMP should be used in conjunction with riparian management and water supply practices (e.g. installation of alternative drinking water sources away from the waterway), but where alternative water sources are not feasible, restricted access points should be constructed.

- Exclude livestock from waterways: Prevent livestock from entering waterways or trampling riverbanks by fencing the stream corridor. Exclusion will generally reduce erosion and habitat degradation, improve water quality, and health and safety of livestock. Various types of fences can be used (e.g. single wire electric to flood proof multi strand fences). Any fencing or riparian planting must take access for drain maintenance into consideration. (See Taranaki Regional Council Sustainable Land Management Programme 24: Fencing options and costs. www.trc.govt.nz/PDFs/info_land/24_riparian_fencing.pdf). See Water quality
- Restricted access to watering points: To reduce erosion (but not water contamination) use fencing to deny access to the water except at designated points where an erosion resistant ramp in the stream has been constructed. Fencing should extend into the water to prevent livestock from escaping into the water
- Stream crossings: Bridges or culverts are preferred crossings. Where this is not feasible, a stabilised area (e.g. gravel pad) should be constructed across the channel to reduce erosion and provide safe access for people, livestock, equipment, or vehicles. Use fencing to prevent animals from wandering off the crossing. Design guidelines are provided in MfE (2004) Culvert and bridge construction guidelines for farmers. (Available at www.mfe.govt.nz/publications/water)
- Farm tracks: Farm tracks should be constructed of suitable material and designed to limit erosion and control runoff into waterways. (See Taranaki Regional Council Sustainable Land Management Programme 12: Farm track construction, www.trc.govt.nz/PDFs/info_land/12_farm_track.pdf; Environment Waikato (1995) Design guidelines for earthworks, tracking and crossings, www.ew.govt.nz/enviroinfo/land/management/runoff/tracks.htm).

Citation:
Hudson, H.R. 2005. Drainage problems and solutions: sedimentation. Pages 4.1-4.19 in Hudson, H.R., editor. H20-DSS: Hillslopes to Oceans Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington. Available online at www.nzwerf.org.nz

5 Drainage problems and solutions: vegetation

5.1 Introduction

Vegetation management is a major component of drainage maintenance in New Zealand (Hudson & Harding 2004). Traditionally the focus has been on the control of aquatic "weeds" and bank vegetation, for hydraulic efficiency and bank erosion protection, but there is an increasing recognition of the broader role of vegetation in aquatic systems (e.g. habitat, food, amenity and cultural values). Effective vegetation management is shifting toward careful planning, preparation, and practices to maximise beneficial vegetation growth (e.g. erosion control and habitat), and at the same time minimise potential adverse effects (e.g. flow impedance; and excessive growth causing erosion).

The following aspects of vegetation control are examined:

- Effects on hydraulic performance
- Effects on aquatic ecosystems
- Controls of excessive growth:
    - Nutrients
    - Light and temperature
    - Hydrologic regime
- Management measures
- Best management practices (BMPs)

5.2 Effects on hydraulic performance

Aquatic plants can provide significant resistance to streamflow, but there is little comprehensive knowledge of the hydraulic effects of various types of weed and weed management practices (Pitlo & Dawson 1990; Purseglove 1998). Much of the available comprehensive hydraulic information is from flume experiments with artificial plants; and for plants that are not a particular problem in New Zealand streams (e.g. Smailes 1996; Bennett *et al.* 2002).

Some studies show significant hydraulic benefit from weed management. For example, Dunderdale & Morris (1996) report that discharge capacity increased from 0 to 38% with 40 to 80% weed removal. Ryder (1997) reports large reductions in water depth and width with mechanical weed clearing (hydraulic excavator) in Ives and Clear creeks, Southland. Experiments presently being undertaken in Birdlings Brook, Canterbury, show water level reductions of 0.5 to 1.0 m with partial and full clearance of weeds (primarily watercress, but also floating sweet grass and monkey musk) in a stream with a bankfull depth of ~1.5 m.

Since the hydraulic effects of weed removal are often obvious, benefits of weed clearance are often perceived as applicable in most, if not all, circumstances, without examination of the behaviour of particular plant communities in particular circumstance (e.g. behaviour of watercress in a flood vs. low flow). Management tends to focus on process (how many kilometres of channel were cleaned) rather than performance (what the effects of cleaning were on water levels in the channels and on farm productivity and accessibility) (Hudson & Harding 2004). Vegetation management is generally undertaken to address several problems:

- Weeds are removed as a precaution against weeds being ripped out in high flows and blocking culverts
- Drainage outfall is not achieved as completely as required (i.e. in terms of water table draw down)
- Drainage may not be as rapid as required (e.g. fields may be waterlogged for several days rather than a couple of days, which may destroy crops and impede access for extended periods)
- Weeds elevate water levels and increase the incidence of flooding
- Weeds slow flows and encourage deposition of suspended sediment which reduces capacity and raises water levels
- Weed beds and associated sediment deposits may change the magnitude and direction of currents which may cause bank erosion

5.3 Effects on aquatic ecosystems

Streamside and aquatic plants are an essential component of aquatic ecosystems (MfE 1992; Wade 1994):

- Primary production converts solar energy and nutrients to organic matter that provides food for higher trophic levels and produces oxygen
- Plants recycle nutrients and purify water bodies by removing nutrients from the water column
- Rooted plants stabilise streambeds and banks
- Rooted plants promote settling of suspended solids hence maintaining water clarity
- Plants provide instream and streamside habitat for invertebrates, fish and birds

Proliferation of plants can degrade desired water uses in some instances. Adverse effects of excessive aquatic plant growth include (MfE 1992; Wade 1994, Bunn et al. 1999):

1) Water taste and odour problems.
2) Decomposition of accumulated aquatic plants in sediments leads to high rates of benthic respiration and oxygen consumption.

Respiration by aquatic plants (at night) also decreases dissolved oxygen levels, which may:

- Stress or eliminate benthic invertebrate communities
- Kill fish as oxygen levels in the water column fall
- Liberate nutrients from anoxic sediments, and
- Cause the release of contaminants (e.g. Mg and Fe), which further compounds water quality problems

3) Weeds out compete more desirable plants and reduce biodiversity.

4) Periphyton and macroalgae growth may reduce light penetration and cause macrophyte and invertebrate decline.

5) Dense accumulations of aquatic macrophytes reduce aquatic habitat because:

- They impede fish passage and available habitat
- They trap sediment which can smother existing communities

6) Toxic algal blooms may occur.

7) Water intakes can be fouled.

8) Prolific weed growth may interfere with recreation (e.g. swimming, fishing and boating).

5.4 Controls of excessive plant growth

Major factors governing plant growth include:

1) Nutrients in the water column and in stream bed sediments.

2) Light and temperature.

3) Hydrologic regime.

5.4.1 Nutrients

High levels of nutrients can produce proliferations of aquatic weeds (see Water quality). Nutrients alone cannot indicate whether a waterbody actually has a nuisance plant problem. Nutrient impacts vary as a function of the load and bioavailability of the nutrient, and the extent to which hydrodynamics and turbidity levels modulate plant and algae response (ANZECC 2000; Harris 2001).

ANZECC (2000) default trigger values for upland rivers and lowland rivers are 26 and 33 mg/m^3 for total phosphorus; and 295 and 614 mg/m^3, respectively, for total nitrogen for slightly disturbed systems. Time between high flow events that uproot periphyton and macrophytes is particularly important in determining the biomass in streams Biggs (2000).

The water column is not the only source of nutrients. Biggs (2000) discuss the role catchment inputs from soil erosion, and groundwater flows. Root uptake of nutrients from bed sediment has been identified as important for macrophyte growth (e.g. Owens & Edwards 1961, Chambers *et al.* 1989).

Thus, the reduction in nutrient inputs in the water column (e.g. with better sewage treatment) will not necessarily lead to decreased biomass in watercourses (Carr & Chambers 1998).

5.4.2 Light and temperature regime

Sunlight is the source of energy for the growth of benthic algae, phytoplankton and macrophytes. Both the type of light (spectrum) and quantity of light received are important (MfE 1992). Hence, controlling light input (e.g. by riparian shading) provides a powerful management tool for controlling aquatic plants. Temperature influences maximum rates of photosynthesis and growth of phytoplankton, periphyton and macrophytes (MfE 1992).

Crabbe (1994) surveyed drains in the Bay of Plenty and concluded natural shading could be used to control aquatic weeds in many 1-2 m wide drains. With artificial shading (90% reduction in light level) in a small drain in the Waikato, Scarsbrook *et al.* (2000) found a change in the type and density of plants growing under shade, but not a change in the amount of cover across the channel. The biomass of the dominant aquatic plant *Polygonum* was reduced to 20% of the unshaded reach; and native species became co-dominant (particularly *Potamogeton* and *Nitella*). In Spring Creek, Marlborough, Young *et al.* (2000) found *Lagarosiphon*, willow weed and watercress were significantly reduced, while the native *Nitella* was unaffected by low light levels.

In his Riparian Management Classification (RMC) Quinn (2003) suggested four channel width classes related to the types of vegetation required to provide stream shade: <2 m (Tiny); 2 to <6 m (Small); 6 to <12 m (Medium); and >12 m (Large). Long pasture grasses and tussocks are expected to shade tiny streams effectively, whereas high shrubs will shade tiny and small streams and trees will shade channels up to the medium size class. For channels >12 m riparian trees are unlikely to be effective for temperature and algal control. Topographic shade, particularly in incised channels, is important (Rutherford *et al.* 1997). Dawson (1978) found that in lowland streams approximately 2 m wide with banks 1-2 m high, little other control is needed where there is no grazing and tall herbs and grasses can grow.

Also, it should be noted that because of thermal inertia, it is more important to maintain dense shade along small (first and second order) streams than larger streams and rivers. Similarly, when attempting to reduce stream temperatures in a catchment, it is more effective to restore riparian shading on the shallow first and second order streams than the deeper higher order rivers (Rutherford *et al.* 1997).

An adverse effect of increased shading is that there is a reduction in the uptake of dissolved nutrients into plants (Quinn *et al.* 1997). Increased shade may result in increased nutrient levels in downstream reaches (Howard-Williams & Pickmere 1999), which may be important for particular water uses. In these circumstances Quinn (2003) suggests riparian planting needs to be planned and managed to maintain open lighting conditions (>c. 50%) and to retain nutrient removal functions within the riparian zone.

5.4.3 Hydrologic Regime

Two aspects of the hydrologic regime are considered – water availability and water velocity. A common treatment overseas is to drain ponds to dry out aquatic plants. These exposed plants may be grazed by livestock, ploughed, burnt or sprayed (Wade 1990). In freezing conditions this is a particularly effective treatment (Angelo *et al.* 1998). Drawdown of hydro lakes has been discontinued in New Zealand (Coffey 1975; Clayton 1982) largely because of economics (lost hydro power).

Ecological studies do not show any consistent relationship between water movement and the distribution and abundance of submerged plant communities (Wade 1994). Chambers *et al.* (1991) observed that macrophyte cover decreased with increasing velocity over the range 0.001 to 1 m/s, and at velocities in excess of 1 m/s aquatic macrophytes were rare in the Bow River, Alberta (a gravel bed river). Two explanations proposed are mechanical stress on the plants and alteration of the composition of the riverbed changing nutrient availability (Chambers *et al.* 1991). Clausen & Biggs (1997) found a relationship between flood frequency and periphyton biomass in New Zealand rivers. In flashy rivers (when an index flow of three times the median flow is frequently exceeded) the biomass, taxonomic richness and diversity of periphyton decreased significantly.

In regulated rivers in New Zealand macrophytes prefer finer sediments and lower velocity zones. At constant flows in summer the percent of the channel filled by macrophytes decreased with increasing mean velocity (from 75% cover at 0.1 m/s to 10% at 0.9 m/s) (Henriques 1987). In stable streams in New Zealand Riis & Biggs (2003) found vegetation abundance across the channel increased with velocity up to 0.4 m/s, after which vegetation abundance decreased. They attribute increasing abundance at low velocities to increasing nutrient diffusion. Riis & Biggs (2003) found the upper limit of mean velocity in the plant-free area in a cross-section is 0.80 m/s. Above this velocity, they would expect no vegetation to be present.

Different plant species have different hydrodynamic drag (reviewed by Pitlo & Dawson 1990). In stable streams Riis & Biggs (2003) suggest that relatively streamlined plants may dominate faster flowing streams, and species with high drag may only be present in slow flowing water. For example, Canadian pondweed (*Elodea canadensis*), which has a relatively high drag, preferred habitats with velocity less than 0.4 m/s. The more streamlined water buttercup (*Ranunculus trichophyllus*) tended to inhabit waters flowing at 0.3–0.6 m/s.

New Zealand experimental work suggests that uprooting rather than stem breakage causes plant removal (Riis & Biggs 2003). At water velocities up to 1.5 m/s (which is much faster than most lowland streams) there was <1% stem breakage. They suggest that in general, if the streambed becomes mobile during a flood, then sediment erosion could uproot plants. If the bed is stable, only a small amount of vegetation will be removed with stem breakage. They also found fewer plants were present when floods occurred more frequently. This is attributed to the recolonisation rate of plants. If some plants remain, recolonisation may occur within 3 or 4 months. If all the plants are removed (including the seeds and underground parts), it took 14 months before 90% of vegetation had recovered. In this case colonisation relies on upstream supply of dispersal organs, such as stem fragments and seeds.

5.5 Management measures – decision framework

The first step in managing “weeds” (plants growing in the wrong place) is problem framing:

- Determine the nature (e.g. blocked drain; invasive species) and extent (e.g. blocked culvert; local invasion) of the problem
- Identify the problem plant species
- Determine the likely benefits of treatment (e.g. removal, containment or eradication). Both the effect on hydraulics and the effects on aquatic ecosystems should be considered
- Determine the risk of not intervening

Decision framework

Problem framing:

- Define the problem
- Identify the problem plant species
- Determine benefits and effects
- Determine if intervention is warranted
- Determine timeframe, success rate, costs.

Develop a weed management plan:

- Treatments based on species
- Timeframes
- Examine longer term options
- Costs

Follow up:

- Monitor
- Assess
- Report

Plant identification

Sources of information on aquatic plants in New Zealand include:
Coffey, B.T.; Clayton, J.S. 1988. New Zealand waterplants: a guide to plants found in New Zealand.
ccc.govt.nz/parks/TheEnvironment/weedguide_status.asp
envbop.govt.nz/land/media/pdf/ Pp1300.pdf
niwa.co.nz/rc/prog/aquaticplants/species
Thekrib.com/Plants/Plants/NZ/

Problem framing will determine if immediate relief is required (e.g. excavation of the channel to remove weeds and reduce flooding); whether some delay is acceptable (e.g. plants take days to weeks to respond to chemicals); or if a longer term view can or should be taken.

Treatments may appear to conflict with traditional approaches. For example, in performance-based management of drainage outfall, the treatment of aquatic weeds at a particular time may not be required because there is no significant impairment of drainage conveyance. However, over the long term the most effective treatment may require spraying several times in one season for eradication when there is no obvious hydraulic benefit

As a second step, develop a weed management plan to select an appropriate treatment (or combination of treatments) that will not exacerbate the problem, or have major unintended effects; and select an appropriate time frame to undertake weed treatment. (This is an iterative process with problem framing). At this stage some treatments, although effective (e.g. chemical), may be excluded because of unintended local or downstream effects (e.g. residues in water supplies).

Treatments vary with the species and season. Successful vegetation management must be based on the correct taxonomic identification and knowledge of the auto-ecology of the species; otherwise treatments can be ineffective or even counterproductive (De Waal *et al.* 1995). For example:

- *Glyceria maxima* (reed sweet grass) quickly become a large and vigorous plant that can block waterways. New infestations should be treated as early as possible. Destroying the young plants at an early growth stage, before they have become established or produce seed, is the most economical and effective method of treatment. If treatment is delayed until the infestation is established, eradication in one season is improbable. Follow-up work over at least two or three seasons will be required (TVWSWG 1997)
- Eurasian water milfoil has been extensively harvested and tilled, especially in southern British Columbia. Unfortunately, this species spreads by vegetative growth of plant fragments and mechanical removal typically produces large amounts of viable fragments that can either re-infest the harvested area or spread to new sites (CWS 1999)

Timing, frequency and duration of treatment are often critical:

- Aquatic herbicide cannot be used as a pre-emergent (applied prior to the germination of plant seeds or the re-growth of sprouts). Use is limited to the period when plants are present and growing (Norland 1998). Dawson (1996) found treatment of emergent New Zealand Pygmy Weed (*Crassula helmsii*) by glyphosate was far less effective in the autumn (~15% control) than in the summer (~85%). Diquat-alginate was effective on submerged plants in both periods (>90% control)
- Howard-Williams *et al.* (1996) found that in hydro lakes in the North Island regrowth of *Egeria densa* and *Lagarosiphon major* declined after three six-monthly harvests allowing the establishment of low growing native *Nitella* spp. beds
- Triploid grass carp were successfully used to eliminate extensive *hydrilla* weed beds (*Hydrilla verticillata*) from Elan Lake, Hawke's

Bay, in a trial starting in 1988. But by 1991 occasional small plants growing from tubers were found (Hofstra *et al.* 1999). By 1996 (and in subsequent surveys) newly formed tubers were found, which suggests that New Zealand *hydrilla* is more durable that expected (NIWA 2001). This suggests that it would take at least 10 years without *hydrilla* weed beds before the propagule bank (tubers and turions from which plants can regrow) would be sufficiently depleted to have any chance of eliminating this species from a waterbody. There is concern that there is a potential for *hydrilla* to develop new tubers before the plants are actively controlled or grazed, and thereby continue the cycle

Similar plants might respond differently to treatments or combinations of treatments:

- Abernethy *et al.* (1996) investigated whether management measures have similar effects on water milfoil (*Myriophyllum spicatum*) and Canadian pondweed (*Elodea Canadensis*). The ecology of the two species is similar. Four months from the start of the experiment single cut (day 35) and double cut (day 35 and 66) milfloil had significantly reduced biomass (45% and 90% respectively compared with uncut milfoil). Plant length reduced significantly (22% for single cut and 70% for double cut). For pondweed, the reductions in biomass were 41% and 59%, respectively. There was no significant change in plant length for pondweed after one cut, and a 44% reduction after two cuts
- In shading experiments with no shade, low shade (23% reduction in light) and high shade (40% reduction), there was little significant response by either species. When cutting and shading were combined a stronger response to shade stress was seen in milfoil than pondweed

A broader view of the problem may be required:

- Local treatment may be ineffective if re-invasion occurs from upstream or from the import of material on equipment or in soil
- Direct treatment of vegetation will remain necessary for many systems but the frequency and intensity of treatment may be significantly reduced if nutrients are controlled and if shading is introduced in an integrated catchment management programme

Finally, treatments should be considered as experiments (See Introduction: adaptive management). Monitor, assesses and report successes and failures so that better treatments can be developed and refined. As more knowledge is gained, BMPs can be developed and added. Treatment may need to continue for several years to be successful; and long term monitoring may be required to assess whether control has been achieved (e.g. persistence of *hydrilla* propagules).

5.5.1 Best management practices

Management of aquatic plants is achieved with either preventative measures or treatment (Hudson & Harding 2004). Although a broad range of measures are discussed, some only have passing comment because widespread use is premature (e.g. biological controls such as insects); or not considered acceptable (e.g. grass carp).

The first priority should be to undertake preventative measures, specifically controlling agricultural inputs and contaminant runoff (MfE 1997). This includes selecting the most appropriate land uses; efficiently applying farming inputs; and reducing the generation and losses of sediment and contaminants.

A broad range of management practices and guidelines focused on the dairy industry are available from Dexcel (www.dexcel.co.nz/farmfacts).

Additional BMPs include:

- Filter strip: A strip of vegetation along a waterway margin that intercepts sediment, organics, nutrients, pesticides, and other contaminants from shallow surface flow. Effectiveness is rated as no control to ineffective for soluble nutrients and pesticides; to low to medium effectiveness for absorbed (attached to sediment) nutrients and pesticides (Nokes & Ward 1992). Summarising various references, Gitau *et al.* (2001) report 5-59% removal of dissolved phosphorous and 28-80% removal of particulate phosphorous
- Grassed waterways: Broad, shallow, natural or constructed channel that is grassed so as to move surface water across farmland without causing soil erosion (e.g. rills, gullies). They filter sediment and sediment associated contaminants (e.g. nutrients and pesticides), but are inefficient at filtering soluble contaminants (Nokes & Ward 1992)

Controlling agricultural inputs and contaminant runoff

"The main task in minimising agricultural impacts on water quality is to encourage farmers to adopt practices that minimise contamination by agricultural runoff. The details of these practices are likely to be relatively site-specific, depending on the particular problems and opportunities of the farming situation. However, in general, techniques which farmers can carry out to minimise contamination by agricultural runoff include:

- Selecting the most appropriate land use for the site and circumstances - this is likely to have the greatest bearing on the level of aquatic impacts;
- Increasing efficiencies in the application of farming inputs - these responses avoid or reduce the quantity of potential contaminants, such as fertilisers and pesticides, making less available for loss to the environment;
- Increasing the resistance of farming systems to losses of nutrients and chemicals - these responses address major pathways by which sediment, nutrients, pesticides and other contaminants reach water; and
- Making greater use of field and landscape buffer zones- these responses intercept contaminants and reduce the erosive force of runoff water." (MFE 1997).

- Streamside planting: Plants are established or encouraged to grow along the channel margin, on the banks, floodplain and berms along the stream to provide erosion protection, habitat, food supplies, amenity and cultural values and to enhance water quality by reducing light and temperature and filtering and absorbing sediment and contaminants. Desirable species may suppress weeds because of competition. (See Biodiversity: streamside planting)
- Limiting the spread of weeds: Cleaning weeds from hydraulic excavators, weed cutters and watercraft to prevent transfer between waterways; control of the disposal of spoil from weed removal; control of upstream sources of weeds

Common vegetation treatments used in New Zealand are:

- Chemicals
- Mechanical (e.g. hand pulling and cutting, flair harvesters, weed baskets, and hydraulic excavators)

More experimental approaches include:

- Biological (e.g. grass carp, introduced invertebrate grazers, and algal inhibitors)
- Hydrological (e.g. flushing flows; drawdown to expose aquatic plants; enhancing channels to indirectly control weeds by changing water depth and velocity)

In many cases a combination of treatments is required; or some treatments should be avoided (e.g. *Glyceria maxima* BMP).

5.5.1.1 Streamside planting

Streamside (riparian) planting is strongly advocated in New Zealand and overseas. As noted by Quinn (2003), the policy statements of all New Zealand's regional councils recognise riparian management as an important aspect of water management. Most proposed regional plans include a range of methods for promoting riparian management, including funding part of the costs of riparian management activities undertaken by farmers. Costs and benefits are well established (e.g. Dexcel Farm Fact 3-20: Riparian Management; Environment Waikato online calculation sheet for planting and fencing waterways: www.ew.govt.nz/enviroinfo/land/management/runoff/costing.asp). (See Biodiversity: streamside planting).

Different types of shading are required for temperature and periphyton control depending on the channel. The alignment of the channel is also important, with north bank planting being more effective.

- In very small incised streams (<2 m wide with banks 1-2 m high) topographic shading is effective
- In very small streams with low banks (<2 m wide with banks <1 m) pasture grasses and tussocks shade effectively
- Small streams (2-6 m) will be shaded effectively by high shrubs

- Medium streams (6-12 m) will be shaded effectively by trees
- Large streams (>12 m) are unlikely to be effectively shaded

Shading is likely to be effective where the combined bank and vegetation height is equal to or greater than the channel width.

Rutherford *et al.* (1997) review research in New Zealand and provide tentative shade targets. Shading of 60 to 80% is expected to control algal blooms and more than 90% shade is required to reduce periphyton biomass in low gradient streams to the low levels seen in forest streams. Their tentative recommendation is for a maximum streamside vegetation shade level of about 70%. Deciduous trees are preferred to provide dense shade during critical summer periods but which allow ground cover to develop during autumn-winter to control surface runoff and erosion.

5.5.1.2 Chemical treatments

Chemicals are the most common and inexpensive treatment to control aquatic and streamside plants in New Zealand (Hudson & Harding 2004). The main chemicals used by councils which are registered for use around waterways in New Zealand are Glyphosate (e.g. Roundup®; but several brands are listed in the NZ Agrichemical Manual 2004) and Diquat dibromide (e.g. Diquat®, Reglone®, Reward®, and Torpedo®). In contrast, the State of Washington currently permits use of six aquatic herbicides; with ongoing review of other chemicals (Bond & Bond 2004). For example, Renovate® (Trilopyr), a systemic herbicide, was recently approved by the US EPA for aquatic use on both emergent and submersed plants (this is the first aquatic herbicide to receive registration since 1988).

Under Hazardous Substances and New Organisms Regulations (2001) (HASNO) strict rules are applied to chemical applicators (e.g. “approved handlers” are required); and to the ecotoxological effects of these chemicals. Resource consent is required unless chemical applications are covered by a condition in a regional plan. Consult with the regional council before proceeding.

In “Managing waterways on farms” MfE (2001) note contamination of water is most likely to occur as a result of careless or excessive application of chemicals; and that sensible and effective application will not only benefit the environment but reduce management costs. Suggested management precautions for on-farm applications included:

- Spray only at rates recommended
- Avoid spraying when rain is likely
- Take all necessary precautions to minimise spray drift
- Do not mix, fill or empty spray containers in stream beds, nor use contaminated containers to source water from the stream
- Where practical, targeted or spot application of a chemical is preferable to broadcast application

In terms of drain management MfE (2001) suggest the negative impacts of chemical treatments can be reduced by:

- Not spraying the entire length of the drain. Instead spray reaches of 10-20 m and leave only 10-20 m, undisturbed
- Only spraying the centre of the drain where faster flows occur, so that the edges of the drain remain undisturbed to provide cover, food and habitat
- Spot spraying, to avoid spraying riparian vegetation
- Not spraying during peak native fish spawning and migration periods
- Using contact herbicides (e.g. “Torpedo®”) which act directly on plant tissue

The rationale for partial spraying is not explained by MfE (2001):

- Newbold *et al.* (1989) state the objective of partial spraying of clearing of alternate banks is to maintain floristic, invertebrate and bird diversity
- Way *et al.* (1971) and Brooker & Edwards (1973) found oxygen depletion from decaying aquatic plants stressed fish. Strip application may be warranted to limit oxygen depletion from plant decay. In large water bodies, with confined weed areas, this may not be a problem (Clayton 2004). Investigations in drains are required
- The hydraulic effects of partial clearing of banks and channel are unquantified. Experience in Southland suggests partial spraying compromises outfall. Preliminary trials in Canterbury to evaluate the hydraulics of alternative treatments show rapid re-colonisation occurs with partial cleaning or spraying

Spray exclusion periods recommended by MfE (2001) are based on concerns regarding perceived effects on invertebrates from Diquat and Paraquat, and persistence in the environment:

- Historically there have been widespread concerns over the use of chemicals for aquatic plant control (e.g. Cooke *et al.* 1993; Wade 1994). These concerns have been the subject of considerable research and a rigorous review process for certification of chemicals (Madsen 2000)
- Paraquat was used for weed control, but is no longer approved for use in New Zealand waterways. The studies referred to by MfE (2001) (Burnett 1972; Hunt 1974; and Way *et al.* 1971) examined effects of Paraquat, but not Diquat dibromide
- Diquat dibromide is slightly toxic to moderately toxic to birds (USEPA 1986). There are conflicting results in some studies on fish and benthic invertebrates. Pimentel (1971); Simonin & Skea (1977); and Johnson & Finley (1980) suggested little effect, but a New Zealand study indicated toxic effects on benthic invertebrates (Young *et al.* 2000). There was little or no bioaccumulation of Diquat dibromide in fish NLM (1995)

- Diquat dibromide has a half life of less than 48 hours in the water column. It is readily absorbed by suspended sediment and may persist for 160 days in sediment (Gillett 1970; Tucker 1980)
- Glyphosate is slightly toxic to aquatic invertebrates (WSSA 1994), and wild birds (Kidd & James 1991; WSSA 1994), but non-toxic to fish and mammals (Monsanto 1985; USEPA 1987; Malik *et al.* 1989).
- Glyphosate has an average half life of 47 days (Wauchope *et al.* 1992). In pond water EPA (1992) reported a half life of 12 days to 10 weeks. Glyphosate is readily absorbed by soil, and there may be some loss to waterways by soil erosion (e.g. <2% of applied chemical – Malik *et al.* 1989), but this must be dependent on local site conditions and reinforces the point about maintaining good ground cover and erosion control
- To place the hazard to people in perspective, Diquat dibromide and glyphosate are toxic in concentrated form, but are comparatively less toxic than the commonly consumed chemicals caffeine (e.g. present in tea, coffee and some soft drinks) and nicotine (the neuroactive ingredient in tobacco) (Felsot 1998)

There are several additional considerations regarding chemical treatments of submerged and emergent plants using Diquat dibromide and Glyphosate.

5.5.1.2.1 Submerged & floating plants

Diquat dibromide is the only registered chemical for aquatic application in New Zealand. Diquat is a quick-acting contact herbicide and plant growth regulator that causes injury only to the parts of the plant to which it was applied. Diquat dibromide is reportedly non-selective, and will affect non-target plants (Howard 1991); with varying susceptibility. Diquat (Reglone®) was effective on target weed species (e.g. elodea, lagarosiphon and hornwort) while not affecting most of the desirable native New Zealand species in lakes (e.g. Chara and Nitella species) (Clayton 2004). Diquat was only partially successful in the control of aquatic weeds, particularly those that re-grow from stems or shoots buried in bottom sediments (e.g. Champion *et al.* 2002).

Peirce (1998) notes that submerged plants are perhaps the hardest aquatic weeds to kill because chemicals used need to be maintained at a sufficiently high concentration in the water for enough time to kill the weeds. Water volumes need to be determined reasonably accurately and the chemicals must be applied uniformly to achieve the desired results.

Diquat is rapidly absorbed from the surrounding water and concentrated in the plant tissue so that aquatic weeds are affected even at low concentrations (NLM 1995). Without sodium alginate in the formulation it is less effective in water velocities >0.03 m/s. However, anecdotal observations of applications in faster waters (with and without alginate) indicate that it may be equally effective. It is strongly, and rapidly, adsorbed and inactivated by clays and other organic particles (Wade 1994), hence the performance of Diquat is greatly reduced in turbid waters or waters where plants are covered by silt; or where there is a heavy covering of filamentous alga on the water (Way *et al.* 1971). High water hardness also reduces the uptake of Diquat.

Dawson (1996) found different doses were required to control New Zealand Pygmy Weed (*Crassula helmsii*). Diquat effectively controlled submerged plants in low biomass trials (13-16 kg/m^2) (>90% control in the summer and ~70% in the autumn). Diquat-alginate had >90% control. In order to achieve >90% control at higher biomass (~20 kg/ m^2) Diquat and Diquat-alginate had to be applied at 50 times the label rate. This has serious implications because HASNO and regional council consent conditions require users to follow the manufacturer's instructions and application rates.

5.5.1.2.2 Emergent plants

Glyphosate is a broad spectrum herbicide used to control floating leaf plants (e.g. water lilies) and shoreline plants (e.g. purple loosestrife). It is a systemic herbicide that enters the plant through active green plant tissue and is translocated throughout the plant often killing the entire plant. It is non-selective; all treated plants die. It is generally applied as a liquid to leaves.

Glyphosate is not effective on submerged plants – at least 75% of the plant must be above water level or efficiency may be reduced. Submergence will wash off the herbicide. Rainfall within 2 hours of application may reduce effectiveness. The rain free period may be reduced to 30 minutes if a wetting agent (e.g. Pulse®) is added. Glyphosate is readily adsorbed by soil. Environment Waikato used Glyphosate 360 with the addition of an organosilicone penetrating agent because of the silt on the vegetation (Guy Russell pers. comm.).

The amount of herbicide to be applied varies with the product and the plant species (e.g. 160 ml/100 litres for annual weeds to 800 ml/100 litres for willow with handgun spraying (Orion 2004). Label rates of application may be insufficient to control aquatic plants. Dawson (1996) found Glyphosate was quite successful on emergent plants (>80% control). But at higher biomass (but lower than experienced in streams and lakes), even 10 times the normal maximum dose was insufficient to give more than a two-thirds control in a single application. Some mechanical harvesting to reduce biomass prior to multiple herbicide applications was recommended.

5.5.1.3 Conclusions-Recommendations

While considerable research has been undertaken overseas and in New Zealand, much is still to be learned before comprehensive BMPs can be promoted for a range of problem aquatic vegetation control. Some treatments are ineffective or even counterproductive.

Consideration should be given to registration of other chemicals for aquatic use. Diquat dibromide, which is registered for aquatic use in New Zealand. is a contact herbicide that is only partially successful in the control of aquatic weeds, particularly those that re-grow from stems or shoots buried in bottom sediments. In contrast, systemic herbicides, such as Renovate® (recently registered by the US EPA) are capable of killing entire plants by translocating from foliage or stems and killing the root.

Treatments should be considered as experiments with monitoring, assessment and reporting of successes and failures so that better treatments can be developed and refined.

An example of a best management practice for a problem emergent plant, *Glyceria maxima* has been developed.

Citation:
Hudson, H.R. 2005. Drainage problems and solutions: vegetation. Pages 5.1-5.15 in Hudson, H.R., editor. H20-DSS: Hillslopes to Oceans Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington. Available online at www.nzwerf.org.nz

6 Drainage problems and solutions: water quality

6.1 Water quality problems

Water quality problems were not traditionally considered part of river engineering and drainage works to control flooding, erosion and drainage outfall. However, degraded water quality is found in waterways throughout New Zealand (e.g. Close & Davies-Colley 1990a, 1990b; James *et al.* 1999). Many of these problems are related to agricultural activities because agriculture dominates the surrounding land (e.g. Marshall & Winterbourn 1979; Harding & Winterbourn 1995; Quinn et al. 1997; Nguyen et al. 1990; Wilcock et al. 1998; Young et al. 2000).

As a consequence of the efficient removal of surface and subsurface water, the drainage network (both constructed and natural) becomes a source, a sink, and a conduit of sediment and contaminants. What happens in the catchments ultimately determines water quality in receiving waters. Additionally, removal of streamside vegetation can raise water temperatures and cause thermal stress.

Associated physical, chemical and biological stressors that affect biodiversity or ecological health in aquatic ecosystems include (ANZECC 2000; Hudson & Harding 2004):

- Increased range of water temperature (effecting biological diversity)
- Low dissolved oxygen (asphyxiation of respiring organisms)
- Elevated nutrient levels (nuisance growth of aquatic plants)
- Increased suspended particulate matter (e.g. smothering of benthic organisms, inhibition of primary production)
- Reduced water clarity (e.g. reduction in photosynthesis; change in predator–prey relationships)
- Increased biological contaminants (e.g. bacteria, viruses, parasites, micro-algae bio-toxins)

Many of the solutions to water quality related issues require an integrated catchment management approach. It is with this perspective that the following aspects of water quality are examined as they are highly affected by waterway management:

- Causes and effects of water quality degradation
  - Water temperature
  - Dissolved oxygen
  - Biological contaminants
  - Nutrients
- Sedimentation - water clarity (see Sedimentation)
- Management measures
- Best management practices

6.2 Causes and effects of water quality degradation

6.2.1 Introduction

As discussed in ANZECC (2000), aquatic ecosystems comprise the animals, plants and micro-organisms that live in water, and the physical and chemical environment and climatic regime with which they interact. It is predominantly the physical components (e.g. light, temperature, mixing, flow, habitat) and chemical components (e.g. organic and inorganic carbon, oxygen, nutrients) of an ecosystem that determine what lives and breeds in it, and therefore the structure of the food web. Biological interactions (e.g. grazing and predation) can also play a part in structuring many aquatic ecosystems. Aquatic ecosystems can only be maintained if the ecosystems are protected from degradation.

6.2.2 Water Temperature

While thermal stress may be from natural temperature fluctuations, stress may be increased because of anthropogenic activities. Thermal stress might be from industrial point sources (e.g. increases from thermal power station cooling; or decreases with cool water releases from reservoirs). Point sources are usually controlled by discharge consents that adhere to temperature guidelines that consider variation from ambient temperatures.

Changes in waterway size and shape, and reduction in streamside vegetation may also alter water temperature. Channel excavation, or sediment deposition, may produce wider and shallower waterways. Also the volume of water retained is decreased because of increased efficiency of water removal. Water temperature will increase because a wider channel has more surface area exposed to the sun's rays. Shallower water is heated more effectively, and there is less thermal mass to absorb the sun’s energy.

> **Temperature guidelines**
>
> Previous guidelines on temperature increases relate to heated effluent discharges. ANZECC (1992) recommended a maximum permissible increase in the temperature of any inland or marine waters should be either <2^{o}C or that set by the formula related to exposure, optimum growth and lethal temperatures. There was insufficient information to recommend guidelines for temperature decreases (e.g. cold water releases from reservoirs).
> ANZECC (2000) developed a protocol to be used to derive appropriate temperature guidelines for Australian and New Zealand waters. The method used depends upon the ecosystem type, the desired level of protection, and the availability of suitable reference systems and adequate data for these systems.

Pre-disturbance, many New Zealand waterways had extensive streamside cover. The removal of tall vegetation which overhangs and shades waterways increases the maximum water temperatures, daily mean temperatures, and causes increased daily water temperature fluctuations, especially during summer. For example, Quinn *et al.* (1992) show that for a small Southland stream a shaded reach had c. 4-10℃ lower temperatures than a more open, channel reach with grazed banks.

Changes in water temperature can have a substantial effect on aquatic ecosystems (ANZECC 2000):

- Influences on the physiology of the biota (e.g. growth and metabolism, reproduction timing and success, mobility and migration patterns, and production may all be altered by changes to the ambient temperature regime)
- Influences on ecosystem functioning (e.g. through changes in the rate of microbial processes and altered oxygen solubility)
- Influences on the toxicity of chemicals (e.g. many chemicals exhibit between a two and four fold increase or decrease in toxicity for each 10℃ rise in temperature Mayer & Ellersieck 1986)

If the overall water body temperature of a system is altered, an aquatic community shift can be expected. The preferred temperature ranges and tolerances are known for many New Zealand aquatic species. For example, banded kokopu prefer temperatures of c. 15-18℃, and temperatures around 30℃ are lethal (Richardson *et al.* 1994). Snails, riffle beetles and a few species of caddis-fly are particularly resistant to high water temperatures (Jowett 1997), whereas stoneflies are particularly sensitive and are usually restricted to rivers with summer water temperatures that do not exceed 19℃ (Quinn & Hickey 1990; Quinn *et al.* 1994). Temperatures of 24-26℃ are lethal to many stream invertebrates (Jowett 1997).

If water temperatures are raised above the natural range, there may be physiological stress or lethal effects. For example, brown trout spawn in winter and egg mortality increases when water temperature exceeds c. 10℃ (Scott & Poynter 1991). The optimum temperature range for adult trout is 12–19℃, and the lethal temperature is 25–30℃, depending on acclimatisation temperature (citations in Elliot 1994). Coldwater fish, such as trout and salmon, will disappear as a result of egg and fry mortality, direct adult mortality or reduced reproductive activity.

Higher temperatures often exacerbate low dissolved oxygen level problems in waterways. There may be increased microbial breakdown of organic matter, a process that requires dissolved oxygen. Warm water naturally holds less dissolved oxygen. Persistent warm conditions may lead to a depletion of dissolved oxygen in the water body (Hoare & Rowe 1992).

6.2.3 Dissolved oxygen

Under natural conditions there is considerable daily variation in dissolved oxygen (DO) levels, but the concern here is related to anthropogenic activities:

- Temperature affects on DO (particularly lack of mixing in warm, stagnant waterways)
- Oxygen losses occurring from algal respiration
- Oxygen losses from decomposition of organic matter

Low dissolved oxygen (DO) concentration has an adverse effect on many aquatic organisms (e.g. fish, invertebrates and micro-organisms) (ANZECC 2000) (Table 6.1). Prolonged exposure to low dissolved oxygen levels (<5-6 mg/L) may not directly kill an organism, but increases its susceptibility to other stresses. Exposure to <30% saturation (<2 mg/L oxygen) for 1-4 days may kill most of the biota in a system. If oxygen-requiring organisms perish, the remaining organisms will be air-breathing insects and anaerobic (not requiring oxygen) bacteria (Gower 1980).

Salmonids (e.g. brown trout and Chinook salmon) are cold water fish, with a wide range of dissolved oxygen requirements reported for various life stages and ambient conditions. Lethal levels for adults and juveniles are c. <3 mg/L. In the Brown trout BMP dissolved oxygen of >11mg/L May to October; and >8 mg/L for the rest of the year were recommended.

If all oxygen is depleted, aerobic (oxygen-consuming) decomposition ceases and further organic breakdown is accomplished anaerobically. Anaerobic microbes obtain energy from oxygen bound to other molecules such as sulfate compounds. Thus, anoxic conditions result in the mobilization of many otherwise insoluble compounds. The breakdown of sulfate compounds will often impart a "rotten-egg" smell to the water, affecting its aesthetic value and recreational use (Osmond *et al.* 1995).

Dissolved oxygen (DO)

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface, with the amount held depending on water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen) and with decreasing salinity (freshwater holds more oxygen than saltwater). Once absorbed, oxygen is either incorporated throughout the water body via internal currents or is lost from the system. Flowing water is more likely to have high dissolved oxygen levels than is stagnant water because of the water movement at the air-water interface. In flowing water, oxygen-rich water at the surface is constantly being replaced by water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air-water interface. Because stagnant water undergoes less internal mixing, the upper layer of oxygen-rich water tends to stay at the surface, resulting in lower dissolved oxygen levels throughout the water column. (Osmond *et al.* 1995).

		Production impairment	Instream DO (mg/L)
Salmonids			
	Embryo & larval stages	None	11
		Slight	9
		Moderate	8
		Severe	7
		Limit to avoid acute mortality	6
	Other life stages	None	8
		Slight	6
		Moderate	5
		Severe	4
		Limit to avoid acute mortality	3
Non-salmonids			
	Early life stages	None	6.5
		Slight	5.5
		Moderate	5
		Severe	4.5
		Limit to avoid acute mortality	4
	Other life stages	None	6
		Slight	5
		Moderate	4
		Severe	3.5
		Limit to avoid acute mortality	3
Invertebrates			
		None	8
		Moderate	5
		Limit to avoid acute mortality	4

Table 6.1. Dissolved oxygen requirements (mg/L) (based on WOTW 2004)

ANZECC Dissolved Oxygen (DO) guidelines

The 1992 ANZECC Guidelines recommended that dissolved oxygen should not normally be permitted to fall below 6 mg/L or 80-90 % saturation, determined over at least one diurnal cycle. These guidelines were based almost exclusively on overseas data, since there were very few data on the oxygen tolerance of Australian or New Zealand aquatic organisms. The Australian data are restricted to freshwater fish, and suggest that DO concentrations below 5 mg/L are stressful to many species (Koehn & O'Connor 1990).

ANZECC (2000) discuss the variability of DO by eco-region, which is a more sophisticated approach facilitated by application of the LENZ or REC classifications of eco-regions and river environments.

6.2.3.1 Temperature – dissolved oxygen

As water warms it holds less dissolved oxygen and the total amount of DO may be limited by temperature. At high water temperatures, even with 100% saturation, there may be too little oxygen for particular species or life stages (Table 6.1). In Fig. 6.1, at sea level with 100% air saturated water there is 14.6 mg/L at 0℃; and DO at 100% saturation decreases to 8.6 mg/L at 25℃.

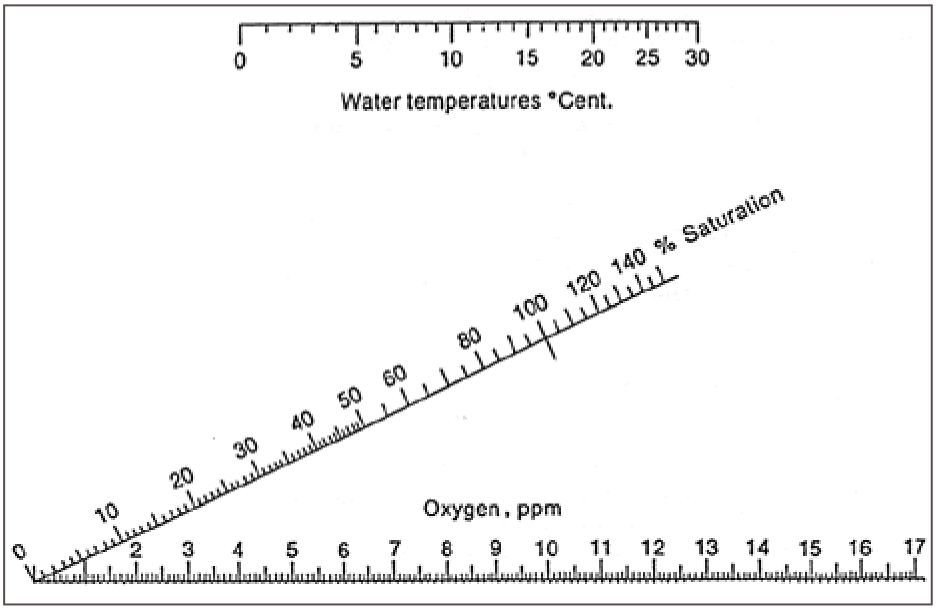

Fig. 6.1 Relationship between temperature, % saturation and dissolved oxygen (mg/L =ppm) (WOTW 2004).

6.2.3.2 Algal respiration – dissolved oxygen

Oxygen is produced during photosynthesis and consumed during respiration and decomposition. Photosynthesis requires light whereas respiration and decomposition occur 24 hours a day. Proliferation of periphyton (the slime and algae found on the stream bed) may reduce dissolved oxygen to suboptimal or lethal levels.

As discussed in “Vegetation”, nutrients alone cannot indicate whether a waterbody actually has a nuisance periphyton problem. Nutrient impacts vary as a function of the load and bioavailability of the nutrient, and the extent to which hydrodynamics and turbidity levels modulate plant and algae response (ANZECC 2000; Harris 2001). Guidelines for nutrient levels are presented for maintenance of benthic invertebrates; trout and angling in the New Zealand periphyton guidelines (Biggs 2000).

Nutrient guidelines to limit algal respiration dissolved oxygen reductions are proposed by Osmond *et al.* (1995). They note algal production is correlated to the levels of nitrogen (N) and phosphorus (P) in the water column (usually one is limiting). Phosphorus is the primary concern in most freshwater systems because it limits algal growth. However, if phosphorus availability is high, nitrogen may also be a concern. Above a 10:1 (N:P) ratio in the water column, the freshwater system will likely experience an algal bloom, the severity of which will be in relation to excess phosphorus available. Below that ratio, nitrogen is the limiting nutrient in the system and the bloom will be related to excess nitrogen (Schindler, 1978). Problems are not expected at total phosphorus concentrations <300 mg/m^3; possible problems at 300-500 mg/m^3; with problems at >500 mg/m^3. For orthophosphate (dissolved phosphorus) the corresponding values are <500 mg/m^3; 500-600 mg/m^3 and 800-1000 mg/m^3. An accrual period is not considered in these values (cf. Biggs 2000).

6.2.3.3 Organic matter – dissolved oxygen

Organic matter is derived from multiple sources including plant growth within the stream, soils from streambank erosion, leaf litter and debris from the catchment, and from anthropogenic sources such as sewage waste and agricultural runoff. Aerobic bacteria consume oxygen from the water during the process of decomposition of organic matter.

When excessive organic matter is brought into waterways dissolved oxygen concentration decreases. In severe cases anoxic (near zero dissolved oxygen concentration) and hypoxic (<2.0 mg/L DO) events occur, resulting in fish kills. In many cases, anoxia and hypoxia result from eutrophication and reflect the underlying problem of excessive nutrient loads (Radke *et al.* 2003).

6.2.4 Biological contaminants

Biological contaminants can be derived naturally in waterways (e.g. from fish and birds); with others directly discharged or carried into waterways from various sources (e.g. sanitary sewer overflows; malfunctioning or improperly designed and constructed sewage disposal systems; storm runoff from urban areas; bather defecation; wild and domestic animal waste and agricultural runoff). Domestic animal waste and agricultural runoff are often significant problems (e.g. Smith *et al.* 1993).

The presence of animal contaminants is an important issue in agricultural water quality management, particularly with the overall trend towards decreasing water quality and the increasing reuse of municipal and agricultural wastewaters (ANZECC 2000). Unsafe densities of pathogens in receiving waters can lead to restrictions on shellfish harvesting, fish kills, and potential health problems in humans (e.g. gastroenteritis), livestock and other organisms (Metcalf & Eddy 1991; Lepesteur *et al.* 2002).

6.2.5 Nutrients

Nitrogen (N) and phosphorus (P) are elements which are essential building blocks for plant and animal growth. Nutrient loads have been enhanced by human activity in many New Zealand streams. Enhanced periphyton biomass through nutrient enrichment is attributed to point source discharges of wastes; and intensification of land use (diffuse sources). Biggs (2000) suggest that historic proliferations downstream of point sources (e.g. dairy factories, meat and food processing and domestic sewage outfalls) have largely been eliminated. However, there may be enough residual inorganic nitrogen and phosphorus to cause proliferations of periphyton (e.g. wastewater including sewage). Diffuse sources (e.g. stormwater and agricultural runoff) are extremely important.

Urban stormwater sources of nutrients include fertilisers applied to lawns and gardens, leaky on-site wastewater disposal systems, and domestic pet excreta. Agricultural sources of nitrogen and phosphorus include livestock waste (e.g. animals in waterways, runoff from dairy sheds, pastures, feedlots, manure land application practices, and uncontrolled manure storage areas); land application of sewage sludge; nitrogenous fertilisers; irrigation return flows; and decomposing plant material (Straub, 1989).

Nutrient over-enrichment can cause the eutrophication of waterways. Eutrophication can cause excessive primary production (e.g. toxic algae blooms), a reduction in trophic structure (e.g. a shift in benthic invertebrate species from clean stream stoneflies, mayflies and caddisflies to filter feeding caddisflies, snails, beetles and worms (citations in Biggs 2000); change in energy flow and nutrient dynamics (e.g. high loading of organic matter can potentially lead to anoxic or hypoxic conditions; nitrification and denitrification rates can be inhibited in the absence of dissolved oxygen); and low dissolved oxygen concentrations which (with toxic algae) can harm benthic invertebrates, fish and other organisms (Radke *et al.* 2003). Periphyton proliferation directly affects aesthetics and recreation (e.g. swimming and fishing) and other water uses (e.g. blockage of water intakes).

The New Zealand periphyton guidelines (Biggs 2000) recommend periphyton biomass and cover guidelines for contact recreation and aesthetics; maintenance of “clean water” benthic invertebrate communities; and trout habitat and angling. They note:

- Periphyton communities are nitrogen limited in the majority of undeveloped forest and tussock lands
- Nitrate is usually present in moderate-high concentrations in streams where nitrate enriched groundwater is an important component of summer flows (e.g. lowland gravel bed streams in Canterbury)
    - Phosphorus limitations of periphyton growth tend to occur in these situations
    - Control of phosphorus (e.g. from fertilisers) is likely to be easier than nitrogen as a means of reducing periphyton proliferations in these situations

There is a suggestion that some nutrient enrichment stimulates fish production (e.g. Motueka and Mataura rivers) and that some of New Zealand’s most renowned trout fisheries have periodically high periphyton biomass (Biggs 2000). However, these steams have a moderate frequency of scouring floods; and the duration of high periphyton biomass is short. In other streams fish kills have been reported with very low night-time dissolved oxygen and high daytime pH as the result of *Cladophora* dominated proliferations (Manawatu River, Biggs 2000).

Nutrients alone cannot indicate whether a waterbody actually has a nuisance plant problem. Nutrient impacts vary as a function of the load and bioavailability of the nutrient, and the extent to which hydrodynamics and turbidity levels modulate plant and algae response (ANZECC 2000; Harris 2001). ANZECC (2000) Default trigger values for upland rivers and lowland rivers are 26 and 33 mg/m^3 for total phosphorus; and 295 and 614 mg/m^3, respectively, for total nitrogen for slightly disturbed systems.

Biggs (2000) recognise that linking periphyton biomass to stream nutrient concentrations is very difficult. Guidelines are provided for soluble inorganic nitrogen (SIN) and soluble reactive phosphorus (SRP) supply concentrations to prevent periphyton biomass from exceeding target levels, for accrual times of 20-50 days. For 200 mg chlorophyll a/m^2 to be exceeded (trout habitat and angling target) in mainly N limited diatom dominated communities, mean monthly SIN concentrations for 20, 30, 40, and 50 days accrual are <295 mg/m^3, <75 mg/m^3, <34 mg/m^3, <19 mg/m^3, respectively. For 75 and 100 days accrual, SIN values of <10 mg/m^3 are recommended. Corresponding SRP concentrations are <26, <6, <2.8, <1.7, <1, and <1 mg/m^3, respectively. To maintain benthic invertebrate production (50 mg chlorophyll a/m^2) SIN is <20 mg/m^3 (20 days accrual) and <10 mg/m^3 for longer periods of accrual. SRP values are all <1 mg/m^3.

Biggs (2000) caution users and notes the guidelines are very restrictive and may be exceeded naturally without excess proliferations of periphyton (perhaps because of high grazing activities by invertebrates).

For nutrient guidelines related to depression of dissolved oxygen see Vegetation: nutrients.

6.3 Management measures and BMPs

It is generally accepted that the most effective approach to reduce contaminant loadings in waterways is to control the generation of contaminants. In agricultural areas this is accomplished by implementing better land management practices. Hicks (1995) and MAF (1997) identify the following management measures and practices to control sediment and agricultural contaminants movement to surface and groundwater:

- Selecting the most appropriate land use for the site and circumstances
- Increasing the efficiency in the application of farming inputs so that fewer contaminants are available to be washed into receiving waters. Guidelines are provided in NZFMRA (2002) and www.dexcel.co.nz
- Decrease the amount of runoff (e.g. control soil compaction and pugging by managing livestock and vehicles; control water paths and flow concentration by contour ploughing; maintaining dense grass cover)
- Control stock in waterways

Detailed BMPs have been developed in the conservation literature, by Regional Councils and industry groups. Particularly effective practices include the following:

- Limiting pugging and compaction damage: Pugging damage occurs when the soil is so soft that the weight of grazing animals cannot be supported by the soil surface. Compaction damage is caused by farm vehicles and machinery. Management measures including maintaining a good ground cover; block grazing and on-off grazing; use of feed pads; selective use of different soil types and land management units; and avoiding working the soil when it is wet (Dexcel Farm Fact 3-21: Limiting pugging and compaction damage; Taranaki Regional Council Sustainable Land Management Programme 52: Managing stock on wet soils)
- Conservation Crop Rotation: An adapted sequence of crops designed to provide adequate organic residue for maintenance or improvement of soil tilth. This practice reduces erosion by increasing organic matter, resulting in a reduction of sediment and associated pollutants to surface waters (USEPA 2003). Crop rotations that improve soil tilth may also disrupt disease, insect and weed reproduction cycles, reducing the need for pesticides. This removes or reduces the availability of some pollutants in the watershed. Deep percolation may carry soluble nutrients and pesticides to the ground water. Underlying soil layers, rock and unconsolidated parent material may block, delay, or enhance the delivery of these pollutants to ground water. The fate of these pollutants will be site specific, depending on the crop management, the soil and geologic conditions. The mean reduction in dry cropland phosphorus was 78% (USEPA 2003). Nokes & Ward (1992) report the practice is medium to highly effective for sediment, absorbed nutrients and pesticides, but had no control of was ineffective for temperature, soluble nutrients and soluble pesticides and pathogens
- Exclude livestock from waterways: Prevent livestock from entering waterways or trampling riverbanks by fencing the stream margins. A primary benefit is the reduction of direct inputs of animal waste into waterways. (See Sedimentation)
- Restricted access to watering points: To reduce erosion (but not water contamination) use fencing to deny livestock access to the water except at designated points where a stabilised area (e.g. gravel pad) has been constructed. Fencing should extend into the water to prevent livestock from wandering into the waterway
- Stream crossings: Bridges or culverts are preferred types of crossings. Where this is not feasible, a stabilised area (e.g. gravel pad) should be constructed across the channel to reduce erosion and provide safe access for people, livestock, equipment, or vehicles. Use fencing to prevent animals from wandering off the crossing. Design guidelines are provided in MfE (2004) Culvert and bridge construction guidelines for farmers. (Available at www.mfe.govt.nz/publications/water)

A second line of defence is to retain sediments and contaminants on the land before they get into waterways. Management measures and BMPs attempt to detain water and treat contaminants through chemical and biological transformation:

- Water and sediment control basin: An earthen embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin. These basins have medium to high effectiveness for sediment and absorbed nutrients and pesticides; and no or low effectiveness for dissolved nutrients and pesticides (Nokes & Ward 1992). Effectiveness may exceed 90% efficiency in trapping sediment and total phosphorus in silt loam soils (UESPA 2000)
- Grassed waterways: Grassed waterways are broad, shallow, saucer-shaped channels designed to move surface water across farmland without causing soil erosion (e.g. rills, gullies). They filter sediment and sediment associated contaminants (e.g. nutrients) with low to medium effectiveness, but have no control or low effectiveness for soluble nutrients and pesticides (Nokes & Ward 1992)
- Filter strips: A strip of vegetation that intercepts sediment, organics, nutrients, pesticides, and other contaminants from shallow surface flow before these contaminants enter a waterway. Provision of forage, field borders, access and habitat. Effectiveness is low to medium for sediment control (Nokes & Ward 1992); with an average effectiveness in reducing erosion of 65% (USEPA 2003); and low to medium for absorbed nutrients and pesticides (Nokes & Ward 1992) unless specifically designed and managed for the treatment of solid wastes (USEPA 2003)
- Constructed wetland: A wetland that has been constructed for the primary purpose of water quality improvement. This practice is applied to treat waste waters from confined animal operations, sewage, surface runoff, milkhouse wastewater, silage leachate, and subsurface drainage by the biological, chemical and physical activities of a constructed wetland. Preliminary findings suggest constructed wetlands are effective in removing nutrients (34-94% reduction) from subsurface drainage from intensively grazed dairy pastures (Tanner *et al.* 2003). Results from seven domestic wastewater treatment wetlands in New Zealand showed performance comparable with North American wetlands (e.g. average BOD removal of 59-84%; suspended solids reductions of 67-84%; total kjeldahl nitrogen reductions of 17-33%; Sukias & Tanner 2004). In agricultural areas relatively large constructed wetlands are probably required for effective nitrate and total phosphorous removal (Tanner 2003). (See Tanner & Kloosterman 1997 for guidelines for constructed wetland treatment of farm dairy wastewaters in New Zealand: www.niwa.co.nz/pubs/no8/dairywaste2/constructed.pdf)

- Streamside planting: Plants are established or encouraged to grow along the channel margin, on the banks, floodplain and berms along the stream to provide erosion protection, habitat, food supplies, amenity and cultural values and to enhance water quality by reducing light and temperature and filtering and absorbing sediment and contaminants. Desirable species may suppress weeds in the channel and on the banks. (See Biodiversity: streamside planting)

While filter strips/streamside planting can effectively control sediment and nutrient delivery to streams, they should be used as a second line of defence, as an addition to, and not as an alternative to, well-planned land management.

- Filter strips >30 m are needed in most cases with erodible soils and poor upland management. In these cases it is clear that the installation of a grassed filter strip is not a practical means to control non point source pollution
- If good management practices are implemented, the sediment and associated contaminant load decreases dramatically and the filter requirement greatly reduces to practical widths (generally in the 2 to 5 m range)
- To control soluble contaminants such as nitrates, extensive forest buffers are required (in the order of 50 to 100 m wide), or runoff must be routed through constructed wetlands
- For riparian nitrate removal groundwater must move slowly through the treatment zone, and at a shallow enough depth to be within the rooting zone of riparian vegetation
- Soils must be anaerobic or of low oxidation/reduction potential (Eh) at least part of the year; and vegetation must release enough organic matter at the depth of groundwater to maintain a low enough Eh to allow rapid rates of denitrification (Correll 1997)
- Our understanding of water quality buffering mechanisms of riparian zones is far from adequate; and there is uncertainty as to how and when these functions will be saturated or exceeded (Correll 1997)

Vegetated drains can strip sediment, nutrient and pesticides, even in storm runoff (Moore *et al.* 2001). But increased plant growth is in itself a problem in terms of drain hydraulics. Plants can be removed by hand or mechanically; or they can be chemically treated in situ.

Chemical treatment may result in large amounts of dead and dying vegetation. If left in the stream, decomposition of this material may reduce dissolved oxygen levels and cause fish kills.

- Combination treatments may be required. The bulk of weeds may have to be removed mechanically, with the remainder treated chemically
- Strip treatment (i.e. alternating strips along the banks) has been suggested (Newbold *et al.* 1989). Strip spraying could work on emergent and bank vegetation, but it would not be able to be

controlled in submergent vegetation treatments. Costs would increase because multiple passes are required to control a reach. Hydraulics effects are unknown

- Dead-dying plants can be removed following chemical treatment

Finally, it is generally accepted that there is no single “silver bullet” to improve water quality – a system of management practices must be employed. (See Management context: operational decision making).

Citation:
Hudson, H.R. 2005. Drainage problems and solutions: water quality. Pages 6.1-6.13 in Hudson, H.R., editor. H20-DSS: Hillslopes to Oceans Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington. Available online at www.nzwerf.org.nz

7 Drainage problems and solutions: biodiversity

7.1 Introduction

Drainage of extensive areas of New Zealand has caused significant loss or degradation of wetlands and streams (Cromaty & Scott 1996). Many drains are new streams or remnants of meandering streams and wetlands that existed prior to agricultural development. These ecosystems often contain valuable fish populations and generally sustain diverse animal and plant communities. A central issue is how to avoid, remedy or mitigate adverse effects and provide optimum drainage management (See Management context).

This section considers management measures and BMPs to:

- Avoid adverse effects: Identifying sensitive times and places so as to avoid adverse effects on flora and fauna
- Remedy adverse effects: Rehabilitate disturbed areas and remove decomposing weeds
- Mitigate adverse effects: Identify and repair impediments to fish passage; and mitigate habitat degradation (e.g. with land retirement and streamside planting; constructed wetlands)

7.2 Avoid adverse effects

Concern is often expressed that drainage management may directly destroy or disturb aquatic and streamside life (Hudson & Harding 2004). Direct effects include crushing or removal or bird and fish eggs, disturbance and removal of fish with sediment removal and drain cleaning, and destruction of habitat. Indirect effects include introduction of suspended sediment leading to clogging of spawning redds and disruption of feeding; and disturbance of bird nesting and roosting because of noise and proximity of activity.

One of the foundations of sustainable management is to avoid adverse effects. This requires knowledge of spatial distribution of species, the sensitivity of species to disturbances, and how these patterns change over time (daily, seasonally, and year to year). As well, knowledge is required regarding fish passage requirements and limitations on upstream migration.

Work windows are often specified to avoid adverse effects. These activity “windows” (or exclusions of activity) are central to best management practice. There are several aspects to the determination of places and times to avoid. BMPs for whitebait and trout were developed to illustrate the type of information drain managers require:

- Whitebait (inanga): Inanga larvae (*Galaxias maculates*) are the most important species in the whitebait catch. Spawning habitats are vulnerable to damage by stock, channelisation, pollution, and a reduction in bank vegetation by mowing (Richardson & Taylor 2002). Spawning areas are identified and activities within these areas are avoided during the main period of spawning (February to mid-April).

Permanent fencing of spawning areas (native vegetation and long grass at the freshwater-saltwater transition at spring tide levels) is recommended

- Brown trout: Brown trout (*Salmo trutta*) are valued introduced sports fish. Undertake waterway management activities in brown trout (*Salmo trutta*) streams to maintain an adequate food supply, suitable dissolved oxygen levels, cool stream temperatures, instream and overhead cover, clear, clean water; and clean gravel for spawning.

There are few lowland streams which are not in highly modified landscapes. It is important to protect the few sites that remain:

- Identify sensitive areas: Flora, fauna and habitat surveys should be undertaken to identify culturally and ecologically sensitive areas and to identify rare, vulnerable, endangered and protected plant and animal species
- Delineate areas to avoid: Care must be taken to protect significant trees and other vegetation during operations. The areas should be identified and marked (e.g. flagged), and preferably fenced off to exclude stock and vehicles
- Protect sensitive areas: Vegetated buffers should be left around sensitive areas to prevent water and sediment problems. Diversion ditches and berms may be required

7.3 Remedy adverse effects

Disturbed land should be rehabilitated to prevent permanent damage to soil and water resources in and near channel work sites; to restore the productivity of soils to permit their pre-disturbance use or an alternative uses; and to control erosion, preserve the environment, maintain the visual quality of the landscape, and provide an economic use of the land:

- Rehabilitating land following stream works: To rehabilitate land impacted from stream channel works, such as drain excavation and stream bank protection. The aims are to protect sensitive sites, to prevent off-site damage, and to rehabilitate the stream banks and channel margins to a desirable condition.

Decomposition of organic matter causing decreases in oxygen and fish kills may result from chemical treatment of weeds where large amounts of dead and dying vegetation are left in the stream. Solutions include partial spraying (which may not be very effective because multiple passes are required to control a reach) or removal of dead-dying plants following treatment.

7.4 Mitigate adverse effects

The NZWERF 2001 workshop on drainage management examined the notion of drain “naturalisation”. Rhoads and Herricks (1996) describe the objectives of naturalisation as establishing stability, self-regulation, and diversity of form and function as geomorphological and ecological goals of stream management. Naturalisation embraces the notion of emulating the condition of undisturbed systems as an appropriate way of achieving the form and function goals (e.g. Brookes 1996). But, naturalisation explicitly recognises that frequent human intervention occurs.

A drain naturalisation programme would:

- Provide the required drainage outfall specified in a performance based management programme
- Reduce the cost of maintaining drains by emulating aspects of natural channels rather than attempting to maintain inherently unstable channels (e.g. reshaping banks; compound channels)
- Enhance habitat diversity and water quality with in channel detention wetlands for sediment and nutrient control
- Undertake streamside planting with a mix of native and exotic species (the latter primarily for bank stabilisation) (See Land retirement and streamside planting)

Fish migration is often impaired in lowland streams by floodgates and culverts. Gates should be modified or manipulated to allow easier passage. Fish bypasses may be required (e.g. gravel ramps for whitebait). Culvert replacement/repair should always be carried so that the culvert is the same gradient as the reach and the culvert invert is the lesser of either one third of the culvert diameter or 300 mm below the existing bed level.

7.4.1 Land retirement and streamside planting

7.4.1.1 Introduction

Land retirement and streamside planting is widely advocated overseas and in New Zealand (See Vegetation: streamside planting). However, while costs are known, or can be estimated, benefits are poorly quantified. The following are addressed:

- Costs
- Benefits
- Suggested approach
- Stream planting guide

7.4.1.2 Cost

Aspects of riparian land retirement and stream side planting costs are well known in New Zealand (e.g. Brown & Mackay 2000; GWRC 2003; Environment Waikato “Winning Margins” fact sheets). Costs include:

- Material costs, such as fencing, stock crossings and alternative water supplies (water troughs, pipes and pumps) to retire land along a stream or wetland
- Material costs, such as herbicides, weed mats and plants to establish and maintain streamside vegetation
- Labour for fencing, planting and maintenance

- Land cost, notably lost production on rural land (but this may be compensated by forage production or woodlots)
- Ongoing costs, such as weed and pest management; maintaining fences in flood prone areas; and costs for pumping water and powering electric fences

Establishment costs depend on the kind and extent of activities, and the surrounding land use. Indicative costs are shown for fencing both sides of a one kilometre stream reach with a 5 m retirement on both sides (i.e. 1 ha of land in total) (Table 7.1; based on Environment Waikato's "Winning Margins" fact sheets; Taranaki Regional Council Fact Sheet 24: Riparian fencing options and costs; and GWRC 2003). Costs vary regionally and by site; and there are varying degrees of subsidy. For example, Taranaki Regional Council provides free riparian planning advice and supplies seedling plants at cost ($1 to $3 depending on type and size) (Taranaki Regional Council Sustainable Land Management Programme 21: Why manage streambanks? The importance of riparian management).

In addition, there are costs for stock crossings and alternative water supplies. These costs vary depending on the site, with low key crossings costing hundreds of dollars to a well designed crossing in a 5 m wide channel costing in the $2,500 range (Water and Rivers Commission 2000). Alternative water supply costs are highly variable.

Table 7.1. Indicative costs for management of a 5 m wide margin along both banks of one kilometre of stream.

Item	Materials			Labour		Total
Fencing	**Length**	**$/m**	**Total**	**$/m**	**Total**	
1 wire electric	2000 m	$0.85	$1,700	$ 0.75	$1,500	$3,200
4 wire (2 electric), posts 5-10 m apart	2000 m	$1.00-$1.50	$2,000-$3000			
8 wire post (3-4 m apart) & batten	2000 m	$9.00	$18,000	$3.00	$6,000	$24,000
Planting	**No./ha**	**$/plant**	**Total**	**$/plant**	**Total**	**Total**
Poplar (1 m poles)	450	$1.40	$630	$2.00	$900	$1,530
Natives	2500	$3.50	$8,750	$2.00	$5,000	$13,750
Exotic forest (pinus radiata)	900	$0.30	$270	$1.10	$990	$1,260
Exotic forest (other)	900	$0.80	$720	$1.85	$1,665	$2,385
Native forest	1000	$4.65	$4,650	$3.60	$3,600	$8,250
Weed control						**$/ha**
Natives						$4,165*
Poplar & shrub willow						$585

* The GWRC estimate appears to be extremely high.

One of the most significant costs is lost production on retired land. One hectare of land is lost per kilometre of stream with a 5 m retirement on both sides of the stream. Recommendations for extensive buffers (e.g. 10-20 m – Auckland Regional Council – Parkyn *et al.* 2000) are costly. However, often only the steep banks are retired, and fencing is placed along the top of the streambank, with little loss of highly productive land. In any case, the buffer must be designed for a particular purpose to be effective.

7.4.1.3 Benefits

There are numerous reported benefits to retirement of stream margins and streamside planting (e.g. reviews in USEPA 1993; Collier *et al.* 1995; Lovett & Price 1999; MfE 2001; Hudson & Harding 2004). In brief, these mechanisms and benefits include:

- Bank vegetation tends to reduce rates of lateral channel erosion by slowing down the flow and increasing resistance of the banks to erosion. Vegetation also provides resistance to surface wash processes and insulates riverbanks reducing the effects of freeze-thaw on sediment supply (see Sedimentation: streambank erosion)
- Habitat is improved directly and indirectly. Riparian vegetation provides food (e.g. insects and organic matter) and cover in streams. Trees, shrubs, tall grass and high banks also provide shade, which is essential to regulate stream temperature and autochthonous production. Habitat diversity increases with a mix of instream and bank vegetation and large woody debris. Buffers along streams provide wildlife corridors
- Vegetated stream margins intercept undesirable contaminates from runoff before they enter a waterbody. They remove sediment, organic matter and other pollutants from runoff by filtration, deposition, infiltration, absorption, decomposition, and volatilization, thereby providing a buffer between contaminant source, such as crop fields, and waterbodies, such as drains, streams and ponds. Secondary benefits include provision of forage, field borders, and access
- Exclusion of livestock from waterways usually reduces inputs of animal waste and decreases stream bank erosion; livestock losses may be reduced, and animal health may improve
- With appropriate streamside planting landscape, mahinga kai, amenity and cultural values are improved

Non-structural bank protection measures have a long history of use in New Zealand (e.g. Beck 1937 - tree planting to control bank erosion in the Ashburton River). In the appropriate circumstances, often combined with bank re-shaping, bank plantings can provide very cost-effective bank protection (e.g. Patterson 2000 for a comparison of costs of bioengineering approaches with structural bank protection).

Habitat improvements are widely cited as a reason for streamside planting, particularly of native species (e.g. Collier *et al.* 1995). In the Waikato several streams reaches with stock exclusion, tree planting and/or remnant vegetation generally had rapid improvements in water clarity, bank stability and nutrient contamination compared with unfenced and actively grazed reaches or streams. However, there were no significant changes in macroinvertebrate communities toward “clean water” or “native” communities at most of the sites over the c.2 to >20 year history. Several possible reasons were proposed, including the likelihood that time scales of recovery may be large. Temperature is discussed in Vegetation: light and temperature regime.

In terms of buffers, it must be strongly emphasised that the effectiveness of riparian treatments depend on several factors:

- The contaminant to be controlled (e.g. sediment, nutrients, pesticides in particulate or dissolved form)
- The flowpath of the water (i.e. surface or subsurface runoff)
- The nature of the soil and sediment associated contaminants to be controlled
- Site specific upland conditions (e.g. soil types, topography, land use)
- Site specific channel conditions (e.g. stream width determines the effectiveness of riparian vegetation for temperature control; and bank height determines effectiveness of roots in bank protection)
- Operations and maintenance
- The combination of management practices utilised
- The influence of upstream conditions on the reach (e.g. a source of beneficial colonists; a source of sediment and contaminants and pest plants and animals)

Table 7.2 provides estimates of the relative effectiveness of types of streamside vegetation. Actual effectiveness at a specific site may differ considerably.

Table 7.2. Relative effectiveness of different buffer vegetation types in an agricultural setting (based on Dosskey et al. (1997) and others).

Benefit	**Vegetation type**			
	Reeds	**Grass**	**Shrub**	**Tree**
Stabilise bank erosion	Low-High	Medium	High	High
Filter sediment	High	High	Low	Low
Filter nutrients, pesticides, microbes				
- Sediment bound	High	High	Low	Low
- Soluble	High	Medium	Low	Medium
Aquatic habitat (cover, food, shade)	High	Low*	Medium	High
Terrestrial habitat				
- Grassland species	Medium	High	Medium	Low
- Forest species	Low	Low	Medium	High
Visual diversity	High	Low	Medium	High
Flood attenuation	Low	Low	Medium	High
Economic products	Low	Medium	Low	Med-High

* High for inanga (principal whitebait species) spawning

Australian experience shows the costs involved in riparian retirement and planting far outweigh the tangible benefits to landowners (Blennerhassett & Chamarette 2001; Hassall & Associates 2002). Studies in the United States conclude that on a societal scale the overall benefits are greater than the cost, but from an individual landowners perspective, benefits may not always outweigh costs even with substantial State assistance (Lynch & Tjaden 2000).

It is widely recognised that stock may cause erosion; and deterioration of water quality by direct input of waste into the stream (See Water quality: biological contaminants). However, actual impacts are dependent on characteristics of the stocking and site characteristics (see Sedimentation: streambank erosion). Fencing to exclude stock is often a major cost, but this often reported to be offset by reduced livestock injury and losses from drowning. Additional benefits include faster more efficient mustering of stock, improved livestock health (e.g. reduced mastitis and liver flukes).

Ecosystem “services” are increasing recognised as being important for long term sustainability. Riparian lands provide important ecosystem services, including water filtration, maintenance of soil fertility, pollination, pest control, and cultural and spiritual fulfillment (Lovett *et al.* 2004). Despite receiving these benefits, many ecosystems that deliver these services overseas and in New Zealand are in decline or have been lost (e.g. Tipa & Teirney 2003). Stream margin retirement and streamside planting can restore some of these services.

7.4.1.4 Suggested approach

Developing effective riparian buffer systems require several steps:

1) Identify problems and determine the causes
2) Determine the critical areas that disproportionately contribute to problems
3) Set realistic goals
4) Select appropriate management measures to control the generation of sediment and contaminates in the first instance and to control the movement of sediment and contaminants into and through waterways
5) Identify the best types of buffer to address the priority problems
6) Determine the minimum acceptable buffer width considering other supporting management measures
7) Develop an implementation and maintenance plan.
8) Follow up with monitoring, assessment and reporting.

The particular problem to be addressed and local conditions will determine the actions taken (e.g. bank reshaping) and type of streamside planting and subsequent management (Table 7.2).

In planning land retirement and streamside planting provision must be made for access for maintenance as required under the Land Drainage Act (see

Drainage management context: policies-legislation) and regional plans-policies. This may effectively limit planting of trees to one bank.

A hierarchy of approaches can be employed (with various components mixed and matched):

1) Passive management of fenced off streams and wetlands
   - One or both banks are fenced
   - The retired land extends to the top of bank
   - Vegetation is controlled with selective grazing (see Riparian livestock BMP)
   - There may be no further treatment

2) Active management of fenced off streams and wetlands
   - Pest plants and animals are controlled
   - Livestock access is controlled
   - Conventional pasture grasses can be established in the retirement area as a forage crop and nursery crop
   - One bank may be planted with shelter trees
   - The other bank can be planted with low vegetation that does not prevent channel maintenance

3) Specialised buffers to address particular problems
   - Bank erosion is controlled by structural measures where required (e.g. rock); and elsewhere with bank reshaping and/or planting (e.g. pasture grasses, flax, willows depending on the nature of the problem)
   - Contaminant inputs are controlled by a multi zone buffer extending onto the surrounding land (e.g. grassed along the paddock; tall trees; shrubs and water edge plants).
   - These buffers are relatively wide (often in the order of 30 m)

7.4.1.5 Stream planting guide

The combination of plants selected for streamside planting must be suitable for the intended purpose(s) (Table 7.2) and must be suitable for the site conditions. Generic planting guides have been developed for regional councils (e.g. Environment Waikato 2002 Clean streams and others). However the focus is on native species, although these species may not be the most suitable for some purposes (e.g. bank protection).

Conventional pasture grasses are often planted on the banks of drains and along floodway (Van Kraayenoord & Hathaway 1986). The remainder of the floodway channel and the floodway berms could be planted in a mixture of native shrubs and small trees with an inter-planting of shrub willow to provide erosion protection. Economic products could include short rotational and long-term tree species such as Tasman poplar, black and gray alders, Douglas fir and Holm oaks.

Van Kraayenoord & Hathaway (1986) recommend shrub and osier willows for several reasons including: they are less liable to windthrow than trees; they are male clones that can not produce unwanted seedlings in river channels, they are multi-stemmed and flexible and lay over in floods rather than break. In addition, they are bitter tasting and unpalatable to rabbits, hares and possums (Tasman poplar which are highly palatable to possums). Stock may eat willows, so stock should be excluded from the river protection plantings. The exotic hybrids have a theoretical risk of interbreeding.

Several exotic trees tolerate high rates of channel erosion and waterlogged soils which may occur along the stream edge and lower bank. Typical tree heights are 20-25 m; and growth is fast to very fast.

Common name	Species
Aokautere Willow	Salix matsudana X alba cv Aokautere NZ 1002
Moutere Willow	Salix matsudana X alba cv Moutere NZ 1184
Veronese Poplar	Populus deltoides x P.nigra 'Veronese'
Wairakei Willow	Salix matsudana X alba cv Wairakei NZ 1149

Adair willow (Salix matsudana X alba cv Adair NZ 1143) is highly tolerant of waterlogging, but moderately tolerant of bank erosion. Several other exotic trees are moderately tolerant of channel erosion and waterlogging. These trees are medium to very fast growing, with typical heights of 17.5 m to 25 m; with an intermediate to spreading form.

Common name	Species
Adair Willow	Salix matsudana X alba cv Adair NZ 1143
Androscroggin Poplar	Populus maximowiczii x P. trichocarpa 'Androscroggin'
Argyle Poplar	Populus deltoides x P. nigra 'Argyle'
Oxford Poplar	Populus maximowiczii x P. xberolinensis 'Oxford'
Pakai Poplar	Populus deltoides x P.trichocarpa 'Pakai'
Rochester Poplar	Populus maximowiczii x P. nigra 'Rochester'
Tasman Poplar	Populus X euramericana cv Tasman
Toa Poplar	Populus deltoides x P. nigra x P. yunnanensis 'Toa'

Once it has been determined that streamside planting is desirable, the native streamside planting guide will help determine what to plant,[1] where to plant, and how to plant and maintain the streamside (How to use the native planting guide).

Consideration should be given to bank reshaping to enhance the chances of successful (Sedimentation: streambank erosion).

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[1] The planting guideline is suitable for a wide range of conditions in New Zealand. To confirm appropriateness in specific locations we recommend you evaluate a more comprehensive guide to over 300 native species and exotic species:

www.landcareresearch.co.nz/research/biodiversity/greentoolbox/gtbweb

The appropriateness of stream side planting will be determined by several factors such as the problem to be addressed (e.g. surface runoff; subsurface contaminants) and local conditions such as soil type and wind. For example, in high wind zones with shallow, wet, soils trees may be blown over and cause major bank instability.

The effectiveness of various types of streamside vegetation are yet to be rigorously tested in New Zealand conditions, but the streamside planting designs are thought to be generally applicable. Local conditions determine actual benefits. For example, east-west running streams with north bank planting will be more shaded than north south running streams

7.4.1.5.1 How to use the native planting guide

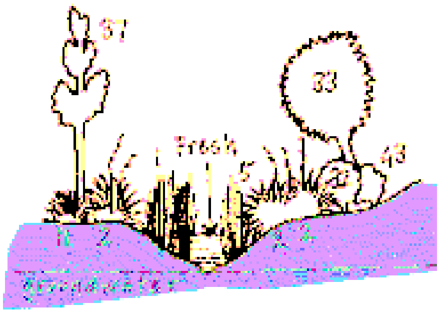
For each ecological region appropriate plants are determined on the basis of the channel shape (profile) and how frequently the plants are flooded (zones). Select the profile (or reshape the bank), and select the zone to identify suitable plants. The bank profile diagram shows the plant form (shape and relative height) and preferred position(s) for planting (Fig. 7.1).

Plants are selected by clicking on individual plants to see what they look like, and to get information on the shade, moisture and shelter conditions for that plant (Fig. 7.1). Alternatively, the “planting zones” dialog box is opened to select plants on the basis of bank position - frequency of flooding:

- Stream edge
- Lower bank
- Upper bank
- Crest or levee
- Back swamp
- Terrace face
- Upper terrace

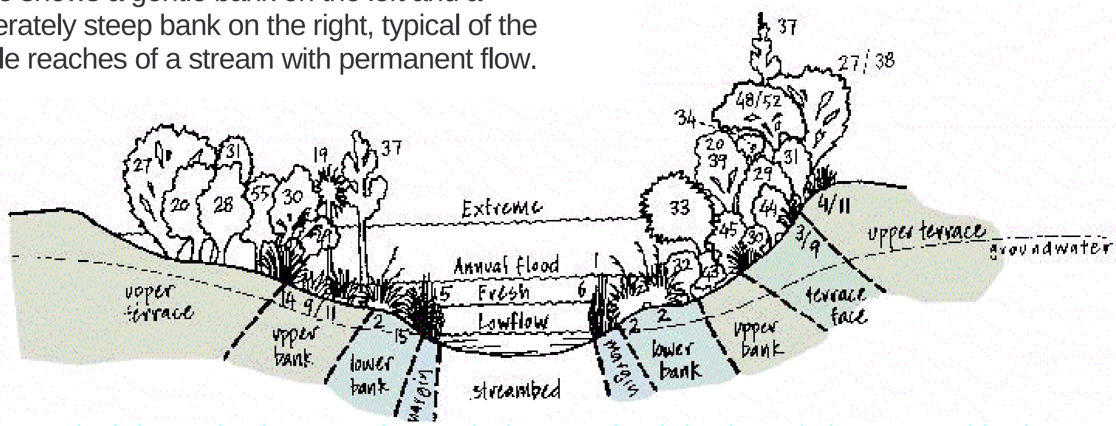
Table 7.3 is the complete list of species referred to in the streamside planting guide. For details on which species are appropriate for each part of a stream or river bank, choose the type of waterway from the profiles diagrams, then choose the zone. The plant “key” corresponds to the plant numbers in Fig. 7.1.

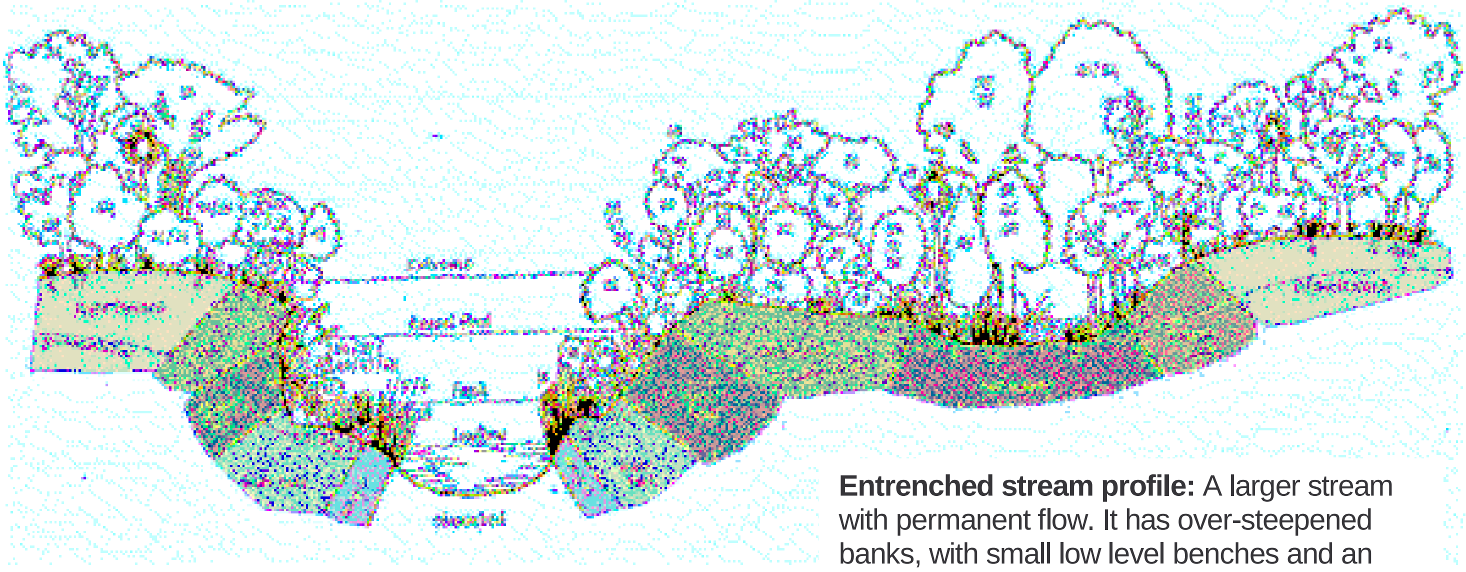
Fig. 7.1 Bank profiles (based on CCC 1996).



Low bank profile: This profile shows a small stream with low banks typical of an upper stream reach with seasonal water flows in winter or after heavy rain.

Moderately entrenched stream profile: This stream profile shows a gentle bank on the left and a moderately steep bank on the right, typical of the middle reaches of a stream with permanent flow.





Entrenched stream profile: A larger stream with permanent flow. It has over-steepened banks, with small low level benches and an extensive floodplain.

Table 7.3.Streamside native plants that are suitable for a wide range of New Zealand conditions

Key	Common name	Species	Planting Condition
1	bog rush	Schoenus pauciflorus	Permanently wet soil, in the open
2	harakeke, NZ flax	Phormium tenax	Wet to moist soil, in the open
3	hounds tongue fern	Phymatosorus pustulatus	Moist soil, in shade
4	kakaha, bush lily	Astelia fragrans	Moist soil, in semi-shade
6	kiokio	Blechnum minus, B. chambersii, B. fluviatile	B. minus - wet soil, in semi-shade. B. chambersii and B. fluviatile - moist soil, in shade
8	NZ iris, mikoikoi	Libertia ixioides	Moist to dry or free draining soil, in shade
9	pikopiko	Polystichum richardii	Moist to well drained soil, in shade
10	pukio, tussock sedge, makura	Carex secta, C. virgata, C. maorica	Wet soil, in the open
11	puniu, prickly shield fern	Polystichum vestitum	Moist soil, in shade
13	spike-sedge	Eleocharis acuta	Semi-aquatic conditions, in the open
14	toetoe grass, toitoi	Cortaderia richardii, C. fulvida	Moist soil, in the open
15	tussock rushes	Juncus gregiflorus, J. pallidus	Moist to wet soil, in the open
19	cabbage tree, ti kouka	Cordyline australis	Anywhere except in dense shade
20	five finger, whauwhaupaku	Pseudopanax arboreus, P. anomalus	Free draining deep soil, in semi-shade
22	hinau	Elaeocarpus dentatus	Moist soil, in semi-shade
23	horopito, peppertree	Pseudowintera colorata	Moist to seasonally wet soil, in shade
25	kahikatea, white pine	Dacrycarpus dacrydioides	Moist to seasonally wet soil, in semi-shade
26	kaikomako	Pennantia corymbosa	Moist to seasonally wet soil, in semi-shade
27	kanuka	Kunzea ericoides	Free draining soil, in the open
28	kapuka, broadleaf	Griselinia littoralis	Moist soil, in the open or in shade
29	karamu (shining)	Coprosma lucida	Free draining soil, in open or semi-shade
30	karamu	Coprosma robusta	Wet or dry soil, in the open or in shade
31	kohuhu, black matipo, tawhari	Pittosporum tenuifolium	Wet or dry soil, in the open or in shade
32	koromiko	Hebe salicifolia	Moist soil, in the open

<u>Key</u>	<u>Common name</u>	<u>Species</u>	<u>Planting Condition</u>
33	kotukutuku, tree fuchsia	<u>Fuchsia excorticata</u>	Moist or free draining soil, in semi-shade (protect from frost)
34	lancewood, horoeka	<u>Pseudopanax crassifolius</u>	Moist or free draining soil, in open to semi-shade
35	mahoe	<u>Melicytus ramiflorus</u>	Moist or free draining soil, in shade to semi-shade (protect from frost)
36	makomako, wineberry	<u>Aristotelia serrata</u>	Moist or free draining soil, in semi-shade (protect from frost)
37	manatu, lowland ribbonwood	<u>Plagianthus regius</u>	Moist to seasonally wet soil, in the open
38	manuka, tea tree	<u>Leptospermum scoparium</u>	Dry to wet soil, in the open
39	mapou	<u>Myrsine australis</u>	Moist to free draining soil, in semi-shade (protect from frost)
40	matai, black pine	<u>Prumnopitys taxifolia</u>	Moist soil, in semi-shade
41	mikimiki	<u>Coprosma propinqua</u>	Wet or dry soil, in the open.
42	mikimiki	Coprosma aff. parviflora (sp.t)	Wet or dry soil, in the open
43	mikimiki	<u>Coprosma rubra</u>, <u>C. areolata</u>	Moist soil, in semi-shade
44	mikimiki, round-leaved coprosma	<u>Coprosma rotundifolia</u>	Plant in moist soil, in semi-shade
45	mikimiki	Coprosma virescens, C. crassifolia	Moist to dry soil, in the open
47	poataniwha	<u>Melicope simplex</u>	Plant in moist soil, in semi-shade
48	pokaka	<u>Elaeocarpus hookerianus</u>	Moist or seasonally wet soil, in the open or in semi-shade
49	putaputaweta, marbleleaf	<u>Carpodetus serratus</u>	Moist free draining soil, in semi-shade
50	rohutu, NZ myrtle	<u>Lophomyrtus obcordata</u>	Moist to free draining soil, in the open or in semi-shade
51	silver fern	<u>Cyathea dealbata</u>	Moist soil, in shade (protect from frost)
52	South Island kowhai	<u>Sophora microphylla</u>	Free draining soil, in the open
54	totara	<u>Podocarpus totara</u>	Moist or free draining soil, in semi-shade
55	turepo, milk tree	<u>Streblus heterophyllus</u>	Moist to seasonally wet soil, in semi-shade (protect from frost)
56	weeping mapou	<u>Myrsine divaricata</u>	Moist to seasonally wet soil, in the open
57	wheki, hard treefern	<u>Dicksonia squarrosa</u>	Moist soil, in shade (protect from frost)

7.4.1.5.2 Steps for successful streamside planting

1) Planning:
   - Look at your stream over different seasons, and see what opportunities there are for improvement, given the available resources
   - Characterise the stretch of river bank by referring to the stream waterway profiles and planting guide
   - Organise resources including labour for site preparation, planting, and on-going maintenance - don't bite off more than you can chew!
   - Determine the most appropriate approach to re-vegetation:
     - Natural regeneration
     - Direct seeding
     - Plant seedlings
2) Seek advice on resource consents and design:
   - Get in touch with the local Council for further advice and check if you require resource consents
   - Design assistance may be offered by your Regional Council or seek professional advice (e.g. landscape architects) for advice. Check your library for resources
3) Prepare a planting plan:
   - Identify and mark out the different vegetation zones illustrated in the stream profile diagrams. Consider slope, distance from the stream, how damp the area is, and how the stream flows throughout the year
   - Compile a list of plant species for each zone
   - Place plants according to the zone they belong in, and the size they grow to. You typically need approximately one plant per square metre. Rushes, small sedges and ferns can be planted up to three per square metre
   - Near the water's edge place tussock, reeds and shrubs, with small trees located above these
   - On higher terraces and banks, plant tree and shrub species in groups
4) Order seeds and plants well in advance
   - Order seeds well in advance of when they are to be planted or propagated
   - If you are using seedlings, order plants well in advance. Select a nursery specialising in native plants and that can guarantee they were sourced locally
   - Water plants every day otherwise they may become stressed and die
5) Planting times
   - Check the planting times from the seed provider. Plant water edge-marginal plants in the summer. Other seedlings should

be planted during autumn (hardy plants) or spring (frost-tender plants)
- Some ground cover seedlings, slow growing, and/or frost sensitive species should be planted after some initial cover has established and dense grass has been managed (i.e. 1-2 years after first plantings). Examples include most ferns and tree ferns

6) Prepare the site

- Prepare the site well in advance of planting. Remove invasive weeds, including convolvulus, ivy, periwinkle, pampas grass, grey willow, alder and yellow flag iris
- Clear all vegetation for about 1 metre diameter around each planting position
- Rip ground or fork it to about half a metre depth if it is heavily compacted. Apply soil conditioner if topsoil is degraded

7) Setting out

- Set out plants in their correct zones, remembering to space plants according to how large they will grow (see stream profile diagrams). Ensure the plants have been well soaked and that they do not sit in the sun for a long time

8) Planting

- Prune off entangled roots, set the plant into a bed of soft, worked soil at the bottom of the hole, and repack crumbled soil around the root mass tightly to prevent air gaps
- On dry, steep sites dig the plant into a deep hole so that there is a hollow left in the ground around the stem to catch the rain
- On wet sites, plant in a shallower hole so that the top of the root mass and associated soil is at ground level or even slightly mounded above it in permanently saturated conditions
- Ensure plants within the waterway are well planted, and compacted around their base
- Give the plants and the surrounding dry ground a good watering after planting. Where possible, stake plants so they are easily identified

9) Fertiliser and mulch

- For poor soils apply slow-release fertiliser to each plant and spread short-term fertiliser (e.g. super-phosphate) onto the ground after planting and before mulching
- It is best to fertilise in the second year after planting, as plant roots are not well developed enough to utilise fertiliser prior to this
- On dry sites mulch with bark chips (up to 10 cm depth), newspaper, woollen mats, or other degradable materials such as carpet underlay (which is not rubberised)
- Do not use mulch on wet sites or anywhere near the water flow, as mulch is likely to be washed away, and may cause stream blockages

10) Establishment and on-going maintenance

- Regularly check on the plants' health for several years after establishment
- Remember that plants on dry banks will survive and thrive if watered regularly in summer. Replant areas where plants may have died
- Weeding around plants is essential to avoid competition and stress. Weeds can be controlled by regular spot-spraying or removal by hand, until the problem is resolved
- Monitor the growth of your streamside - enjoy how your site will thrive, develop, attract wildlife, and become self maintaining

Natural regeneration:

The area can be fenced off allowing natural regeneration to occur. Some form of pre-treatment may be required (e.g. burning or herbicide treatment). If natural regeneration fails, then consider direct seeding or planting seedlings.

- Advantages:
    - Relatively inexpensive, requiring fencing and continuing weed maintenance
    - Minimal labour requirement
    - Natural regeneration can outstrip plantings
    - Seedlings have well developed root systems and tap roots and so are better able to cope with climatic extremes
    - Mirrors the local flora and successional processes
    - Can result in vegetation communities that are diverse in composition and structure
    - Can be used in conjunction with other techniques
- Disadvantages:
    - A nearby source of propagates is required (e.g. from local plants, from vegetated areas upstream, or from seed stored in the soil)
    - Regeneration may be patchy. If the desired cover is not attained, direct seeding or planting may be necessary
    - Once grazing is excluded, weeds may become a problem if not controlled

Direct seeding:

Direct seeding of prepared ground, which is fenced, is efficient and cost effective. A diverse mixture of seeds can be sown to suit different soil types and zones and to provide trees shrubs and groundcover to mimic nature. The availability of seeds may be limiting.

- Advantages:
    - Relatively inexpensive, requiring less labour and time than planting seedlings

    - Large areas can be sown rapidly using conventional methods (hand or broadcast)
    - Seedlings develop good root systems and tap roots

- Disadvantages:
    - Direct seeding can be less reliable, and more variable, than planting seedlings
    - Seed predation can be a problem
    - Some species require particular germination conditions (e.g. fire)
    - Some seeds may take months or years to germinate
    - Weed control may be an issue

Planting seedling:

Planting seedlings is widely used. As with direct seeding, site preparation is essential and will involve weed control and fencing. Nurseries are geared up to propagate plants. Propagation can be by seed or cutting. For tussock-forming species plants can be divided.

- Advantages
    - Techniques for seedling planting are well established and generally produce reliable results
    - Plants have a ‘head start’ compared with direct seeding, and this provides instant satisfaction for the effort
    - Plantings can be individually placed where required
    - Plantings can be undertaken in combination with seeding
    - The method is useful for species that may not germinate readily or have special requirements
    - It is useful in areas where access for machinery is limited

- Disadvantages:
    - Generally plant costs are greater and planting is more labour intensive
    - ‘Transplant shock’ may occur – seedlings may take a while to begin to grow following planting
    - Roots are not as well developed as seedlings from direct seeding or natural regeneration

(Much of the information for the streamside planting guide was presented in "Indigenous Ecosystem booklets, maps and charts" (Lucas Associates, and Meurk & Lynn); the Christchurch City Council Streamside Planting Guide: www.ccc.govt.nz/parks/TheEnvironment/streamside_zones.asp; and Askey - Doran (1999). The list of generally suitable species was screened using the green tool box (www.landcareresearch.co.nz/research/biodiversity/greentoolbox/gtbweb)

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8 Glossary

Selected terms are defined. Italicised words within definitions are defined separately; and bold words within definitions are defined at that point.

Sources are referenced. There may be minor differences of an editorial nature to the referenced definition. Numerous citations are from the following sources: HEL - Handbook of environmental law (Harris, R. editor); NWD – Nevada Water Dictionary (Nevada Division of Water Planning dictionary of technical water, water quality, environmental, and water-related terms (http://water.nv.gov/Water%20planning/dict-1)); and RMA refers to the Resource Management Act (1991) (http://www.legislation.govt.nz). Other terms are from specified sources or are generally accepted definitions.

Definitions in this glossary which explain or summarise elements of existing water law, plans or policies are not intended to change those laws, plans or policies in any way.

Acute: Designates an exposure to a dangerous substance or chemical in sufficient dosage to precipitate a severe reaction. Acute exposure refers to such dosage levels received over a period of 24 hours or less. Longer-term exposures are referred to as Chronic exposure. (NWD). Arising suddenly and intensely. Opposite of Chronic, as in chronic toxicity.

Adaptive management: A process for implementing policy decisions as an ongoing activity that requires monitoring and adjustment. Adaptive management applies scientific principles and methods to improve resource management incrementally as managers learn from experience and as new scientific findings and social changes demand. (NWD).

Aggradation, aggrading: Build up in the level of a bed of a water body caused by the deposition of sediment. The opposite of *Degradation*.

Agrichemicals: Agrichemicals include all herbicides, insecticides, and other pesticides used on farms. (Dexcel farm facts 9-4: agrichemical use). In a broader sense agrichemicals refer to all chemical used on farms including pesticides, fertilisers, solvents and degreasers, paint, oil etc. See *Pesticide.*

Algae: Simple single-celled, colonial, or multi-celled, mostly aquatic plants, containing chlorophyll and lacking roots, stems and leaves. Aquatic algae are microscopic plants that grow in sunlit water that contains phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain. (NWD).

Algal (algae) bloom: (1) Rapid growth of algae on the surface of lakes, streams, or ponds; stimulated by nutrient enrichment. (2) A heavy growth of algae in and on a body of water as a result of high phosphate concentration such as from farm fertilisers and detergents. It is associated with *Eutrophication* and results in a deterioration in water quality. (NWD).

Algicide: One of a group of plant poisons used to kill filamentous algae and phytoplankton. (NWD).

Alluvial, alluvium: (1) In a general sense all deposits of sediment (clay, silt, sand, gravel, or other particulate material) deposited by a stream. (2) Fertile floodplain soils consisting of fine sediments, replenished by flooding.

Amenity values: Amenity values are defined in s.2 of the RMA to mean those natural or physical qualities or characteristics of an area that contribute to peoples' appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes. (HEL).

Anaerobic: Characterising organisms able to live and grow only where there is no air or free oxygen, and conditions that exist only in the absence of air or free oxygen. (NWD). See *Anaerobic decomposition, Anaerobic digestion.*

Anaerobic decomposition: The degradation of materials by *Anaerobic* micro-organisms living beneath the ground or in oxygen-depleted water to form reduced compounds such as methane or hydrogen sulfide. (NWD).Generally a slower process than *Aerobic digestion.*

Anaerobic digestion: The degradation of organic matter by micro-organisms in the absence of oxygen, particularly as related to the treatment of sewage sludge. Sewage treatment plants often use anaerobic digesters to reduce the volume of sludge produced in primary and secondary treatment, and they sometimes use the resultant methane gas as a heating fuel. (NWD).

Anoxia: (1) Absence of oxygen. (2) The total deprivation of oxygen, as in bodies of water, lake sediments, or sewage. Although not well defined, **Functional anoxia** generally refers to a body of water sufficiently deprived of oxygen to where Zooplankton and fish would not survive. (NWD).

Anoxic: (1) Denotes the absence of oxygen, as in a body of water. (2) Of, relating to, or affected with anoxia; greatly deficient in oxygen; oxygenless as with water. (NWD).

Aquatic: (1) Consisting of, relating to, or being in water; living or growing in, on, or near the water. (2) Taking place in or on the water. (3) An organism that lives in, on, or near the water. (NWD).

Armour, armouring: (1) Formation of a layer of rocks on the surface of a streambed that resists erosion by water flows. The rocks can be naturally occurring, caused by the scour of smaller particles, or placed to stop channel erosion. (2) A protective layer of very large rocks placed to prevent water erosion or mass movement off a structure or embankment. (See *Rip Rap*).

Bank: The slope of land adjoining a body of water, especially adjoining a river, lake, or a channel. With respect to flowing waters, banks are either right or left as viewed facing in the direction of the flow. (NWD). See *River bank*.

Bank and channel stabilization: Implementation of structural features along a streambank to prevent or reduce bank erosion and channel degradation. (NWD). See *Channelisation.*

Bankfull stage: The water level (stage) when the banks of the river are overtopped and water overflows onto the floodplain or surrounding land beyond the normal channel.

Base flow: (1) The flow that a perennially flowing stream reduces to during the dry season. It is supported by groundwater seepage into the channel. (2) The fair-weather or sustained flow of streams; that part of stream discharge not attributable to direct runoff from precipitation, snowmelt, or a spring. Discharge entering streams channels as effluent from the groundwater reservoir. (3) The volume of flow in a stream channel that is not derived from surface run-off…. (NWD).

Batter: The sloped surface of an embankment.

Bed: (a) In relation to any river: (i) For the purposes of esplanade reserves, esplanade strips, and subdivision, the space of land which the waters of the river cover at its annual fullest flow without overtopping its banks; (ii) In all other cases, the space of land which the waters of the river cover at its fullest flow without overtopping its banks; and (b) In relation to any lake, except a lake controlled by artificial means: (i) For the purposes of esplanade reserves, esplanade strips, and subdivision, the space of land which the waters of the lake cover at its annual highest level without exceeding its margin; (ii) In all other cases, the space of land which the waters of the lake cover at its highest level without exceeding its margin; and(c) In relation to any lake controlled by artificial means, the space of land which the waters of the lake cover at its maximum permitted operating level. (RMA). See *Active bed.*

Bed load: Material that moves over a stream bottom by rolling, sliding or skipping along or very close to the bed; compared with the *Suspended load* or *Dissolved load*.

Bed material: The sediment mixture of which the bottom of a *Water body* is composed.

Benthic: At or near the bottom of the water column, including the mud or sand habitat [presumably the *Substrate* irrespective of composition] and the associated species. (HEL).

Benthic invertebrates: Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples are clams, crayfish, and a wide variety of worms. (NWD).

Benthic organisms: Those organisms living at or near the bottom of a body of water. They include a number of types of organisms, such as bacteria, fungi, insect larvae and nymphs, snails, clams, and crayfish…. (NWD). See *Benthic invertebrates*.

Benthos: (1) All the plant and animals living on or closely associated with the bottom of a body of water. (2) Organisms living within a stream's substrate. (NWD).

Berm: (1) A nearly flat area of ground between the active riverbed and a stopbank. In New Zealand berms are generally well vegetated or planted in trees for erosion control and to retard flood flows. They usually flood on annual events. (2) A narrow shelf thrown up on a beach by storm waves.

Best management practices (BMPs): (1) Generally accepted practices/activities that provide for more efficient use of resources and/or contribute to the effective reduction of waste or pollutants. (2) Practices may emerge from successes and failures; are shown to be generally applicable taking into account particular circumstances and requirements, including resources and legal obligations and values; and are technically and economically reasonable, are reasonably capable of being implemented, and for which significant conservation or conservation related benefits can be achieved. See *Management measures*.

Biodiversity, biological diversity: The variety of species, genetic patterns within and between populations, habitats and biological landscapes in a given area. This 'biodiversity' may be measured at a number of geographic scales…. (HEL). (1) The variety of life and its processes. Biodiversity includes the diversity of landscapes, communities, and populations (genetic variation). Also called biological diversity or biotic diversity. (2) Refers to the variety and variability of life, including the complex relationships among micro-organisms, insects, animals, and plants that decompose waste, cycle nutrients, and create the air that we breathe. Diversity can be defined as the number of different items and their relative frequencies…. (NWD).

Biological (biochemical) oxygen demand (BOD): (1) A measure of the quantity of dissolved oxygen, in milligrams per litre, necessary for the decomposition of organic matter by micro-organisms, such as bacteria. (2) A measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements. Measurement of BOD is used to determine the level of organic pollution of a stream or lake. The greater the BOD, the greater the degree of water pollution. (NWD).

Biota: All living organisms. (HEL). See *Abiotic*.

Biotic: Pertaining to life or living things, or caused by living organisms. (NWD).

Blue-green algae: A group of phytoplankton which often cause nuisance conditions in water, so called because they contain a blue pigment in addition to chlorophyll. (NWD).

Brackish: Having a somewhat salty taste, particularly from the mixing of seawater and freshwater.

Buffer strips: (1) Strips of grass or other erosion-resisting vegetation between or below cultivated strips or fields. (2) Grassed or planted zones which act as a protective barrier between an area which experiences livestock grazing or other activities and a water body…. (NWD).

Bund: An embankment (often temporary) used to control or divert the flow of water. See *Dike*.

Canal: A constructed open channel for transporting water from the source of supply to the point of distribution, usually for irrigation or water supply.

Catchment: The land area drained by a drain, stream or river. Also called a *Watershed* or *Drainage basin*.

Caving: The collapse of a stream bank by undercutting due to erosion of the toe or an erodible soil layer in the face of the bank. See *Erosion, Streambank, Toe*.

Channel (watercourse): A natural stream that conveys water; a ditch or channel excavated for the flow of water. River, creek, run, branch, anabranch, and tributary are some of the terms used to describe natural channels, which may be single or braided. Canal, aqueduct, and floodway are some of the terms used to describe artificial (man-made) channels. (NWD). See *Watercourse.*

Channel capacity: The maximum rate of flow that may occur in a stream without causing *Overbank flooding*; the maximum flow which can pass through a channel without overflowing the banks. (NWD).

Channelisation: All the procedures of river channel engineering which are used to control floods, improve drainage, maintain navigation, or restrain bank erosion (Brookes 1989). Structural measures include rip rap, groynes, retards, anchored trees, and weirs. Non-structural channelisation includes increasing the capacity and hydraulic efficiency of a river by straightening, deepening, shaping or widening the channel; constructing new channels; and reducing resistance to flow by clearance of aquatic vegetation and instream debris, removal of riparian vegetation, removing pools and riffles, lining channels (e.g. concrete); and stabilising banks by tree planting. See *Channelised stream.*

Channelised stream: In agricultural areas existing streams have often been channelised and relocated. Channelised streams are characterised by one or more of the following: (1) Channels are usually excavated with a flat bottom and steep side slopes. (2) Channels have long straight reaches which may show some signs of natural channel processes (e.g. meandering, pool-riffle development). (3) Relocated streams typically flow along property or field boundaries. (4) Flow may be ephemeral, intermittent, or perennial. (5) They are an integral component of natural drainage, often with a network of surface and subsurface drains. (6) Perennial streams are likely to have vegetation growth on the bed and banks and support aquatic invertebrates and fish. See *Channelisation, Natural stream.*

Chemical oxygen demand (COD): (Water Quality) (1) A measure of the chemically oxidisable material in the water which provides an approximation of the amount of organic and reducing material present. The determined value may correlate with *Biochemical oxygen demand* (BOD) or with carbonaceous organic pollution from sewage or industrial wastes. (2) A chemical measure of the amount of organic substances in water or wastewater…. (NWD).

Chronic: Showing effects only over a long period. Opposite of *Acute*.

Clarity: Clarity (or visual clarity) relates to the transmission of light through water and is measured by the visual range to a black disk. (MFE 1994). See *Turbidity.*

Conservation: (1) Increasing the efficiency of energy use, water use, production, or distribution. (2) The careful and organised management and use of natural resource, for example, the controlled use and systematic protection of natural resources, such as forests, soil, and water systems in accordance with principles that assure their optimum long-term economic and social benefits. Also, preservation of such resources from loss, damage, or neglect. (NWD).

Conservation tillage: A level of reduced tillage combined with one or more soil and water conservation practices designed to reduce loss of soil or water relative to conventional tillage. Such activities often … retains productive amounts of residue mulch on the surface. (NWD).

Contaminant: (1) In a broad sense any physical, chemical, biological, or radiological substance or matter in the environment. (2) (Water Quality) In more restricted usage, a substance in water of public health or welfare concern. Also, an undesirable substance not normally present, or an unusually high concentration of a naturally occurring substance, in water, soil, or other environmental medium. (NWD). See *Pollution.* Contaminants are defined in S. 30(1)(f) of the RMA: "The control of discharges of contaminants into or onto land, air, or water and discharges of water into water: where contaminant is defined as: "Contaminant" includes any substance (including gases, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar, or other substances, energy, or heat- (a) When discharged into water, changes or is likely to change the physical, chemical, or biological condition of water; or (b) When discharged onto or into land or into air, changes or is likely to change the physical, chemical, or biological condition of the land or air onto or into which it is discharged: (s2 Resource Management Act 1991)."

Cover: (1) Vegetation or other material providing protection to a surface. (2) The area covered by live above-ground parts of plants. (3) Anything that provides visual or physical protection for an animal. Cover for fish includes vegetation that overhangs the water, undercut banks, rocks, logs and other woody debris, turbulent water surfaces, and deep water. (NWD).

Critical area: An area that, because of its size, location, condition, or importance, must be treated with special consideration because of inherent site factors and difficulty of management. Also, a severely eroded, sediment producing area that requires special management to establish and maintain vegetation to stabilise the soil. (NWD).

Culvert: A transverse drain or waterway under a road, railroad, canal, or other obstruction. (NWD).

Debris: Accumulated material; any material, including floating or submerged trash, *Suspended sediment*, or *Bed load*, moved by a flowing stream. (NWD).

Diffuse sources: See *Non-point sources*.

Degradation (stream channels): The removal of bed material and resultant general lowering of the streambed by water erosion. The opposite of *Aggradation*; and distinct from local *Scour* (e.g. erosion at a bend in the river).

Delta: (1) An alluvial deposit made of rock particles (sediment and debris) dropped by a stream as it enters a body of water. (2) A plain underlain by an assemblage of sediments that accumulate where a stream flows into a body of standing water where its velocity and transporting power are suddenly reduced…. (NWD).

Denitrification: The removal of nitrate ions (NO_3^-) from soil or water; involves the *Anaerobic* biological reduction of nitrate to nitrogen gas. The process reduces desirable fertility of an agricultural field or the extent of undesirable aquatic weed production in aquatic environments. (NWD). See *Denitrifying bacteria*.

Denitrifying bacteria: Bacteria in soil or water that are capable of anaerobic respiration, using the nitrate ion as a substitute for molecular oxygen during their metabolism. The nitrate is reduced to nitrogen gas (N_2), which is lost to the atmosphere during the process. (NWD).

Design flow, flood: Commonly used to mean the flow or flood magnitude criterion used for design and operation of various drains, channels or control works.

Dike: (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading…. (NWD). See *Bund, Embankment*.

Diquat: A strong, non-persistent, yellow, crystalline herbicide, C12H12Br2N2, used to control water weeds. (NWD).

Discharge, hydrologic: The outflow, or quantity, of water passing down a stream. Expressed in litres per second (L/s) for small flows and cubic metres per second for larger flows (cms, cumecs, m^3/s, or $m^3\ s^{-1}$).

Discharge, RMA: Section 15 of the RMA controls discharges of contaminants to land, air and water. Regional plans set rules for a range of permitted discharge circumstances. If a rule in a plan does not provide for a discharge the activity is automatically covered by s. 15 and is treated as a discretionary activity (s.77) thus triggering a requirement for a discharge permit. (HEL).

Discharge, sediment: The outflow, or quantity, of sediment passing down a stream. Loads are expressed as milligrams per litre (*Suspended sediment*), or tonnes; and discharge units are typically tonnes per unit time (e.g. tonnes/day).

Dissolved load: The material transported by a stream or river in *Solution* rather than as *Bed load* or *Suspended load.* Analytically, it is the material in a representative water sample that passes through a 0.45-micrometer membrane filter.

Dissolved oxygen (DO): Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface, with the amount held depending on water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen) and with decreasing salinity (freshwater holds more oxygen than saltwater). Once absorbed, oxygen is either incorporated throughout the water body via internal currents or is lost from the system. Flowing water is more likely to have high dissolved oxygen levels than is stagnant water because of the water movement at the air-water interface. In flowing water, oxygen-rich water at the surface is constantly being replaced by water containing less oxygen as a result of turbulence, creating a greater potential for exchange of oxygen across the air-water interface. Because stagnant water undergoes less internal mixing, the upper layer of oxygen-rich water tends to stay at the surface, resulting in lower dissolved oxygen levels throughout the water column. (Osmond *et al.* 1995).

Diversion: (1) A structure in a river or canal that divers water from the river or canal to another watercourse. (2) The transfer of water from a stream, lake, aquifer, or other source of water by a canal, pipe, well, or other conduit to another watercourse or to the land, as in the case of an irrigation system. Also, a turning aside or alteration of the natural course of a flow of water, normally considered physically to leave the natural channel…. (NWD).

Drain: (1) To draw of (a liquid) by a gradual process. (2) A buried pipe or other conduit (closed drain) for the conveyance of surplus groundwater. (3) A ditch or canal (open drain) for carrying off surplus surface water or groundwater. (4) A system to control water tables near the ground surface to maintain levels at or below specified depths. (NWD). See *Drains.*

Drains: Constructed channels designed to remove excess water from depressions, wetlands, surface runoff, groundwater, and from subsurface drains (e.g. tile drains). Drains are constructed channels characterised by one or more of the following: (1) Channels are usually excavated to a uniform bottom with steep side slopes and are typically designed to remove surface water from depressions and wetlands; and to lower groundwater levels; (2) Channels are typically straight for long reaches, and often flow along property or field boundaries, with tight bends (90°); (3) They may show signs of natural channel processes (e.g. meandering, pool-riffle development; erosion and slumping of banks); (4) **Dry drains** are ephemeral or intermittent and flow some of the time. These drains typically do not support aquatic vegetation or aquatic invertebrates and fish. However, there may be some exceptions (e.g. Canterbury mudfish); (5) **Wet drains** are perennial and have standing water or flow almost all the time. They are likely to have aquatic vegetation growth and support aquatic invertebrates and fish. See *Wetland*; surface and groundwater *Runoff*.

Drainage: (1) The removal of excess surface water or groundwater from land by means of surface or subsurface drains. (2) Improving the productivity of agricultural land by removing excess water from the soil by such means as ditches or subsurface drainage tiles (pipes). (3) The downward movement of water through the soil. When this occurs rapidly, the soil is referred to as “well drained”; otherwise poorly drained. Most plant roots need oxygen as well as water, and soil that remains saturated (poorly drained) deprives roots of necessary oxygen. (4) Soil characteristics that affect natural drainage. (NWD). See *Drain, Drains.*

Drainage basin: Synonymous with *Catchment* and *Watershed*.

Dredge, dredging: To clean, deepen, or widen waterbodies by scraping and removing solid materials from the bottom with a mechanical scoop or by suction.

Drop structure: A structure in the stream channel, such as a weir, for dropping water to a lower level and dissipating its surplus energy.

Ecological region, ecoregion: A continuous geographic area over which the macroclimate is sufficiently uniform to permit development of similar ecosystems on sites with similar geophysical properties. Ecoregions contain multiple landscapes with different spatial patterns of ecosystems. (NWD). Ecoregions are made up of **ecodistricts**, which have more localised characteristic soils, species associations and topography…. (HEL).

Ecosystem: (1) A community of animals, plants, and bacteria, and its interrelated physical and chemical environment. An ecosystem can be as small as a rotting log or a puddle of water, but current management efforts typically focus on larger landscape units, such as a mountain range, a river basin, or a watershed. (2) A complex of interacting plants and animals with their physical surroundings. Ecosystems are isolated from each other by boundaries which confine and restrict the movement of energy and matter, for example, an ecosystem could be recognised at a watershed scale by designating an area of common drainage (i.e., topography determines movement of water). (NWD). A typical ecosystem may be that of a harbour, or a forest or a developed area of farmland such as the Canterbury Plains. Ecosystems may be delineated by physical discontinuities such as hills, faulting or waterbodies or the extent of past developments. (HEL). Also see *Biodiversity*.

Ecosystem sustainability: The capacity of an *Ecosystem* for long-term maintenance of ecological processes and functions, biological diversity, and productivity. Also called ecological sustainability. (NWD). See *Sustainable management.*

Embankment: An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes. (NWD). A *Dike*.

Embeddedness: Embeddedness is a substrate attribute reflecting the degree to which larger particles (boulder, cobble, pebble, and large gravel) are surrounded or covered by fine sediment such as sand, silt, or clay. Fine sediment can fill the interstitial spaces between large particles… Substrates with heavy interstitial filling are described as highly embedded and degraded in benthic habitat quality. (Bain 1999). The impairment of benthic habitat quality is rated as negligible (<5% of the gravels-cobbles-boulders surface is covered by fine sediment); low (5-25% cover); moderate (25-50%); high (50-75%); to very high impairment (>75% of the surface is covered by fine material). See *Substrate.*

Endemic species: Native to and restricted to a particular geographical regions. (HEL). Distinct from *Native species.*

Environment: Defined in s.2 of the RMA. The definition includes the social, cultural and economic aspects of the environment…. (HEL).

Erodible: Able to be eroded. See *Erosion*.

Erosion: (1) Detachment of soil particles under the influence of water and/or wind. (2) The wearing away and removal of materials of the earth's crust by natural means. (3) The process by which flood waters lower the ground surface in an area by removing upper layers of soil. As usually employed, the term includes weathering, solution, corrosion, and transportation. The agents that accomplish the transportation and cause most of the wear are running water, waves, moving ice, and wind currents. Most writers include under the term all the mechanical and chemical agents of weathering that loosen rock fragments before they are acted on by the transportation agents; a few authorities prefer to include only the destructive effects of the transporting agents. (NWD).

Erosion, accelerated: Erosion that is much more rapid than normal (*Geological* or *Natural* erosion), usually as a result of the influence of the activities of man (e.g. denuding hill slopes).

Erosion, channel: See *Degradation, Erosion, Erosion streambed, Erosion streambank, Scour.*

Erosion, geological or natural: The normal erosion caused by geological process acting over the long term (e.g. the wearing away of mountains; erosion of river banks) with subsequent deposition of sediment downstream and in receiving waters.

Erosion, gully: The widening, deepening, and head cutting of small channels and waterways by flowing water on a hillslope. In contrast to rill erosion (*Erosion, rill*), gullies are relatively narrow and deep (generally too deep to obliterate by ploughing (exceeding about 30 cm), to metres or tens of metres deep).

Erosion, rill: Removal of soil by shallow, concentrated flows, usually on recently cultivated soil and recent cut and fills. The rills may coalesce to form a gully (*Erosion, gully*). Rill channels can be smoothed out by normal tillage.

Erosion, sheet: The removal of a fairly uniform veneer of soil from the land by shallow surface flow (*Runoff, surface*), often in conjunction with impacts of raindrops (*Erosion, splash*).

Erosion, splash: The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff. (NWD).

Erosion, streambank: *Scour* of streambanks by flowing water, leading to direct removal of the bank, or undercutting and subsequent collapse of the streambank. See *Caving*.

Erosion, streambed: Scouring of the bed of channels by flowing water. Extensive scour may result in channel **degradation**.

Estuary: (1) An area where fresh water meets salt water; for example, bays, mouths of rivers, salt marshes, and lagoons. (2) That portion of a coastal stream influenced by the tide of the body of water into which it flows… (NWD). See *Lagoon*.

Eutrophication: (1) The degradation of water quality due to enrichment by nutrients, primarily nitrogen (N) and phosphorus (P), which results in excessive plant (principally algae) growth and decay. When levels of N:P are about 7:1, algae will thrive. Low dissolved oxygen (DO) in the water is a common consequence. (2) The process of enrichment of water bodies by nutrients. (3) Over-enrichment of a lake or other water body with nutrients, resulting in excessive growth of organisms and the depletion of oxygen. Degrees of Eutrophication typically range from Oligotrophic water (maximum transparency, minimum chlorophyll–a, minimum phosphorus) through Mesotrophic, Eutrophic, to Hypereutrophic water (minimum transparency, maximum chlorophyll–a, maximum phosphorus). Eutrophication of a lake normally contributes to its slow evolution into a Bog or Marsh and ultimately to dry land. Eutrophication may be accelerated by human activities and thereby speed up the aging process…. (NWD).

Fauna: (1) A term used to describe the animal species of a specific region or time. (2) All animal life associated with a given habitat, country, area, or period. (NWD).

Faecal material: (Water Quality) Solid waste produced by humans and other animals and discharged from the gastrointestinal tract. Also referred to as faeces or solid excrement, it is a component of domestic sewage and must be treated to avoid the transmission of faecal bacteria and other organisms or disease. (NWD).

Fertiliser: Any organic or inorganic material of natural or synthetic origin that is added to a soil to supply elements essential to plant growth…. (NWD).

Filter strip: A strip of vegetation, usually grass, often along a stream margin, used for removing sediment, organic matter, and other contaminants from runoff and waste water.

Flood, flood waters: (1) Temporary inundation of normally dry land areas from the overflow of inland or tidal waters, or from the unusual and rapid accumulation or runoff of surface waters from any source. The rise in water may be caused by excessive rainfall, snowmelt, natural stream blockages, wind storms over a lake or any combination of such conditions. (2) An overflow of water onto lands that are used or usable by man and not normally covered by water. Floods have two essential characteristics: The inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake, or ocean. (NWD).

Flood capacity: The flow carried by a stream or floodway at bankfull water level. Also, the storage capacity of the flood pool at a reservoir. (NWD).

Floodplain: The area of land adjacent to a river over which flood waters historically flowed or could potentially flow.

Flora: (1) A term used to describe the entire plant species of a specified region or time. (2) The sum total of the kinds of plants in an area at one time. All plant life associated with a given habitat, country, area, or period. Bacteria are considered flora. (NWD).

Flow: (Hydrology) The downstream movement of water. See *Discharge, hydrologic.*

Freeboard: The height above a design maximum water level and the top of a structure such as a drain channel, drain, or stopbank. The freeboard is intended to allow for unpredictable obstructions (e.g. debris blockages) and uncertainties in analysis, design and construction.

Gabion: A cobble filled wire basket, usually rectangular, used in water control structures and for channel and bank protection.

Grade-control (stabilisation) structure: Various structures (e.g. weirs, dams, sills) built across the channel to control bed erosion. See *Degradation* and *Scour.*

Gravel: A mixture composed primarily of rock fragments 2 mm (0.08 inch) to 7.6 cm (3 inches) in diameter. Usually contains much sand. (NWD). Often referred to as 'shingle.'

Gully: A channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains or during the melting of snow; may be … branching or it may be linear, rather long, narrow, and of uniform width…. (NWD).

Habitat: (1) Living place, includes provisions for life. (2) The native environment or specific surroundings where a plant or animal naturally grows or lives. The surroundings include physical factors such as temperature, moisture, and light together with biological factors such as the presence of food or predator organisms. The term can be employed to define surroundings on almost any scale…. (NWD). The place where organisms live and the total influences in that place that support the organism living, feeding, and reproducing. (HEL).

Hazardous substance: See *Toxic* and *Toxicity.*

Head cut: A break in slope at the top of a gully or section of gully that forms a "waterfall," which in turn causes the underlying soil to erode and the gully to expand uphill. Head cuts also occur in streams where an abrupt change in gradient occurs (e.g. with gravel extraction).

Head cutting, headward erosion: The upstream progression of a *Head cut*.

Headwater(s): (1) The source and upper reaches of a stream; also the upper reaches of a reservoir. (2) The water upstream from a structure or point on a stream. (3) The small streams that come together to form a river. Also may be thought of as any and all parts of a river basin except the mainstream river and main tributaries. (NWD).

Herbicide: Chemicals used to destroy undesirable plants and vegetation. Pre-emergent herbicides, applied to bare soil, prevent germination of weed seeds. (NWD). See *Pesticide* and *Diquat.*

Holistic: Of, concerned with, or dealing with wholes or integrated systems rather than with their parts. With respect to water-related issues, the term most typically describes an analytical and planning approach which examines and considers the inter-related linkages and interdependencies of a socioeconomic system with resource use, pollution, environmental impacts, and preservation of an entire ecosystem. (NWD).

Indigenous: A species native to a country, but which may be shared by other countries. This contrasts with *Endemic* which must be peculiar to one county, and often a single region. (HEL).

Infiltration: (Soils) The passage of water into and through a soil, to groundwater (which may re-emerge as surface water).

Inundate: To cover with water, typically by flooding.

Knickpoint: An abrupt break in slope in a streambed long profile. Rapids, a waterfall, or a plunge pool may mark the break in slope. A knickpoint may progress upstream as material is eroded from the head. See *Head cutting*.

Lagoon: (1) Commonly applied to bodies of ocean water surrounding tropical islands where the water-bodies are semi-enclosed within fringing coral reefs. (2) The term is also commonly applied to elongated water bodies, more or less parallel to the coast, occurring at river mouths. Lagoons may or may not be subject to tidal mixing. The Maori name is hapua for river mouth lagoons such as at the Rakaia mouth; which are different than coastal lake type lagoons such as Waihora/Lake Ellersmere where the outflow is frequently closed (Kirk & Lauder 2000). (3) (Water Quality) Lagoons are scientifically constructed ponds in which sunlight, algae, and oxygen interact to restore water to a quality equal to effluent from a secondary treatment plant. (NWD).

Landslide: A mass of material that has slipped downhill under the influence of gravity, frequently occurring when the material is saturated with water. (NWD). See *Mass movement.*

Mahinga kai: Food and other resources, and the areas they are sourced from or in which they are propagated. (Tipa & Teirney 2003).

Management measures: Economically viable measures for the control of sediment and contaminants which produce the greatest degree of reduction achievable through the application of the best available control practices, technologies, processes, siting criteria, operating methods, or other alternatives. (Based on EPA 1993). See *Best management practices*.

Mass failure: (Stream) The downslope movement of a river bank, with various types of failure mechanism: (1) **Shallow slip -** Failure occurs almost parallel to the bank surface usually when the bank is saturated. Failure normally occurs at the contact of an organic rich layer draped over stiffer clay on the bank face. (2) **Slab failure -** On steep banks (generally >60^{o}) blocks of soil topple into the stream. Tension cracks are often evident before the failure. (3) **Rotational slump -** Often caused by saturation on les steep banks (generally <60^{o}). The failure block is back-tilted away from the channel. The failure may be due to undercutting of the toe or base of the bank, or occur further up the bank. Tension cracks are often evident before the failure. (4) **Cantilever failure -** Failure occurs when undercutting leaves a block of unsupported material on the bank top, which then slides or falls into the stream. (Rutherfurd *et al.* 1999).

Mass movement: (Geology) The downslope movement of a portion of the land's surface (i.e., a single landslide or the gradual downhill movement of the whole mass of loose earth material) on a slope face. All movement of soil and bedrock materials occurring below the soil surface such as landslips, landflows, rock slides, slumps, etc. (NWD).

Mean bed level: The average bed level usually in a line of cross section across a river.

Meander: A sinuous channel pattern characterised by a series of loop-like bends. The outside of the bends tend to erode whereas the inside of the bends (point bars) are depositional.

Milligrams per litre (mg/L): A unit of the concentration of a constituent in water or wastewater and expresses the concentration of chemical constituents in water as the mass (milligrams) of constituent per unit volume (litre) of water. Concentration of *Suspended sediment* also is expressed in mg/l and is based on the mass of dry sediment per litre of water-sediment mixture. It represents 0.001 gram of a constituent in 1,000 millilitre (ml) of water. It is approximately equal to one part per million (ppm). The term has replaced parts per million in water quality management. (NWD).

Minimum tillage farming: A farming technique that reduces the degree of soil disruption. Crop residues are not ploughed under after harvest, and special planters dig narrow furrows in the crop residue when new seeds are sown…. Sometimes incorrectly termed No-till farming. (NWD).

Mouth, stream: The normal definition of river-stream mouth, a place where a stream flows into another stream, lake or the sea, contrasts with s.2 of the RMA. Rivermouth is defined in s.2 of the RMA as the boundary defined by the Minister of Conservation, regional council and district council or as declared by the Environment Court to establish the position of the landward boundary of the coastal marine area in the regional coastal plan. (HEL)

Mud: Fine sediments of clay and silt. *See Particle size.*

Native species: Original fauna or flora, which may exist in several geographic regions (*Indigenous*). More widespread than *Endemic species*.

Natural streams: There are few lowland streams in New Zealand, particularly in agricultural areas, which are unmodified with native vegetation cover and no channel alteration. Natural streams are defined as being characterised by one or more of the following: (1) They do not appear to be channelised or relocated. (2) Channels are typically meandering; with an asymmetric cross section (e.g. deep outer bend, shallow inner bend); and undulating long profile (e.g. shallow riffles and deep pools). (3) Flow may be ephemeral, intermittent or perennial. (4) Perennial streams usually support submergent and emergent aquatic vegetation and have streamside vegetative cover. (5) Woody debris in the channel and along the banks. (6) Support aquatic invertebrates and often have good actual or potential fish habitat.

Nephelometric turbidity unit (NTU): A unit of measure for the turbidity of water using a Nephelometer (a device which measures the intensity of light scattered at right angles to its path through a sample), compared with a standard suspension of a Formazin solution. *Visual clarity* is a preferred measure.

Nitrates: Nitrates represent a class of chemical compounds having the formula NO_3^-. Nitrate salts are used as fertilisers to supply a nitrogen source for plant growth. Nitrate additions to surface waters can lead to excessive growth of aquatic plants. The presence of nitrates in groundwater occurs from the conversion of nitrogenous matter into nitrates by bacteria and represents the process whereby ammonia in wastewater, for example effluent discharges from septic tank systems, is oxidised to nitrite and then to nitrate by bacterial or chemical reactions…. (NWD).

Nitrification: The conversion of nitrogenous matter into Nitrates by bacteria; the process whereby ammonia in wastewater is oxidised to nitrite and then to nitrate by bacterial or chemical reactions. (NWD).

Nitrogen: (1) (General) Chemical symbol N, the gaseous, essential element for plant growth, comprising 78 percent of the atmosphere, which is quite inert and unavailable to most plants in its natural form. (2) One of the three primary nutrients in a complete fertiliser and the first one listed in the formulation on a fertiliser label: 10-8-6 (nitrogen, phosphorus, potassium). (3) (Water Quality) A nutrient present in ammonia, nitrate or nitrite or elemental form in water due possibly to Non-point source (NPS) pollution or improperly operating wastewater treatment plants. (NWD).

Non-point source (NPS): Originating from numerous small, dispersed sources (e.g. runoff from agricultural land), not from one specific location. *Point sources* are derived from specific locations (e.g. a wastewater outfall).

No till farming: Planting crops without prior seedbed preparation, into an existing cover crop, sod, or crop residues, and eliminating subsequent tillage operations. (NWD).

Nutrient: (1) An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others. (2) Animal, vegetable, or mineral substance which sustains individual organisms and ecosystems. (3) That portion of any element or compound in the soil that can be readily absorbed and assimilated to nourish growing plants, e.g., nitrogen, phosphorus, potassium, iron. (NWD). See *Nutrient pollution.*

Nutrient pollution: Contamination of water resources by excessive inputs of nutrients. In surface waters, excess algal production is a major concern. Although natural sources of nutrients exist, major sources are typically anthropogenic (caused by man's activities) and include point sources such as municipal sewage-treatment plants and industrial outflows, and non-point sources such as commercial fertilisers, animal waste…. (NWD). See *Nutrient.*

Obstruction: Includes, but is not limited to, any dam, wall, wharf, embankment, levee, dike, pile, abutment, protection, excavation, channelisation, bridge, conduit, culvert, building, wire, fence, rock, gravel refuse, fill, structure, vegetation or other material in, along, across or projecting into any watercourse which may alter, impede, retard or change the direction and/or velocity of the flow of water, or due to its location, its propensity to snare or collect debris carried by the flow of water, or its likelihood of being carried downstream. (NWD).

Organic matter: (1) Plant and animal residues, or substances made by living organisms. All are based upon carbon compounds. (2) Any material of organic origin such as peat moss, ground bark, compost, and manure to be dug into the soil to improve its condition. (NWD).

Outfall: (1) The place where a sewer, drain, or stream discharges; the outlet or structure through which reclaimed water or treated effluent is finally discharged to a receiving water body. (NWD). (2) (Drainage management) The *Channel capacity* required to achieve drainage.

Overbank flow, flooding: When water overtops the stream banks and flows over the floodplain or surrounding land. See *Bankfull stage.*

Oxbow: An abandoned meander loop in a stream formed by the stream cutting through the neck of the meander loop. Also called a cut-off or oxbow lake.

Oxygen demand: The need for molecular oxygen (O_2) to meet the needs of biological and chemical processes in water. The amount of molecular oxygen that will dissolve in water is extremely limited; however, the involvement of oxygen is biological and chemical processes in extensive. Consequently, the amount of oxygen dissolved in water becomes a critical environmental constraint on the biota living in the water. The metabolism of large organisms like submerged plants and fish, the micro-organisms engaged in decomposition, and spontaneous chemical reactions all require (demand) a portion of a limited resource, molecular oxygen. (NWD). See *Biological oxygen demand (BOD)*.

Particle size: The diameter (usually the intermediate dimension) of sediment particles. Clay 0.00024 – 0.004 millimetres (mm); Silt 0.004 – 0.062 mm; Sand 0.062 – 2.00 mm; Gravel 2.00 – 64 mm; Cobbles 64-256 mm; Boulders >256 mm. (American Geophysical Union Subcommittee on Sediment Terminology - Lane 1947).

Particulate matter: (Water Quality) In water pollution, particulate matter describes solid material in either the solid or dissolved states. Insoluble particulate matter includes particulate substances that either settle from water that is allowed to stand or are removed by passing the water through a filter. Sand, clay, and some organic matter constitute insoluble particulate matter. Dissolved substances that will neither settle if water is allowed to stand nor be removed by passage through a filter, but which will be recovered if the water is allowed to evaporate, are called **dissolved particulate matter**. Salt is an example of this type of particulate matter…. (NWD).

Particulate organic matter (POM): Material of plant or animal origin that is suspended in water. The amount of this type of material suspended in water can be estimated by first removing the suspended material from the water by filtration, followed by either a direct measurement of the amount of carbon retained on the filter or by estimating the amount of carbon present from the weight lost upon heating the filter in excess of 500^0C (932^0F). Generally, the greater the amount of particulate matter present, the more severe the water pollution problem. (NWD).

Periphyton: An assemblage of micro-organisms (plants and animals) firmly attached to and growing upon solid surfaces, such as the bottom of a stream, rocks, logs, pilings, and other structures. While primarily consisting of algae, they also include bacteria, fungi, protozoa, rotifers, and other small organisms…. (NWD). In the New Zealand “Stream periphyton monitoring manual” the periphyton community is described as the slimy coating found on rocks and other stable substrates in streams and rivers, consisting mainly of algae, but including fungal and bacterial matter (Biggs & Kilroy 2000).

Permeability: (1) The capacity of soil, sediment, or porous rock to transmit water; the property of soil or rock that allows passage of water through it. (2) For a rock or an earth material, the ability to transmit fluids; the rate at which liquids pass through soil or other materials in a specified direction. (NWD).

Persistence: The relative ability of a chemical to remain chemically stable following its release into the environment. Persistent chemicals resist biodegradation and thus are of greater concern in the treatment of water and wastes. (NWD).

Pesticide: Any chemical agent used for the control of specific organisms, for example, insecticides (insects), *Herbicides* (plants), fungicides (fungi)…. (NWD). See *Agrichemicals.*

Phosphates: General term used to describe phosphorus-containing derivatives of phosphoric acid (H_3PO_4). The chemical containing the phosphate group (PO_4^{-3}) can be either organic or inorganic and either particulate or dissolved. Phosphates constitute and important plant nutrient…. (NWD).

Phosphorus: (1) An element that is essential to plant life but contributes to an increased trophic level (*Eutrophication*) of water bodies. (2) One of the three primary nutrients in a complete fertiliser and the second one listed in the formulation on a fertiliser label: 10-8-6 (nitrogen, phosphorus, potassium)…. (NWD. See *Phosphates*.

Photosynthesis: The process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a byproduct. Chlorophyll typically acts as the catalyst in this process. (NWD).

Plant nutrients: The primary mineral ingredients of fertiliser: phosphate (PO_4^{-3}), nitrate (NO_3^{-}), and ammonium (NH_4^{+}), together with an extensive array of chemical elements (trace elements) used in lesser amounts to support the growth of plants. (NWD).

Plume: A relatively concentrated mass of contaminants spreading in the environment from a point source (e.g. wastewater discharge into a stream; a leaking storage into groundwater). Discharges of contaminants into flowing stream rapidly mix with the receiving water. Complete mixing occurs when the contaminant is completely dispersed through the receiving water. Complete mixing often occurs by the time the plume has travelled several channel widths downstream; but this is highly dependent upon the discharge and stream characteristics.

Point source (PS): (1) A stationary or clearly identifiable source of a large individual water or air pollution emission, generally of an industrial nature. (2) Any discernible, confined, or discrete conveyance from which pollutants are or may be discharged, including (but not limited to) pipes… containers, rolling stock, concentrated animal feeding operations, or vessels…. (NWD). Contrast with *Non-point source (NPS).*

Pollution: (1) Any alteration in the character or quality of the environment which renders it unfit or less suited for certain uses. With respect to water, the alteration of the physical, chemical, or biological properties by the introduction of any substance that adversely affects any beneficial use. (2) Adverse and unreasonable impairment of the beneficial uses of water even though no actual health hazard is involved…. (NWD). See *Contaminant.*

Pond: A body of water smaller than a lake, often artificially formed. (NWD).

Reach (of river): (1) Most generally, any specified length of a stream or conveyance. (2) A length of channel which is uniform in its discharge depth, area, and slope. (NWD).

Receiving Waters: (1) Rivers, lakes, oceans, or other water courses or bodies of water that receive waters from another source. (2) (Water Quality) Bodies of water that receive treated or untreated effluent discharges. (NWD).

Redd: A type of fish spawning area associated with flowing water and clean gravel. Fishes that utilise this type of spawning area include trout, salmon, some minnows, etc. (NWD).

Riparian: Pertaining to the banks of a river, stream, waterway, or other, typically, flowing body of water as well as to plant and animal communities along such bodies of water. This term is also commonly used for other bodies of water, e.g., ponds, lakes, etc., although Littoral is the more precise term for such stationary bodies of water…. (NWD).

Riparian habitat: (1) Land areas directly influenced by a body of water. Usually such areas have visible vegetation or physical characteristics showing this water influence. Stream sides, lake borders, and marshes are typical riparian areas. Generally refers to such areas along flowing bodies of water. The term Littoral is generally used to denote such areas along non-flowing bodies of water. (2) (US Fish and Wildlife Service) Plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent Lotic and Lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: (a) distinctively different vegetative species than adjacent areas, and (b) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between *Wetlands* and *Uplands*.

Riparian management classification (RMC): Building on his work in the Waikato, Quinn (2003) developed a riparian management classification for Canterbury. He suggested four channel width classes related to the types of vegetation required to provide stream shade: <2 m (Tiny); 2 to <6 m (Small); 6 to <12 m (Medium); and >12 m (Large). Long pasture grasses and tussocks are expected to shade tiny streams effectively, whereas high shrubs will shade tiny and small streams and trees will shade channels up to the medium size class. For channel >12 m riparian trees are unlikely to be effective for temperature and algal control. Landforms were described as plain/floodplain, U-shaped, and V shaped as an indicator of surface runoff and required buffer widths. Streamside planting recommendations are based on local site characteristics (profiles and zones). The River environment classification (REC) was used to provide context, and measured stream characteristics at over 300 sites in Canterbury. In addition, soil maps were used to identify heavy, poorly drained soils amenable to denitrification with riparian planting. A discriminant model, based on field observations and GIS data, could be used to assess likely riparian function ratings at a site. However, as noted by Quinn (2003) "The low hit rate of these models indicates that the currently available GIS data [REC and LENZ] are not suitable for predicting riparian classes and hence riparian functions." The alternative to using the model for Canterbury and elsewhere is to make direct assessments. In any case, the reach and farm scale management plans are based on farmer/landowner goals for their properties; and riparian microhabitat-based native species planting recommendations. This is likely to be the case for waterway management in general. See *River classification*, *River environment classification*.

Riparian (streamside) vegetation: Plants adapted to moist growing conditions found along waterways and shorelines. They are frequently important to wildlife habitat because of their greater density and succulence. (NWD). See *Streamside vegetation, Streamside planting guide.*

Riparian zone: (1) Areas adjacent to a stream that are saturated by ground water or intermittently inundated by surface water at a frequency and duration sufficient to support the prevalence of vegetation typically adapted for life in saturated soil. (2) The transition area between the aquatic ecosystem and the nearby, upland terrestrial ecosystem. Zones are identified by soil characteristics and/or plant communities and include the wet areas in and near streams, ponds, lakes, springs and other surface waters. (NWD). See *Riparian (streamside) vegetation.*

Rip Rap (or riprap): A protective cover of large stones, broken rock, or precast blocks placed or dumped on the river bed or banks, or at structures, to prevent erosion. The rip rap may be secured with wire.

River: A continually or intermittently flowing body of fresh water; and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal). (RMA). See *Stream.*

River bank: The margins of a river within which a river normally flows. (See *Bankfull discharge*). Banks are often relatively steep and exhibit a distinct break in slope from the stream bed. In constructed channels and drains, the banks are usually clearly defined. See *Bed* and *Bank*.

River classification: There are numerous approaches to river classification for particular management purposes. The use of any stream classification system is an attempt to simplify what are complex relationships between streams, their catchments and ecology. In delineating "management units" it is assumed that patterns of similar attributes can be recognised and grouped into meaningful units at various scales; that waterways reflect the catchment they drain; that catchments in similar eco-regions should produce similar waterways; that within eco-regions natural biological assemblages develop reflecting the pool of species available and the constraints of the physical environment; that these assemblages would be expected to be relatively similar within eco-regions, but different between eco-regions. Eco-regions and habitat units cannot, however, be considered in isolation. While a high degree of explanation of biological assemblages may be offered by physical habitat, morphologically similar reaches in New Zealand often have different assemblages of species. These differences are related to catchment position and impediments to migration or other life stages. In addition, the sequence of habitats may also determine structure and function (e.g. the presence or absence of a lagoon may determine what species are found in a stream) (Hudson 1998). See *River environment classification, Rosgen river classification.*

River environment classification: The New Zealand River Environment Classification (REC) represents streams/rivers as networks of sections including their upstream catchments. Sections have an average length of 700 metres. The class of each section is based on evaluation of climate, topography, geology and land cover of the upstream catchment of individual sections of the river network; and the network-position and the landform of the valley of each section of the network. Various rules can be applied to derive management units with biological relevance. Nine core river management units for water allocation were derived for Canterbury based on source of flow (derived from rules related to elevation and precipitation; with addition sources such as lakes, wetlands, springs and regulated manually delineated) and geology (Snelder *et al.* 1999, 2001, 2004). While REC can provide information on the upstream catchment of a particular stream segment, at the present stage of development its applicability to operational waterway management at the reach scale is not obvious: (1) "The classification uses discriminating variables that can be obtained from a GIS database, although these are not necessarily the optimal ones… the characterisation of channel morphology usually includes variables that are measured or observed in the field, in addition to some which can be measured from large-scale topographic maps or aerial photographs. The type of GIS data available in the present study are at a relatively coarse scale, or are simply not able to provide relevant information (e.g. on channel width, depth, roughness, stream power, etc)." (Mosley 1999). (2) "Although classification can be used as a communication tool and as part of the overall restoration planning process, the use of a classification system is not required to assess, analyze, and design stream restoration initiatives. The design of a restoration does, however, require site specific engineering analyses and biological criteria…" (FISRWG 1998). See *River classification*, *Riparian management classification*, *Rosgen river classification*.

River (stream) channel: Natural or artificial open conduits which continuously or periodically contain moving water, or which forms a connection between two bodies of water. (NWD). See *Bed* and *Channel (watercourse).*

Rosgen river classification: A classification based on streams in North America and New Zealand, describing 7 major stream types that differ in entrenchment, gradient, width/depth ratio, and sinuosity, in various landforms (e.g. steep, entrenched mountain streams; meandering channels in broad floodplains; multi channel delta streams) (Rosgen 1996). Within each major category are up to six additional types delineated by dominant channel materials (1- bedrock, 2- boulder; 3- cobble; 4- gravel; 5- sand; 6- silt/clay) for a total of 41 stream types. There are a large number of refinements when other attributes, such as flow regime (e.g. snowmelt dominated, spring fed, tidal influence, regulated), are considered. For each stream type the sensitivity to disturbance, recovery potential, sediment supply, vegetation controlling influence and streambank erosion potential are described based on extensive field observations; and these interpretations can be used for potential impact assessment, risk analysis, and management direction by stream type. Level 3 classifications describe the existing condition of the stream as it relates to its stability, response potential, and function. Stream condition variables include riparian vegetation, width and depth, channel features, flow regime channel stability, and bank erosion potential. Potential condition can be assessed. The classification and analysis criterion can be applied to particular waterway management problems; in essence to predict a stream's behaviour from its appearance and to facilitate the transfer of information on stream management from overseas and within New Zealand.

Roughness: A term used by hydraulic engineers and hydrologists designating a measurement or estimate of the resistance that streambed materials, vegetation, and other physical components contribute to the flow of water in the stream channel and floodplain. It is commonly measured as the Manning's roughness coefficient. (NWD). See *Roughness coefficient*.

Roughness coefficient: (Hydraulics) A factor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water. (NWD). See *Roughness.*

Runoff: (1) That portion of precipitation that moves from the land to surface water bodies. (2) That portion of precipitation which is not intercepted by vegetation, absorbed by the land surface or evaporated, and thus flows overland into a depression, stream lake or ocean (runoff called "immediate subsurface runoff" also takes place in the upper layers of the soil). (3) That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers…. (NWD).

Runoff, agricultural: The runoff into surface waters of herbicides, fungicides, insecticides, and the nitrate and phosphate components of fertilisers and animal wastes from agricultural land and operations. Considered a Non-Point Source (NPS) of water pollution. (NWD)

Runoff, groundwater: That part of the runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water. Also referred to as **base runoff** or *Base flow*. (NWD).

Runoff, subsurface (interflow): Water that moves through the aerated portion of the soil to the stream and behaves more like surface runoff than base flow.

Runoff, surface: (1) That part of the runoff which travels over the soil surface to the nearest stream channel. (2) That part of the runoff of a drainage basin that has not passed beneath the surface since precipitation. (NWD). See *Base flow*.

Runoff, urban: Storm water from city streets and gutters that usually contains a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters. (NWD).

Sand: Coarse-grained mineral sediments with diameters larger than 0.062 mm and smaller than 2 mm diameter. See *Particle size*.

Scour: (1) To clear, dig, or remove by … a powerful current of water. (2) The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material. (3) The powerful and concentrating clearing and digging action of flowing air or water, especially the downward erosion by stream water in sweeping away mud and silt on the outside curve of a bend, or during time of flood. (4) A place in a stream bed swept (scoured) by running water, generally leaving a gravel bottom. (5) The process by which flood waters remove soil around objects that obstruct flow, such as the foundation walls of a house. (NWD).

Sediment: (1) Soil particles that have been transported from their natural location by wind or water action; particles of sand, soil, and minerals that are washed from the land and settle on the bottoms of wetlands and other aquatic habitats. (2) The soil material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by erosion (by air, water, gravity, or ice) and has come to rest on the earth's surface. (3) Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics, and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation. (4) In the singular, the word is usually applied to material in suspension in water or recently deposited from suspension. In the plural the word is applied to all kinds of deposits from the waters of streams, lakes, or seas, and in a more general sense to deposits of wind and ice. Such deposits that have been consolidated are generally called sedimentary rocks. (5) [Fragments of] mineral particles derived from soil, alluvial, and rock materials by processes of erosion, and transported by water, wind, ice, and gravity. A special kind of sediment is generated by precipitation of solids from solution (i.e., calcium carbonate, iron oxides). Excluded from the definition are vegetation, wood, bacterial and algal slimes, extraneous lightweight artificially made substances such as trash, plastics, flue ash, dyes, and semisolids. (NWD).

Sediment control: The control of movement of sediment on the land, in a stream or into a reservoir by means of manmade structures; such as debris dams, wing dams, or channelisation; land management techniques, or natural processes. (NWD).

Sediment deposition (sedimentation): Sedimentation is the process of deposition of sediment and occurs when water currents are insufficient to maintain sediment in the water column or moving at or near the bed. In a more general sense sedimentation is used to describe sediment accumulation from other processes (e.g. wind, rock falls and glaciers). In water treatment, sedimentation refers to the settling of solids out of wastewater. See *Aggradation* and *Erosion*.

Sediment load: The total sediment, including *Bed load* and *Suspended load*, being moved by flowing water.

Seepage: (1) The passage of water or other fluid through a porous medium, such as the passage of water through an earth embankment or masonry wall. (2) Groundwater emerging on the face of a stream bank. (3) The slow movement of water through small cracks, pores, Interstices, etc., of a material into or out of a body of surface or subsurface water. (4) The Interstitial movement of water that may take place through a dam, its foundation, or its Abutments. (5) The loss of water by infiltration into the soil from a canal, ditches, laterals, watercourse, reservoir, storage facilities, or other body of water, or from a field…. (NWD).

Shingle: General term for *Gravel* and other *Bed material* in a river channel. See Particle size.

Silt: Sedimentary particles that are larger than clay but smaller than sand. See *Particle size.*

Siltation: The deposition of finely particles in a waterbody. See *Sediment deposition (sedimentation)*.

Soil: The meaning of this term varies depending on the field of consideration: (1) Pedology - the earth materials which have been so modified and acted upon by physical, chemical, and biological agents that it will support rooted plants; (2) Engineering Geology - the layer of incoherent rock material that nearly everywhere forms the surface of the land and rests on bedrock, also called **regolith**; (3) Ecology - A dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms.

Soil erodibility: An indicator of a soil's susceptibility to raindrop impact, runoff, and other erosive processes. (NWD).

Soil erosion: The detachment and movement of soil from the land surface by wind or water. (NWD). See *Erosion* for various types.

Solution: A homogeneous mixture of a solute in a solvent. For example, when sugar (the solute) is dissolved in water (the solvent), the molecules that comprise the sugar crystal are separated from one another and dispersed throughout the liquid medium. (NWD).

Spill: (1) To cause or allow to run or fall from a container unintentionally so as to be lost or wasted. (2) With respect to a dam and reservoir system, the water passed over a spillway without going through turbines to produce electricity. Spill can be forced, when there is no storage capability and flows exceed turbine capacity, or planned, for example, when water is spilled to enhance fish passage or to support other downstream uses (e.g., agriculture, wetland maintenance, etc.). (3) With reference to reservoir operations, water that is released, either inadvertently or through precautionary releases, in excess of that required to compensate for deliver system losses and to meet irrigation demand. (NWD).

Spring: (1) A concentrated discharge of ground water coming out at the surface as flowing water; a place where the water table crops out at the surface of the ground and where water flows out more or less continuously. (2) A place where ground water flows naturally from a rock or the soil into the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, especially permeable and impermeable strata, on the position of the water table, and on the topography. (NWD).

Stream: A general term for a body of flowing water; natural water course containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural channel as distinct from a canal …. (NWD). Where the stream channel is above the ground water table, the stream flow is **ephemeral**, occurring only after rainfall or snowmelt. **Intermittent** streams flow during wet periods (e.g. during the winter), and may intercept the water table. Following rainfall or snowmelt, as the ground water levels drop, the flow stops in intermittent streams. **Perennial** streams flow most of the time and are sustained by groundwater during dry periods. Streams are defined within the definition of river in s.2 of the RMA. See *Channelised stream, Natural stream, River.*

Stream corridor: The stream corridor consists of the stream channel, streamside (riparian) vegetation, and floodplain features such as wetlands, oxbow lakes, backwaters, islands and adjacent land uses (e.g. forest, pasture) along the stream margin (FISRWG 1998). The stream corridor may be contained within *Embankments*.

Streambank erosion: See *Erosion, Streambank*.

Streambank erosion control: Vegetative or mechanical control of erodible stream banks, including measures to prevent stream banks from caving or sloughing, such as jetties, revetments, riprap and plantings necessary for permanent protection. (NWD).

Streambanks: See *River bank*.

Streambed: See *Active bed* and *Bed*.

Streambed erosion: The detachment and movement of bed and bank material, causing a lowering or widening of a stream. See *Degradation (stream channels)*.

Streamside planting guide: An interactive native planting guideline based on the bank shape and frequency of flooding.

Streamside vegetation: Plants adapted to moist growing conditions found near streams, ponds, lakes, springs and other surface waters. See *Riparian habitat; Riparian zone, Streamside planting guide.*

Strip cropping: Growing crops in a systematic arrangement of strips or bands that serve as barriers to wind and water erosion. (NWD).

Sub-aerial erosion: Occurs on the exposed list erosion of exposed banks above the normal low flow margins that are continuously wet, by several processes: (1) **Windthrow** – Shallow rooted streamside trees are blown over and pull bank material into the stream. Erosion of the bank may occur as water flows around the tree. (2) **Freeze-thaw** – As temperature fluctuates, ice crystals grow and dislodge bank material. Soil particles are disaggregated and are easily washed away. (3) **Desiccation** – Banks that have dried out and cracked are more easily eroded (4) **Slaking** – Soil aggregates disintegrate because of trapped air as banks are rapidly submerged. (5) **Surface wash** – Exposed soil is directly eroded by rainsplash and water running down the bank. (6) **Stock trampling** – Unrestricted stock access directly breaks down banks and moves soil into the stream and exposes soil to surface wash. (Rutherfurd *et al.* 1999):

Submerged aquatic vegetation/submerged plants: Vegetation that is rooted in the bottom of a watercourse that cannot withstand excessive drying and therefore live with their stems and leaves at or below the water surface.

Submergent Plant: A vascular or nonvascular hydrophyte, either rooted or nonrooted, which lies entirely beneath the water surface, except for flowering parts in some species; e.g., wild celery (*Vallisneria americana*) or the stoneworts (*Chara spp.*). (NWD).

Substrate: (1) The substances used for food by micro-organisms in liquid suspension, as in wastewater treatment. (2) The physical surface upon which an organism lives; the surface, natural or artificial, upon which an organism grows or to which it is attached. (3) The layer of material beneath the surface soil. (NWD). See *Embeddedness.*

Sub-surface drainage system: A system of underground pipes to remove excess water accumulating below the soil surface that will not naturally percolate out of the root zone. (NWD).

Suspended load: Portion of sediment that is transported in suspension in the water column. Where the flow slows, the material is deposited. See *Suspended sediment.*

Suspended particulate matter (SPM): A sample drawn from natural water or from a wastewater stream consists of a mixture of both dissolved and suspended matter. Those solid materials that are retained on a filter prescribed by the specific technique being followed are referred to as particulate matter. The suspended particulate matter can be subdivided into two fractions: volatile and fixed. The volatile particulates are those that are lost when the filter is heated to about 550^0C ($1,022^0$F), and the fixed particulates are those that are not lost upon being so heated. The volatile substances are generally considered to be of biological origin, and the fixed solids are considered to be minerals. (NWD).

Suspended sediment: Stream bed and bank material, eroded soil and hillslope sediments that are transported in suspension in the water column of a stream because of the upward components of turbulence and currents. As stream velocities reduce, suspended sediments can be deposited on the bed; whereas extremely fine materials are transported downstream without appreciable deposition in the active bed (*Wash load).*

Suspended sediment concentration: Material sampled from the water column with a suspended sediment sampler, expressed as the dry mass of the sediment (mg) per litre (mg/L) of water-sediment mixture. See *Milligrams per litre.*

Swamp: A term frequently associated with *Wetlands*. Wet, spongy land; low saturated ground, and ground that is covered intermittently with standing water, sometimes inundated and characteristically dominated by trees or shrubs, but without appreciable peat deposits. Swamps may be fresh or salt water and tidal or non-tidal. It differs from a bog in not having an acid substratum.

Sustainable management: New Zealand’s key environmental laws, including the RMA, are explicitly based on the ethic of sustainability with the obligation to sustain the natural environment not just of current use, but for its ecological functions, its intrinsic value and its potential to future generations. “… under this ethic, the environment is no longer the economy’s servant but its host, and extinction’s and environmental degradation are no longer acceptable prices to pay in the pursuit of economic growth” (MfE 1997). In reality, this means ecosystem management in its broad sense (GAO 1994). (Day & Hudson 2001).

Terrace: (Erosion and Irrigation) An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting and temporarily storing surface runoff instead of permitting it to flow uninterrupted down the slope. Outlets may be soil infiltration only, vegetated waterways, tile outlets, or combinations thereof. (2) (Geological) An old alluvial plain, ordinarily flat or undulating, bordering a river, lake, or the sea. Stream terraces … as contrasted to flood plains, and are seldom subject to overflow. Marine terraces were deposited by the sea…. (NWD).

Thalweg: (1) The line connecting the deepest points along a stream. (2) The lowest thread along the axial part of a valley or stream channel. (3) A subsurface, ground-water stream percolating beneath and in the general direction of a surface stream course or valley. (4) The middle, chief, or deepest part of a navigable channel or waterway. (NWD).

Tide, tides: The alternate rising and falling of the surface of oceans, and of seas, gulfs, bays, rivers, and other water bodies caused by the gravitational attraction of the moon and sun occurring unequally on different parts of the earth…. **Spring tide** is the highest high and the lowest low tides during the lunar month. The exceptionally high and low tides that occur at the time of the new moon or the full moon when the sun, moon, and earth are approximately aligned. **Neap tide** is a tide that occurs when the difference between high and low tide is least; the lowest level of high tide. Neap tide comes twice a month, in the first and third quarters of the moon.

Tile drainage: Land drainage by means of a series of subsurface tile drains.

Toe: (1) The downstream edge at the base of a dam. (2) The break in slope at the foot of a stream bank where the bank meets the bed. (3) The line of a natural or fill slope where it intersects the natural ground. (4) The lowest edge of a backslope of a cut where it intersects the roadbed or bench. (NWD).

Toxic: (1) Describing a material that can cause acute or chronic damage to biological tissue following physical contact or absorption. (2) Substances that even in small quantities may poison, cause injury, or cause death when eaten or ingested through the mouth, absorbed through the skin or inhaled into the lungs. (NWD). In New Zealand hazardous substances are defined in s.2 of the Hazardous Substances and New Organisms Act 1996. Harmful substances are defined as any substance defined as such by regulations (also s.2 of the RMA). (HEL).

Toxicity: (1) The ability of a chemical substance to cause acute or chronic adverse health effects in animals, plants, or humans when swallowed, inhaled or absorbed. (2) The occurrence of lethal or sublethal adverse effects on representative, sensitive organism due to exposure to Toxic Materials. Adverse effects caused by conditions of temperature, dissolved oxygen, or nontoxic dissolved substances are excluded from the definition of toxicity. (NWD).

Toxin: Any of a variety of unstable, poisonous compounds produced by some micro-organisms and causing certain diseases or physical reactions. (NWD).

Turbid water, turbidity: Turbid or ‘muddy’ water is caused by the presence of suspended particulate matter (SPM) (usually silt and clay), organic matter (e.g. phytoplankton and detritus), and soluble coloured organic compounds. SPM is normally measured as the dried mass of particulate matter (mg/L) or by light scattering (NTU - nephelometry turbidity unit). There is usually a great deal of scatter in the relationship between SPM and NTU. Rowe et al. (2004) describe 10 NTU as “slightly cloudy water”; 20 NTU as “muddy looking”; and 2000 NTU as “extremely concentrated muddy water.” Smith & Davies-Colley (2002) suggest *clarity* is a more repeatable and meaningful measure. Clarity relates to the transmission of light through water and is measured by the visual range to a black disk.

Upland, uplands: (1) The ground above a floodplain; that zone sufficiently above and/or away from transported waters as to be dependent upon local precipitation for its water supplies. (2) Land which is neither a *Wetland* nor covered with water. (NWD).

Velocity (of water in a stream): The speed water moves downstream, typically expressed as metres per second.

Virus: An infectious agent that can only reproduce inside living cells. Viruses invade healthy cells and cause them to synthesise more viruses, usually killing the cell in the process. They are capable of producing infection and diseases.

Wash load: Extremely fine material that is not found in appreciable quantities in active river bed deposits. In flowing water these materials remain in suspension and usually are transported without deposition, apart from in low velocity zones (e.g. ponded water and overbank areas such as oxbow lakes).

Waste: Defined in s. 2 of the RMA as ‘materials and substances of any kind, form, or description.’ Waste in common terms is matter that is excess, leftovers, scraps, by-products not intended for use at that site. Waste can be in gaseous, solid or liquid form and can be a feed stock for another activity, in which case it ceases to be waste. (HEL).

Wastewater: (1) A combination of liquid and water-carried pollutants from homes, businesses, industries, or farms; a mixture of water and dissolved or suspended solids. (2) That water for which, because of quality, quantity, or time of occurrence, disposal is more economical than use at the time and point of its occurrence. Waste water to one user may be a desirable supply to the same or another user at a different location. (NWD).

Waterbody: Fresh water or geothermal water in a river, lake, stream, pond, wetland, or aquifer, or any part thereof, that is not located within the coastal marine area. (RMA).

Water quality: (1) A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose. (2) The chemical, physical, and biological condition of water related to beneficial use…. (NWD). See *Water quality criteria.*

Water quality criteria: A specific level or range of levels of water quality necessary for the protection of a water use; levels of water quality expected to render a body of water suitable for its designated use. The criteria are set for individual pollutants and are based on different water uses, such as a public water supply, an aquatic habitat, and industrial supply, or for recreation. (NWD).

Water quality indicators: Constituents or characteristics of water that can be measured to determine its suitability for use. (NWD).

Water table, groundwater table: (1) Generally, all subsurface water as distinct from *Surface Water*; specifically, the part that is in the saturated zone of a defined aquifer. (2) Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper level of the saturate zone is called the water table. (3) Water stored underground in rock crevices and in the pores of geologic materials that make up the earth's crust. Ground water lies under the surface in the ground's zone of saturation, and is also referred to as phreatic water. (NWD).

Waterway: Synonymous with *Watercourse*.

Watercourse: Synonymous with *Channel.* In the Soil and Water Conservation Act (1941) 'Watercourse' includes every river, stream, passage, and channel on or under the ground, whether natural or not, through which water flows, whether continuously or intermittently. See *Bed.*

Watershed: See *Catchment*.

Weir: (1) A barrier placed in a channel to divert fish or water. (2) A dam in a river to stop and raise the water, for the purpose of conducting it to a mill, forming a fishpond, or the like. When uncontrolled, the weir is termed a fixed-crest weir. (3) A fence of stakes, brushwood, or the like, set in a stream, tideway, or inlet of the sea, for taking fish. (4) A device for determining the quantity of water flowing over it from measurements of the depth of water over the crest or sill and known dimensions of the device. (5) A bank or levee built to hold a river in its bed, or to direct it into a new bed. (6) (Water Quality) A wall or obstruction used to control the flow from settling tanks and clarifiers to assure a uniform flow rate and avoid short-circuiting [by-passing]….. (NWD).

Wetland: Depressions that are inundated or saturated by water for extended periods. These saturated conditions control the types of plants and animals that live in these areas. Common names are swamps, bogs, and marshes. Wetlands include the transitional areas between aquatic and terrestrial systems. Wetlands generally exhibit the following three attributes:

- Hydric soils (undrained, wet soil which is anaerobic, or lack oxygen in the upper levels).
- Water table is at or above the surface, or within the root zone, for a significant period during the growing season.
- Soil is saturated at a frequency and duration to foster the growth and reproduction of hydrophytic vegetation (e.g. rushes or sedges) and inhibit flood-intolerant species.

Wetland, constructed: A wetland that has been constructed for the primary purpose of water quality improvement. This practice is applied to treat waste waters from confined animal operations, sewage, surface runoff, milkhouse wastewater, silage leachate, and subsurface drainage by the biological, chemical and physical activities of a constructed wetland.

Xeric: Describing an organism that requires little moisture or a habitat containing little moisture; dry environmental conditions as compared to **Hydric** (wet environmental conditions) and **Mesic** (moderate moisture conditions).

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10 Best management practices

- Bank reshaping
- Brown trout
- Channel excavation
- Coarse sediment trap
- Filter strips
- Glyceria maxima (reed sweet grass)
- Grassed waterway
- Interceptor drains and bunds
- Rehabilitating land
- Stock and waterways
- Whitebait (inanga)

Sustainable drainage management

Best management practice

By Henry R Hudson

1 Bank reshaping

Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

Banks are excavated to remove steep drops and unstable materials, and to lower the bank to allow roots to extend through potential failure planes and into the lower bank where there is potential for scour. Channel capacity may be increased by bank reshaping and marginal vegetation may filter contaminants and reduce flow velocities.

Photo: Michael Oliver, Environment Canterbury.

Location

Steep or unstable streambanks.

Work window

- Arrange access in consultation with landowners to avoid disruption of farming operations.
- Do not disturb the channel margins if there is whitebait (inanga) spawning or birds nesting. Inanga lay their eggs in late summer or early autumn in streamside vegetation in areas flooded by high tides.

Treatment objectives

1. Increased bank stability.
2. Banks are re-shaped to a suitable grade and condition for streamside planting.
3. Increase channel capacity.
4. Rehabilitate disturbed land.

Before you start

- ☐ Consult with District/Regional Council staff and landowners about habitat value, and the requirements for avoiding sensitive times and places.
- ☐ Obtain necessary approvals from the local authority.

Procedures

- Excavate unstable banks to a stable form (gentle side slopes) as per Figure 1.

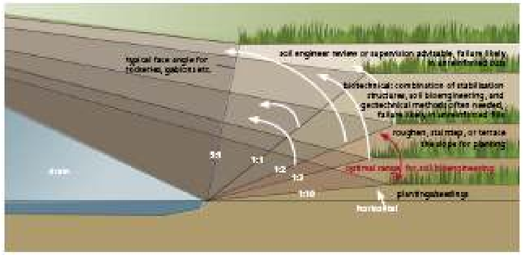

Fig.1. Slope (rise/run), and bank height relative to rooting depth, are important factors in determining appropriate bank protection measures (adapted from FISRWG 1998).

- Requirements for reshaping are largely related to the bank height relative to the rooting depth of stabilising vegetation. If the rooting depth is less than the bank height the streamside vegetation will provide little protection from bank scour.
- Some broad guidelines for root system protection are shown below in Figure 2.
- Establish bank vegetation (See Streamside planting guide, www.nzwerf.org.nz; Rehabilitating disturbed land BMP).

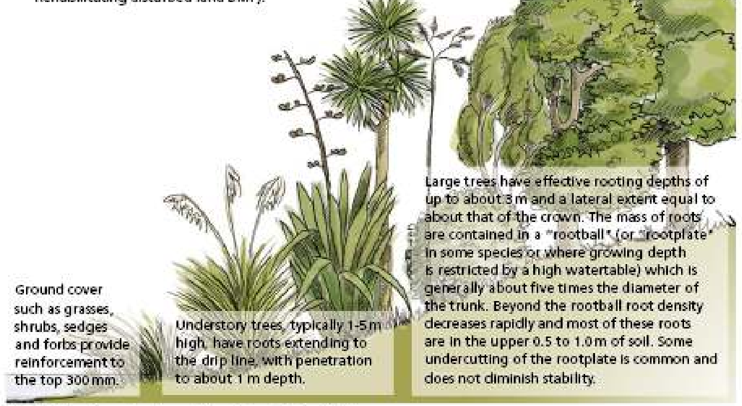

Fig.2. Guidelines for root system protection. Illustration: Greater Wellington.

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Sustainable drainage management

Best management practice

By Henry R Hudson

2 Brown trout

Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

Undertake waterway management activities in brown trout (*Salmo trutta*) streams to help maintain an adequate food supply, suitable dissolved oxygen levels, cool stream temperatures, instream and overhead cover, clear, clean water; and clean gravel for spawning.

Location

- Trout spawning occurs in riffles (gravel ridges in the streambed that generally occur about 6 channel widths apart) in cool water streams (<10.5°C winter water temperature).
- Very young trout with yolk sacs (alevins) stay in the gravel for a few weeks. Fry (young fish that have absorbed their yolk sacs) emerge from the gravel to disperse and feed. The first year of life is usually spent near where they were born.
- As fish get older they utilise a variety of stream habitats. In running water adults hide in undercut banks, instream debris, surface turbulence, rocks, and deep pools. Some adults may migrate out of their birth stream before returning to spawn.

Brown trout. Photo: DOC.

Work window

Spawning periods vary regionally, but the bulk of spawning occurs in May and June; with alevin emergence from the gravel riffles in September-October. Trout may remain in the spawning streams year round.

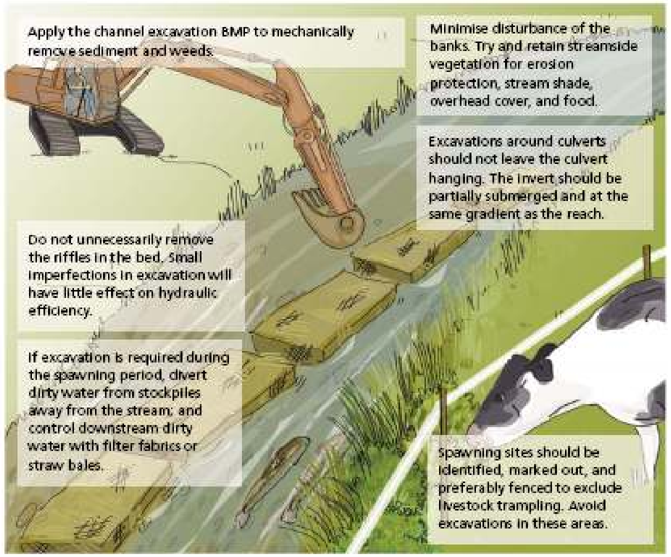
Treatment objectives

1. Channel disturbance that affects spawning reaches should be avoided in the period May to October.
2. Maintain suitable spawning bed material by avoiding deposition of fine sediment over spawning areas. Deposition of fine sediment (i.e. <2 mm diameter: sand, silt, and clay) should not increase the embeddedness of runs and riffles by more than 10% over a 24-hour period. (Embeddedness is the degree to which gravel-sized and larger particles are surrounded, enclosed, or covered by sand-sized and smaller particles. At <25% embeddedness, spawning habitat is excellent; and is considered good from 25-50% embeddedness).
3. The clarity of any receiving water should not be decreased by more than 50% instantaneously, or 30% over a 24 hour period, when measured by the black disc method. Downstream clarity, measured seven channel widths downstream of the end of the works, should be compared with clarity upstream of the works. (Trout are sight feeders and sensitive to reduced water clarity when migrating).
4. Maintain cool stream temperatures (preferably <11°C from May to October; and <25°C during summer low flows) (the lower limit of lethal temperatures).
5. Maintain high levels of dissolved oxygen (>11 mg/L May to October; and >8 mg/L for the rest of the year).
6. Maintain the pool riffle habitat (preferably 50-70% pools, with areas of slow water >50 cm deep during low flows; and 30-50% riffles).
7. Maintain vegetated, overhanging, relatively stable banks.
8. Maintain streamside cover to provide overhead cover and shade.
9. Maintain or provide unhindered fish passage.

Before you start

- ☐ Consult with District/Regional Council staff and Fish and Game about habitat value, and the requirements for avoiding sensitive times and places.
- ☐ Obtain necessary approvals from the local authority.
- ☐ Evaluate if extensive channel excavations can be avoided in the future by trapping sediment at preferred locations (See the Sediment trap BMP).

Procedures



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Sustainable drainage management

Best management practice

By Henry R Hudson

3 Channel excavation

Complexity	Environmental value	Cost
Low (Low / Moderate / High)	Low (Low / Moderate / High)	Moderate–High (Low / Moderate / High)

Definition & purpose

Channel excavation to restore the hydraulic capacity of drains which are obstructed by sediment deposits and weeds.

Location

Places where there are obstructions (sediment, weed, debris) impeding drainage. This might be a single location (e.g. local bed build up) or an extensive reach of drain.

Channel excavation work carried out from the side where the least disturbance will be caused.

Work window

- Arrange access in consultation with landowners to avoid disruption of farming operations.
- If there is significant habitat value schedule work to avoid adverse effects (e.g. fish migration, spawning, nesting).
- Drains are often good eel habitat. Eels hibernate in June so avoid drain cleaning then.

Treatment objectives

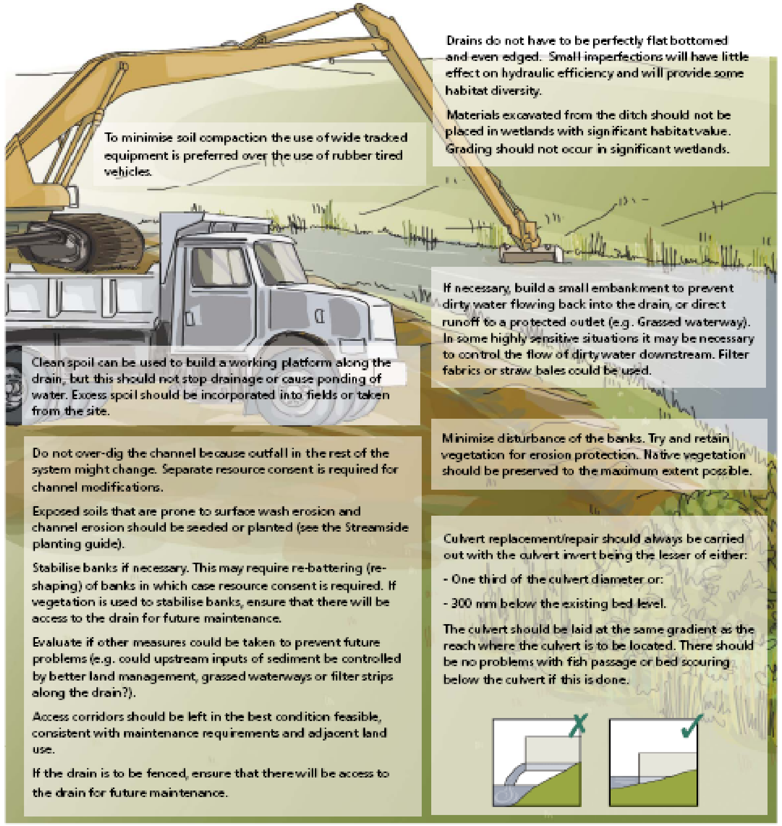
1. Re-establish the drainage outfall required for the drain and its feeder drains (e.g. side drains and field tiles) by removing only the obstructions. The channel should not be enlarged.
2. Provide the required outfall and water-table levels for agricultural productivity and access (e.g. lower the water-table 25-30 cm below the surface within 24 hours, and 30-45 cm below the surface within 48 hours after rainfall).
3. Minimise disturbance, avoid sensitive areas (e.g. patches of native vegetation), and rehabilitate disturbed land (e.g. smooth spoil heaps; reseed exposed soil) particularly if erosion is likely to occur.
4. If eels or other fish are dug out, return them to the channel.

Before you start

- [ ] Check if there is an outfall problem, or just the perception there is a problem.
- [ ] Assess if excavation is the most effective means of obtaining outfall (e.g. would hand removal of small blockages achieve outfall; would spraying be more effective?).
- [ ] Consult with District/Regional Council staff and landowners about habitat value, and the requirements for avoiding sensitive times and places.
- [ ] Obtain necessary approvals from the local authority.

Procedures

Work from one bank if possible to minimise land disturbance. If there is a choice of banks, use the side that will have the least disturbance and maximise preservation of stream shading.



Additional reading

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www.nzwerf.org.nz

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Sustainable drainage management

Best management practice

By Henry R Hudson

NZWERF

4 Coarse sediment trap

Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

Sediment traps are relatively wide, short and deep excavations in the stream bed. Trapped sediment does not progress downstream where deposition would reduce channel capacity. The trap itself has to be excavated when it fills up (after major storms) rather than a much greater length of the stream. Sediment traps confine sediment deposition to a small reach of channel and reduce excavation costs. They are used as the upstream control in sediment detention wetlands for fine sediment trapping.

Location

- A long relatively straight channel reach with good access, room to operate an excavator, room to stockpile or dispose of sand and gravel, and suitable ground conditions are required.
- Sediment traps should not cause channel instability and endanger infrastructure (e.g. bridges), and public health and safety.
- A convenient location to trap and excavate bed material.
- Upstream of reaches where habitat is degraded because of excessive sediment deposition (e.g. sand covering riffles; loss of pools and riffles).

Work window

- If birds are nesting along the channel margin, avoid excavation in that area.
- Do not disturb the bed and banks during trout spawning (riffles in gravel beds in May, June and July).

Treatment objectives

1. Maintain downstream channel capacity by trapping sand and gravel at a convenient location before it moves downstream.
2. Confine channel excavation to a short reach of channel.
3. The bed and banks are stable (i.e. no channel erosion caused by the trap).
4. After a period of adjustment downstream habitat should improve.
5. Sediment traps should be well signposted and secured from inadvertent access (e.g. the access track to the trap is gated and locked).

Before you start

- ☐ Consult with experts at the regional or district council regarding the location and design of in-channel sediment traps, paying particular attention to channel stability and public health and safety.
- ☐ Develop a construction, operational and maintenance plan, and obtain the necessary resource consent and access agreements.

Procedures

These procedures are not a substitute for expert advice on the particular conditions prevailing at the site. Get expert advice on the design requirements (e.g. the river engineers at the Regional Council); and review the more detailed design guidelines.

Construction:

Excavate a pit in the channel. As a rule of thumb make the pit 1.5 times wider than the channel; with a length from 4 to 10 times the width; about 1.5 m deeper than the average bed level. For a 5 m wide channel, the trap width is 7.5 m, and the trap length 30 m to 75 m long.

The upstream edge of the pit probably has to be stabilised with rock to prevent erosion. (If the bed erodes the trap will fill up with this material). Make sure that fish passage can still occur.

Excavation would preferably be undertaken with a dragline or hydraulic excavator from the bank.

The cross section of the trap should be uniform, to limit flow separation, and gradually get wider downstream. Channel side slopes should be 1 vertical: 3 horizontal, or more gentle if possible.

Suitable vegetation should be planted to stabilise the banks and berms, and provide food and habitat for fish and wildlife.

Maintenance:

- Regular inspections should be carried out to determine when the trap should be re-excavated; and after floods to detect problems (e.g. scour; bank failure).
- Bank vegetation should be maintained in good condition.

Sediment removal and stockpiles:

- Excavate the trap when it is filled, otherwise there will be no more trapping.
- Follow the guidelines for channel excavations to remove material.

Decommissioning:

- In many cases a trap can be de-commissioned simply by not removing sediment. The bed will build up, and the edges will infill as vegetation encroaches and traps more sediment. The channel will eventually be indistinguishable from the adjacent channel.
- Once stockpiles have been removed, the site should be levelled and re-vegetated. Unless agreements have been made to retain access tracks, tracks should be covered in soil and re-vegetated.

Additional reading

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Sustainable drainage management

Best management practice

By Henry R Hudson

5 Filter strip

Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

A strip of grass or other leafy vegetation along a waterway margin that intercepts sediment, organics, nutrients, pesticides, and other contaminants from shallow surface flow.

Location

Situated between cropland, grazing land, or disturbed land, and waterways; (2) as part of a riparian buffer system; (3) as part of a two stage floodway; or (4) as part of a waste management system to treat contaminated runoff or waste water:

- Where there is sheet or uniform shallow flow (avoid concentrated flow).
- Where conservation practices on the contributing area reduce soil losses and sources of contaminants to acceptable levels. Filter strips are not a substitute for good land management.
- Generally on slopes less than 10%, when they can be grown on the approximate contour .

This drain was filled with sediment washed from the cultivated field. The filter strip should be about 5 m wide.

Work window

- If birds are nesting, avoid mowing or grazing.
- Do not disturb the channel margins if there is whitebait (inanga) spawning (spawning occurs above normal water level on spring tide flooded channel margins during late summer and autumn, mainly February to April).

Treatment objectives

1. Maintain a continuous grass cover (10 to 20 cm high; 70% + density).
2. There should be no stock tracks or visible signs of erosion.
3. Sediment should be trapped in the first 1 to 2 m of grass and should not enter the waterway.
4. Sediment associated nutrient reductions of 50 to 90% are achievable with trapping occurring in the first 3 to 4 m.
5. To control soluble contaminants such as nitrates, filter strips should be combined with extensive shrub-forest buffers or runoff should be routed through constructed wetlands.

Before you start

- ☐ Consider fencing off the drain and/or planting streamside vegetation in association with the filter strip. (See Streamside planting guide, www.nzwerf.org.nz).
- ☐ Consult with District/Regional Council staff – they will provide advice and there may be assistance with fencing and planting.

Procedures

Establish a dense cover that is perennial, resistant to flood and drought, and able to keep growing after some flooding. Vegetation should be dense, rather than dumped (e.g. flows can bypass tussocks).

The width of the filter strip is highly dependent on the amount of soil erosion and land slope. Soil erosion is largely determined by land management practices.

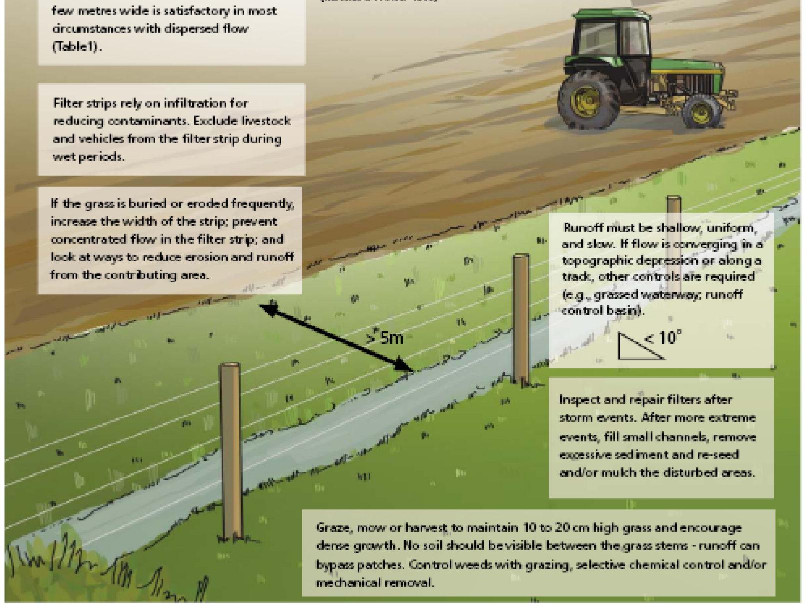
Filter strips >30 m are needed in most cases with erodible soils and poor upland management. With good land management practices a filter strip a few metres wide is satisfactory in most circumstances with dispersed flow (Table1).

Soil loss (t/ha/y)	Filter strip slope (%) - filter width (m)									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
1	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2
5	2	2	2	2	3	3	3	4	4	4
10	2	2	4	5	6	6	7	7	7	7
20	3	9	11	12	12	13	13	13	13	14
30	9	15	17	18	19	19	19	20	20	20
40	15	21	23	24	25	25	26	26	26	26
50	22	28	30	>30						
60	28	>30								
70	>30									

Table 1. Relationship between soil loss, slope and filter strip width for dispersed flow (Karssies & Prosser 1999)

Filter strips rely on infiltration for reducing contaminants. Exclude livestock and vehicles from the filter strip during wet periods.

If the grass is buried or eroded frequently, increase the width of the strip; prevent concentrated flow in the filter strip; and look at ways to reduce erosion and runoff from the contributing area.



Runoff must be shallow, uniform, and slow. If flow is converging in a topographic depression or along a track, other controls are required (e.g., grassed waterway; runoff control basin).

Inspect and repair filters after storm events. After more extreme events, fill small channels, remove excessive sediment and re-seed and/or mulch the disturbed areas.

Graze, mow or harvest to maintain 10 to 20 cm high grass and encourage dense growth. No soil should be visible between the grass stems - runoff can bypass patches. Control weeds with grazing, selective chemical control and/or mechanical removal.

Additional reading

Karssies, L.E.; Prosser, I.P. 1999. *Guidelines for riparian filter strips for Queensland irrigators. CSIRO Technical Report 32/99.* 39 pages.

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Sustainable drainage management

Best management practice

By Henry R Hudson

6 *Glyceria maxima* (reed sweet grass)

Definition & purpose

The aim is to completely eradicate *Glyceria maxima* (reed sweet grass) in waterways. Glyceria is an aggressive aquatic plant pest and can form dense impenetrable stands in watercourses. It is troublesome in drains, slowing water flow. It has been implicated in cyanide poisoning of livestock. Traditional control approaches are often ineffective, and may spread the weed.

Location

Waterways throughout New Zealand.

Work window

- Glyceria quickly becomes a large and vigorous plant, therefore any new infestation should be treated as early as possible. Destroying the young plants at an early growth stage, before they have become established or produce seed, is the most economical and effective method of control. If control is delayed until the infestation is established, eradication in one season is improbable and follow-up work over at least two or three seasons will be required. Application of herbicides is best done in late summer and autumn.
- Avoid nesting birds and inanga spawning areas on lowland stream banks.

Reed sweet grass. Photos: DOC.

Treatment objectives

1. Remove dense stands of Glyceria that restrict access to waterways, impede water flow, cause local flooding, reduce the capacity of drains and accelerate sediment deposition.
2. Plan to kill the plant and remove it. Not removing dead weeds can result in a large amount of decaying vegetation that may pollute the water or block pump intakes and channels and ditches.

Before you start

☐ Consult with District/Regional Council staff and landowners about habitat value, and the requirements for avoiding sensitive times and places.

☐ Understand the plant you are dealing with:

- Glyceria produces an extensive root system to approximately 1 m depth. It also forms a sprawling mat of rhizomes, or underground stems, which comprise 40-55% of the plant's total biomass. These rhizomes produce vast numbers of shoots to quickly expand the plant's size. The plant's growth slows and stops at the onset of cooler temperatures in winter. Growth recommences in spring with a flush of new shoots arising from buds formed along the rhizomes.
- Glyceria produces vast numbers of dark brown seeds, 1.5-2 mm long, throughout summer and autumn. Most seeds are able to germinate immediately, however some remain dormant for several years. Seed may be spread on water, in mud or machinery and vehicles, on footwear and on livestock. Glyceria seed is not readily spread by wind.
- Glyceria may also be propagated by small sections of rhizome being moved around in mud on machinery and implements.

Procedures

Hand removal: Suitable for small plants. Aim to remove all pieces of the roots and rhizomes, otherwise the plant may quickly regrow.

Excavation: Mechanical removal of larger plants is difficult because roots and rhizomes extend widely and are deep (~1 m), and may be missed during excavation. Excavated material should be dumped well away from the area, where it can dry out and kill all plants. Mechanical excavation has the advantage removing the plants from the watercourse. Thorough cleaning of any equipment that comes into contact with the plant or soil is required whenever any work is carried out near Glyceria infestations. (See the Channel Excavation BMP).

Cultivation: If low water levels permit, an alternative to excavation is to cultivate the soil and root areas in autumn. This brings root and rhizome material to the surface to allow winter frosts to desiccate the material. This method will give good control over small infestations and reduce the size of large infestations to more manageable levels. Great care must be taken to thoroughly clean all machinery after cultivation, to reduce the risk of spreading rhizome material.

Chemical control: Where a large area has been invaded herbicides can be used to control Glyceria (e.g. Glyphosate). A complete coverage of all foliage is necessary. Great care must be taken to minimise drift to water and desirable plants. Application of herbicides is best done in late summer and autumn. Plants which have more than about one-third of their stems below water may not be killed by herbicide. Whenever practicable the water level should be lowered to give the maximum possible plant exposure before treatment, and kept down for at least 12 hours after application. Removal of dead plants is desirable – the decaying vegetation provides ideal conditions for invasion by other species or a re-invasion of Glyceria. When dead plants are left they decompose and make the water dirty and smelly.

Additional reading

HBRC. 1995. *Plant pest control: aquatic plant pests – Glyceria maxima.* Environmental Topics, Hawkes Bay Regional Council.

Tamar Valley Weed Strategy Working Group. 1997. Strategic plan 1997. *Codes of Best Practice. Glyceria/reed sweet grass.* www.weeds.tassie.net.au/frames/cntrls

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Sustainable drainage management

Best management practice

By Henry R Hudson

7 Grassed waterway

Complexity	Environmental value	Cost
Low – Moderate – High	Low – Moderate – High	Low – Moderate – High

Definition & purpose

A broad, shallow, natural or constructed channel that is grassed. Surface storm water flows into and down the channel without causing soil erosion (e.g. rills, gullies).

Location

Grassed waterways are often constructed in natural depressions that channel water to a stream or wetland. These depressions are prone to erosion if they have poor vegetative cover. They work best on gentle slopes.

Work window

- Undertake any earthmoving and outlet construction so that the grass cover is established prior to winter storm runoff.
- Avoid construction and maintenance if birds are breeding in the waterway course.

Vegetation cover in the waterway slows the surface runoff and protects the land from erosion.

Treatment objectives

1. Carry relatively large stormflows to streams without erosion.
2. Farm machinery and stock can cross the waterway.
3. Maintenance is low once vegetation is established.
4. Waterways should only be wet during storm runoff, otherwise development of good cover is inhibited and vehicle crossings are not possible without damage to the waterway.
5. If the channel is wet for long periods, use water tolerant plants.

Before you start

☐ Consult with District/Regional Council staff about design requirements such as stormflows and hydraulic roughness of grass cover.

☐ Obtain necessary approvals from the local authority.

Procedures

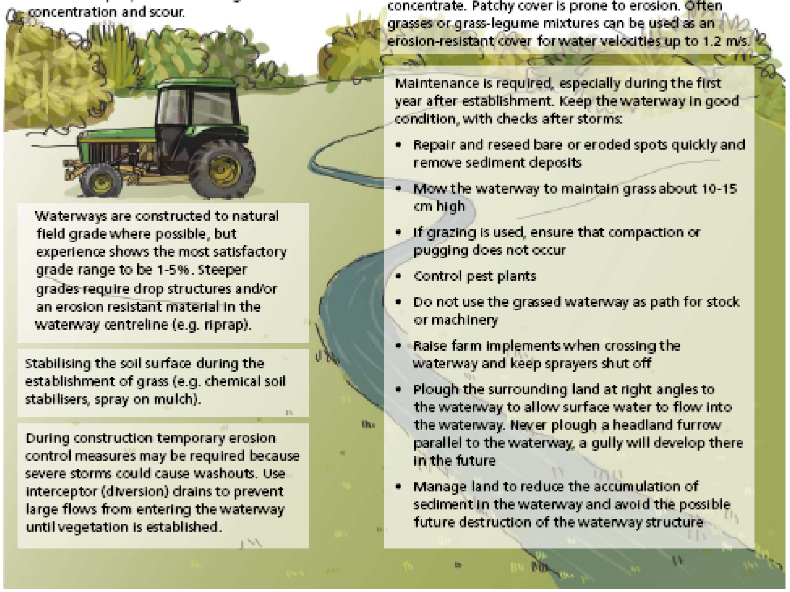
Correctly size the channel so that it will contain the design runoff without spilling onto surrounding land (e.g. cultivated field) and will spread the water sufficiently so that the bed does not erode. Steeper gradient channels require creation of a wider, shallower waterway.

Channel capacity depends upon the width, depth and grade, as well as soil erodibility and vegetative cover in the channel area.

Grassed waterways usually exit into open drains or streams and a stable outlet is necessary. If the waterway abruptly falls into the drain or stream, a rock chute spillway or vertical grade control structure is required.

Ensure that side slopes are less than 1:10 (rise over run) to allow machinery to cross. A common design error is to make the channel too deep, too narrow or too V-shaped, which encourages flow concentration and scour.

The main determinant of the allowable water velocity is the type, condition and density of the grass cover. Uniform cover is important so that flows do not concentrate. Patchy cover is prone to erosion. Often grasses or grass-legume mixtures can be used as an erosion-resistant cover for water velocities up to 1.2 m/s.



Waterways are constructed to natural field grade where possible, but experience shows the most satisfactory grade range to be 1-5%. Steeper grades require drop structures and/or an erosion resistant material in the waterway centreline (e.g. riprap).

Stabilising the soil surface during the establishment of grass (e.g. chemical soil stabilisers, spray on mulch).

During construction temporary erosion control measures may be required because severe storms could cause washouts. Use interceptor (diversion) drains to prevent large flows from entering the waterway until vegetation is established.

Maintenance is required, especially during the first year after establishment. Keep the waterway in good condition, with checks after storms:

- Repair and reseed bare or eroded spots quickly and remove sediment deposits
- Mow the waterway to maintain grass about 10-15 cm high
- If grazing is used, ensure that compaction or pugging does not occur
- Control pest plants
- Do not use the grassed waterway as path for stock or machinery
- Raise farm implements when crossing the waterway and keep sprayers shut off
- Plough the surrounding land at right angles to the waterway to allow surface water to flow into the waterway. Never plough a headland furrow parallel to the waterway, a gully will develop there in the future
- Manage land to reduce the accumulation of sediment in the waterway and avoid the possible future destruction of the waterway structure

Additional reading

Stone, R. 1994. *Grassed waterways*. Ontario Ministry of Agriculture and Food Factsheet Queens's Printer, Ontario.

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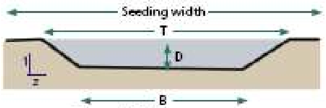
By Henry R Hudson

8 Interceptor drains and bunds

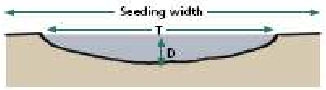
Complexity	Environmental value	Cost
Low – Moderate – High	Low – Moderate – High	Low – Moderate – High

Definition & purpose

Interceptor drains are small channels with a minor ridge along one edge that collects and directs surface water to a desired location such as a stable outlet or sedimentation pond. The drains and bunds can either have a natural grass lining or, depending on slope and design velocity, a protective lining, or gravel bed. They protect sensitive areas or work areas from upslope runoff and erosion; ensure that sediment-laden stormwater will not leave the site without treatment (e.g. diversion to a sedimentation pond); and divert water.



Trapezoidal shape cross section



Parabolic shape cross section

Location

Typical locations are diversions around sensitive areas like streams and wetlands, around soil stockpiles and on-site sewage soakage areas, and along roads.

Work window

Identify habitats to be protected (e.g. native bush, wetlands, streams, nesting sites). Avoid disturbance of these sites.

Treatment objectives

1. Significant habitats and the work site are protected from runoff, erosion and excessive sediment deposition for a 2-year return period, 24 hour-duration storm.
2. The interceptor drain and bund must be stabilised quickly so they do not contribute to the erosion problem they are addressing.
3. The drains and bunds are not a safety hazard.

Before you start

- ☐ Consult with District/Regional Council staff – they will provide advice. Resource consent may be required.
- ☐ Consider other management measures such as sediment detention ponds and grassed waterways to complement the interceptor drain and bund.
- ☐ Plan to complete the interceptor drains and bunds before other works that may cause erosion.

Procedures

As with all structural measures to control sediment and erosion, frequent inspections and maintenance must occur with interceptor drains and bunds. The following guidelines should be used when conducting inspections and maintenance:

- Inspect temporary facilities before, during and after significant storm events and at least once per week during operations.
- Damage from storms or normal construction activities such as tyre ruts should be repaired as soon as practical.

For disturbed areas that are not to be cultivated the preferred approach is to grass the area as soon as possible after construction. In some cases rapid natural re-vegetation occurs. If erosion is observed, the bunds should be grassed.

Permissible channel velocities depend on the slope and degree of channel stabilisation. In general, the maximum velocity for an earth channel is 1 m/s, and for a grassed channel or coarse gravel bed it is 2.5 m/s. For higher velocities a liner or cobble-boulder bed is required.

If an abrupt change in slope is required, grade control structures must be installed.

Side slopes depend on the location and size of bunds. If a large grassed embankment is to be mowed, the maximum slope should be lower than 1 in 3. For small bunds, a 1:1 slope is acceptable.

The bund will normally be constructed from the cut material of the drain. The earth should be compacted as it is placed. Maximum depth of flow in the swale would generally be ~0.5 m based on a 2 year design storm peak flow. Positive overflow must be provided to accommodate larger storms.

Mark out the site and confirm the location and dimensions with the consent authority (if required). Ensure that runoff water and sediment are directed to sediment ponds. Clean water diversions should flow to a controlled outlet (e.g. established grass or coarse gravel) to prevent erosion at the outlet. Use onsite material to develop the ditches and bunds.

Additional reading

NRCS. 1995. Diversion. *Conservation Practice Standard 362*. National Resource Conservation Service, United States Department of Agriculture.

Quilty, J.A., Hunt, J.S.; Hicks, R.W. 1978. *Urban erosion and sediment control*. Soil Conservation Service Technical Handbook No. 2. Ministry for Conservation and Water Resources, New South Wales.

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Sustainable drainage management

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By Henry R Hudson

9 Rehabilitating land following stream works

Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

To rehabilitate land impacted from stream channel works, such as drain excavation and stream bank protection. The aims are to protect sensitive sites, to prevent off-site damage, and to rehabilitate the stream banks and channel margins to a desirable condition.

Location

Stream and river channels subject to channel excavation and bank protection works.

Work window

- Identify habitats to be protected (e.g. native bush, wetlands, streams, nesting sites). Avoid disturbance of these sites.
- Avoid bird-nesting periods.
- Do not disturb the channel margins if there is whitebait (inanga) spawning. Spawning occurs above normal water level on spring tide flooded channel margins during late summer and autumn (mainly February to April).

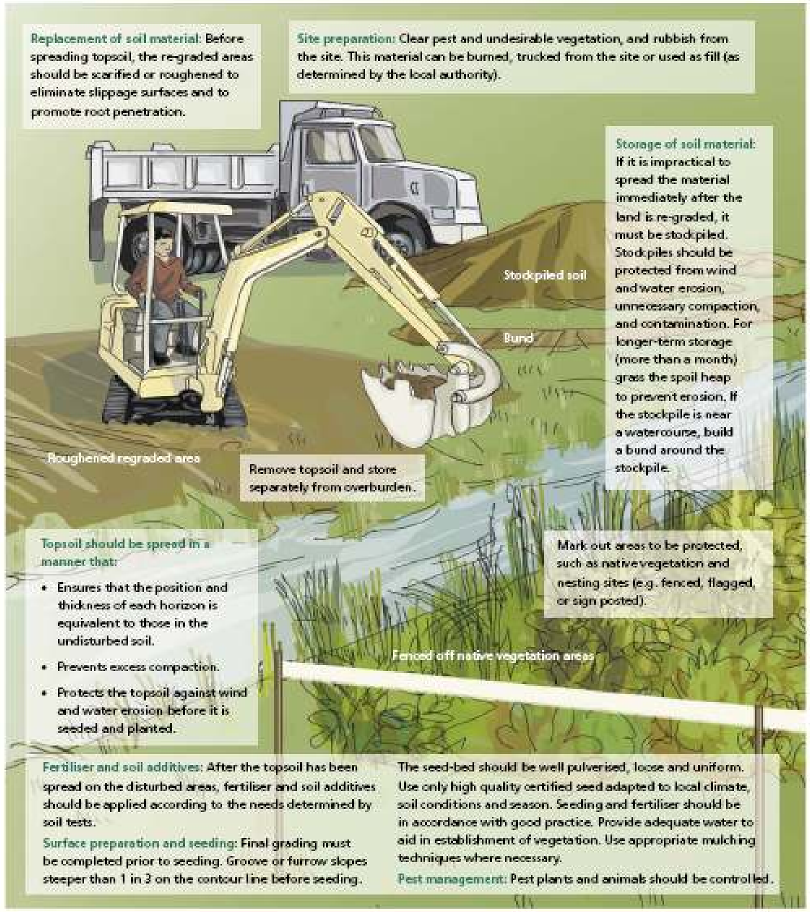
Sediment control and re-vegetation of drainage management work sites is often required to prevent soil erosion contributing to waterways.

Treatment objectives

1. Erosion is controlled during works and rehabilitation.
2. Suitable sites are used for the storage of soils, access roads and interceptor drains.
3. Land productivity is rehabilitated (e.g. pasture; streamside planting).
4. Banks and land will be well vegetated (70% + ground cover density, with no visible exposed soil) with no signs of erosion (rills or gullies).
5. Banks will be stable with no signs of bank collapse.
6. Surface runoff should be slowed and intercepted by streamside vegetation.
7. Water quality and stream channel and stream bank habitat should improve.

Before you start

- ☐ Consult with District/Regional Council staff – they will provide advice and there may be help to fence and plant. Resource consent may be required.
- ☐ Consider streamside planting as well as pasture rehabilitation.



Additional reading

ARC. 1999. *Erosion and sediment control. Guidelines for land disturbing activities in the Auckland region.* Auckland Regional Council Technical Publication No. 90.

NRCS. 1984. *Land reconstruction, currently mined land.* Conservation Practice Standard 544. National Resource Conservation Service, United States Department of Agriculture.

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By Henry R Hudson

10 Stock and waterways

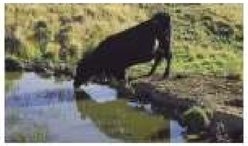
Complexity	Environmental value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

Definition & purpose

Prevent livestock from entering waterways or trampling riverbanks by fencing the stream corridor. Exclusion will generally reduce erosion and habitat degradation; improve water quality; and health and safety of livestock.

Location

Typically the fencing is placed along the top of the bank, but more benefit can be derived from a wider stream corridor.



Stock trampling riverbanks can cause erosion and habitat degradation as shown above.
Photo: Greater Wellington.

Work window

- If birds are nesting along the channel margin, avoid mowing or grazing.
- Do not disturb the channel margins if there is whitebait (inanga) spawning. Spawning occurs above normal water level on spring tide flooded channel margins during late summer and autumn (mainly February to April).

Treatment objectives

1. Livestock are prevented from entering the waterway or trampling the banks apart from allowing short periods of grazing to manage weeds.
2. There will be no stock losses to drowning.
3. Banks will be well vegetated (70% + ground cover density, with no visible exposed soil) with no signs of trampling or erosion (rills or gullies).
4. Banks will be stable with no signs of bank collapse (some bank stabilisation work may be required).
5. Wet areas should be included within the fenced area (perhaps temporarily) to prevent pugging (i.e. animal hooves sinking into the soil).
6. Surface runoff from paddocks should be slowed and intercepted before it gets to the waterway.
7. Water quality and stream channel and stream bank habitat should improve.

Deer are excluded from the drain in the top photograph; but have free access to the same drain in the bottom photograph.

Before you start

- ☐ Consult with District/Regional Council staff – they will provide advice and there may be help to fence and plant. Resource consent may be required.
- ☐ Put livestock watering points in the paddock.
- ☐ Consider streamside planting and making the corridor wider.

Procedures

Decide on the type of fencing (e.g. single wire electric to flood proof multi strand fences):

	Conventional	Electric
Advantages	Relatively little day to day maintenance Not reliant on external power source Functions when overgrown Long life (unless washed out)	Inexpensive to construct and repair Quick to construct and repair Particularly useful for flood gates Curves do not need corner assemblies Options for permanent and 'wash away' flood gates Animals can escape from floods Gates can be inexpensive and simple
Disadvantages	Can be costly Labour intensive to install Time consuming to repair	Requires regular checking to ensure proper function Electricity required (mains, battery, solar)

- Any fencing or riparian planting must consider drain maintenance:
  - On one side have a temporary fence to allow access.
  - Make permanent fences close to the top of the bank so that an excavator can reach over the top and clear the channel.
  - Make the fenced area wide enough to allow an excavator to work between the fence and the top of the bank. While there is a loss of land, there may be advantages in terms of more sensible fence lines, more forage behind the fence, and greater benefits for nutrient and sediment trapping.
- Once stream banks are stable and re-vegetated, controlled grazing may be used to maintain pasture grasses and control weeds. Grazing periods should be limited to minimise animal wastes entering the stream.
- Grazing should be managed to minimise erosion, and to maintain good soil structure and vegetation cover (>70% density). Do not mob-stock or heavy-set stock during wet soil conditions.
- Repair any flood damage or livestock damage as soon as possible.
- Exclude livestock during critical wildlife periods (i.e. during bird nesting periods and inanga spawning).
- Cattle and deer watering facilities should be located on the paddock (e.g. nose pumps and other watering troughs). If this is not feasible, create stable (e.g. gravel pad), fenced areas from stream watering.

Additional reading

Taranaki Regional Council Sustainable Land Management Programme Fact Sheet 24: Fencing options and costs. www.trc.govt.nz/PDFs/info_land/24_riparian_fencing.pdf.

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Sustainable drainage management

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By Henry R Hudson

11 Whitebait (inanga)

Complexity	Environmental value	Cost
Low — Moderate — High	Low — Moderate — High	Low — Moderate — High

Definition & purpose

Protect inanga habitat, especially spawning areas, during critical periods to halt/reverse the decline in the whitebait fishery.

Location

- Spawning occurs along vegetated stream banks in estuarine areas, above normal water levels up to the area flooded at extreme tides (spring tides).
- Inanga live in slow moving channels in low altitude, low gradient waterways; with most fish found at altitudes of less than 20 m and less than 10 km from the coast.

Inanga eggs in streamside vegetation. Photo: DOC.

Inanga. Photo: DOC

Work window

- Spawning occurs in late summer and autumn, mainly February to April inclusive. The eggs are laid near the spring high tide, and develop out of the water. They usually hatch soon after being resubmerged on the next series of spring tides. The larvae are washed out to sea.
- Whitebait (juvenile inanga) migrate from the sea into river mouths in spring. Over the summer they grow to maturity. In autumn they migrate downstream to spawn in estuaries.
- Mechanical clearing or spraying of stream sides in late autumn, winter or early spring is preferable.

Life cycle of Inanga. Illustration: Greater Wellington.

Treatment objectives

Inanga are the most abundant of the species collectively called whitebait. Mortality is extremely high. Management strategies that improve spawning habitat and increase survival of adult fish further upstream are likely to substantially benefit the fishery.

Before you start

- ☐ Consult with Department of Conservation or Regional Council staff to identify spawning sites.
- ☐ Consult with District/Regional Council staff – they will provide advice and there may be help to fence and plant. Resource consent may be required.
- ☐ Consider streamside planting and making the streamside corridor wider.

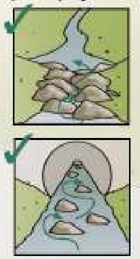
Procedures

The inanga eggs develop out of the water between extreme tides:

- livestock should not wander through streams because they muddy the water and trample the banks .
- Do not mow or spray in the spawning area and escape routes.

Floodgates are often obstacles because they are normally closed when the tide is flooding to prevent saltwater intrusion. This stops whitebait flowing in with the tide - they have to swim against the ebbing tide to get to their spawning grounds when the floodgates open. Gates can be modified or manipulated to allow easier passage.

Fish bypasses could be constructed to facilitate whitebait passage. These may be simple gravel ramps.



Livestock should be fenced out of spawning areas at least a couple of weeks prior to the main spawning period to allow lush grass growth and to stop destruction of the spawning area.

Spawning sites should be identified, marked out, and preferably fenced off. The same sites are used year after year.

Stream banks can be reshaped (re-battered) and planted with native species, or grasses, to provide optimum habitat.

Streambank vegetation is important, this includes pasture. Grass should not be mown down to the waters edge as short grass offers little protection to eggs and they usually dry out and die. A strip of longer grass should be left to overhang the water.

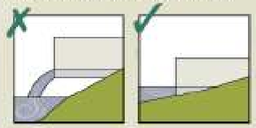
Cleared streams with a uniform bottom are a poor habitat (they are faster flowing and tend not to have the slow flowing pools inanga prefer).

Excessive aquatic weeds are a problem. Inanga live near the edges of weed beds and require clear patches of water for feeding. Mechanical clearing or spraying in late autumn or winter after inanga adults have moved back to the estuaries to spawn is preferable.

Instream cover, particularly woody debris is important. However, woody debris is generally considered incompatible with drainage management and is cleared before it becomes a problem.

Culverts are also a problem. Small cascades and high velocities prevent access. Inanga are not strong swimmers and most whitebait are incapable of getting over a 5 cm high waterfall. Culvert replacement/repair should always be carried out so that the culvert is the same gradient as the reach and the culvert invert is the lesser of either:

- One third of the culvert diameter; or
- 300 mm below the existing bed level.



Preferred sites for young and mature inanga are slow moving (3 to 7 cm/s for feeding) and relatively deep pools (>30 cm); usually with fine bed materials. Land use does not seem to be important.

Additional reading

Richardson, J.; Taylor, M.J. 2002. *A guide to restoring inanga habitat.* NIWA Science and Technology Series No. 50. (Reprinted with minor revisions 2004). www.niwa.cri.nz/pubs/st/restoration.pdf

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