Section

1

1. Farming and Water Quality-Defining the Issue

Key Learning Objective

After studying this section, you should have a good appreciation of the complex legal and social issues surrounding water quality in New Zealand and how Regional Councils are tackling these issues at a local scale. You should also gain some appreciation of the role agriculture plays in terms of water quality in New Zealand. This relationship will also be explored further, in later chapters.

General Background

As humans have arrived and settled in New Zealand over the last 1,000 years they have made major changes to the landscape. Small settlements and then towns and cities have been built – usually adjacent to the coast or a river or lake. The indigenous vegetation over much of New Zealand has been replaced with plant species useful for agriculture, horticulture or forestry. Large numbers of mammalian herbivores (e.g. sheep and cattle) have been introduced to a land in which no such animals existed prior to human occupation.

Unsurprisingly, these changes in land use and vegetation have had an impact on both the quantity and quality of the water in the rivers and lakes that drain these altered landscapes. These impacts are generally regarded by people as being adverse and undesirable. There is a perception within society that "natural" is "good" and there has been growing pressure in recent decades to maintain New Zealand's rivers and lakes as close as possible to the "natural state". It is this growing pressure that has led to the development of this course and your participation in it.

Although there are major concerns within the community about both the quantity and quality of surface water (e.g. in rivers and lakes) and sub-surface ground water in New Zealand, this course will focus mainly on issues associated with water quality. It will also focus mainly on the impacts of agricultural activities on water quality, although it is important to realise that urban and industrial activities also have a major impact.

Reports in newspapers and on television give the impression that the negative impact of agriculture on water quality is a recent phenomenon and that water quality is now being rapidly degraded, largely as a result of the intensification of dairying. It is important to realise that this is an over-simplification of the situation, and a lack of awareness of how both agriculture and water quality have changed over time can lead to misunderstandings. An example of such a misunderstanding is the recent portrayal of farmers' opposition to the Horizons Regional Council's OnePlan as evidence of a lack of concern for the environment. This is not the case.

Forty years ago, the water quality in some of New Zealand's rivers and estuaries was much worse than it is now. This was largely because untreated municipal, industrial and agricultural wastes were routinely discharged directly into rivers and streams. Since that time, much stricter controls have been placed on the discharge of such wastes and as a result water quality in sections of many rivers has improved.

For dairy farmers, these strict controls initially meant that they were no longer allowed to discharge yard wash-down water directly into local streams, and instead had to install some type of treatment and storage system. Commonly this was a two-pond system that treated the effluent prior to discharge into the stream. More recently, Regional Councils have required that these two-pond treatment systems be replaced by land application systems.

For the last forty years therefore, dairy farmers have been interacting intensively with local authorities over the impact that their farming operations have had on the environment. During this time the councils' focus has been mainly on the management of dairy shed effluent. For example, in cases where farmers have been prosecuted it has almost always been for problems in their management of dairy shed effluent. Farmers could therefore, justifiably conclude that management of dairy shed effluent was the most important "environmental" issue on their farms.

Now, "suddenly", councils have become concerned about aspects of dairy farming other than the disposal of dairy shed effluent. Some farmers are understandably confused about this sudden change in emphasis, and also by claims that water quality is decreasing rapidly. For some older farmers this appears to conflict with their own perception of improving water quality. As a farmer acquaintance said recently,

> "the streams used to run green till lunchtime".

This was a result of the yard wash-down water being discharged directly into streams. This no longer occurs and as a result, many small streams running through dairy farms are much cleaner now than they were 40 years ago. What has changed over the last 20 years is the type of water quality degradation and where in the stream network it is occurring.

Another example of a longstanding environmental issue affecting farmers has been erosion. The effect of accelerated erosion on the sediment concentrations in rivers has been recognised for at least 100 years. A series of severe storms in the 1930s caused erosion on a massive scale and led eventually to the passing of the Soil Conservation and Rivers Control Act in 1941. Although this Act has now been repealed, it is interesting to note that it contained several provisions allowing the state to control the way farmers managed their properties. Although these provisions were seldom enforced, they were much more draconian than measures currently being proposed in plans by some Regional Councils.

In summary therefore, although the impact of agriculture on water quality is a serious issue, it is not a new problem. Farmers have been working with local authorities for decades to reduce the impact of their farming operations on the wider environment. The key to successful management of the current issues is a good understanding of the nature of the problem and an equally good understanding of the history and current reality of farming. This course will help you achieve that understanding.

What do we mean by water quality?

We all have an intuitive understanding of the concept of water quality. We can also probably compare two rivers, streams or lakes and decide in general terms which has the higher water quality. When pressed however, we may have difficulty coming up with an exact definition. Water of low quality is often described as 'polluted' and it is an interesting exercise to try to come up with a definition of polluted water. It would be worthwhile pausing at this stage and jotting down a few trial definitions of your own. When this is discussed in class, ideas that are often put forward include:

Table 1.1 Suggested definitions of water quality and related comments.

Suggested Definitions	Comments
Polluted water contains impurities while unpolluted water is ‘pure’.	But virtually all water contains some dissolved chemicals. It requires sophisticated laboratory equipment to produce absolutely ‘pure’ water and even then, exposure to the atmosphere immediately results in gases such as carbon dioxide dissolving in the water. If water was absolutely pure it would sustain little life.
Unpolluted water is ‘natural’ but polluted water has been affected directly or indirectly by humans.	The Whangaehu river drains the crater lake of Mt Ruapehu. As a result, it ‘naturally’ contains many dissolved chemicals and is extremely acidic. Is it ‘polluted’?
Unpolluted water can be drunk safely by humans.	Does this mean that all sea water is polluted?

Although many of these comments are trivial they do point to the difficulty of defining 'polluted' water. In practice however, whether or not water is considered 'polluted' often depends on its intended use.

Thus:

'*water might be considered polluted when it is unsuitable for a legitimate intended use*'.

Some people will object strongly to a definition such as this, because it is very anthropocentric. It implies that the quality of a body of water only has meaning in terms of the use that humans can make of it. It might not recognize intrinsic value in a river or lake, independent of any use.

Nevertheless, the definition can be useful - particularly if 'use' is interpreted very widely to include maintenance of intrinsic values and enhancement of environmental quality.
Of particular interest in the above definition is the word 'legitimate'. Referring to the earlier table of definitions, most people would agree that it is not reasonable to expect that sea water be drinkable. Therefore, a proposal to use unmodified sea water for drinking would not be a 'legitimate intended use'. And we would not classify all sea water as polluted solely on this basis.

It is for society to determine whether or not a proposed use is 'legitimate'.

Once an activity has been judged 'legitimate' then we have to decide what we mean by 'suitable'. This often involves technical judgments on the physical, chemical and biological properties of the water that are important for the intended use.

The Resource Management Act, 1991, provides the framework within which these judgements on water use and water quality can be made.

Legislative and regulatory framework

Policies and regulations affecting water quality are created by both central and local government. At the central or national level, the key piece of legislation is the Resource Management Act 1991.

Within this framework, local authorities – notably Regional Councils – are charged with implementing the policies developed by central government. In doing this they develop their own sets of policies, objectives and rules that are suited to their local areas. At present, many Regional Councils throughout New Zealand are developing new plans for managing water quality in their regions. There is considerable variation in the approaches being adopted by different Regional Councils to this task.

RESOURCE MANAGEMENT ACT

The passage of the Resource Management Act, 1991 was a landmark in environmental management in New Zealand. The Act is a large and complex document and it is not within the scope of this course to offer students anything but the most superficial understanding of its provisions and implications.

The following extract from the Resource Management Act 1991 explains its purpose and principles.

- *"The purpose of this Act is to promote the sustainable management of natural and physical resources.*
- *In this Act,* ***sustainable management*** *means managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—*
  - (a) *sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
  - (b) *safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
  - (c) *avoiding, remedying, or mitigating any adverse effects of activities on the environment."*

A key philosophical approach of the original Act was the devolution of much of the responsibility for water quality management to the regions.

THE LAND AND WATER FORUM

The following information is from the Land and Water Forum's website (http://www.landandwater.org.nz/)

In 2009, The Land and Water Forum was formed. The forum is a consultative group including industry, environmental and recreational NGOs, iwi, scientists, and other organisations. The forum consists of about 30 stakeholders who report to a wider group of about 70 organisations and active partners. The Forum's objective is to develop a shared vision and a common way forward among all those with an interest in water, through a stakeholder-led collaborative process. The Forum has played a key role advising government on policy to improve freshwater and land management in New Zealand.

The first step was the release in June 2009 of a strategy titled "A New Start for Fresh Water". This name has now changed to "A Fresh Start for Fresh Water". Key developments within this strategy led to the release of the National Policy Statement on Freshwater Management (NPS-FM) in May 2011.

> *The first phase of the Forum's work lasted from August 2009 to August 2010 and resulted in the report "A Fresh Start for Freshwater".*
>
> *On 18 May 2012, the Forum released the "Second Report of the Land and Water Forum". It provides a national framework within which Regional Councils will work with their communities and iwi to set freshwater objectives and develop limits for its use. It provides a consistent and transparent process for setting objectives and limits, and one that will lead to effective and enduring outcomes, including greater certainty for investment and development.*
>
> *On 15 November 2012, the Forum released the "Third Report of the Land and Water Forum" on managing within limits. It recommends integrated decision-making in catchments, continuous improvement of management practices to improve water quality and clearer rights to take and use water within set limits."*
>
> *On 27 November 2015 the Forum released the "Fourth Report of the Land and Water Forum on how to maximise the economic benefits of freshwater while managing within water quality and quantity limits that are set consistent with the National Policy Statement on Freshwater Management 2014 (NPS-FM). It also recommends exclusion of livestock from waterways on plains and lowland hills, addresses a number of urban issues and suggests tools and approaches to assist the Crown's exploration of rights and interests with iwi."*

Since then, the Forum has provided advice and commentary documents to the government on the development and implementation of the NPS-FM and the National Objectives Framework.

NATIONAL POLICY STATEMENT FOR FRESHWATER MANAGEMENT 2011

The Resource Management Act 1991 allows the central government to develop national policy statements about important environmental issues. The purpose is outlined in clause 45:

Clause 45 - ***Purpose of national policy statements (other than New Zealand coastal policy statements)***

> *(1) The purpose of national policy statements is to state objectives and policies for matters of national significance that are relevant to achieving the purpose of this Act.*

The Act lists the issues that the Minister may consider when deciding whether it is desirable to prepare a national policy statement on a particular matter. Three that seem very relevant to the issue of water quality and quantity are:

> *(f) anything which, because of its scale or the nature or degree of change to a community or to natural and physical resources, may have an impact on, or is of significance to, New Zealand:*
> *(g) anything which, because of its uniqueness, or the irreversibility or potential magnitude or risk of its actual or potential effects, is of significance to the environment of New Zealand:*
> *(h) anything which is significant in terms of section 8 (Treaty of Waitangi):*

The NPS-FM came in to effect in 2011 and guided the objectives and policies for freshwater management required under the Resource Management Act 1991. The objective of the NPS-FM was to support improvements in freshwater management in New Zealand by encouraging local resource management planning and an appropriate level of flexibility, whilst achieving a nationally consistent approach.

The NPS-FM sets out objectives and policies that:

"direct local government to manage water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits". It "Directs regional councils to consider specific matters about freshwater when they are developing their regional plans."

The NPS-FM was amended and replaced in 2014 to introduce the National Objectives Framework. The National Objectives Framework was adopted to direct Regional Councils to set freshwater objectives and limits in their regional plans and to allow the adoption of the NPS-FM in a way which was consistent across New Zealand. The National Objectives Framework includes standard lists of possible values for which a particular freshwater body could be managed, such as swimming, fishing or irrigation. The target values chosen will be determined by each region, but the national bottom line or minimum standard that applies to these attribute states, will be set at a national level. The framework determines that water bodies are managed as 'freshwater management units' (FMU) and Regional Councils are required to consult their communities to identify key attributes for each of their FMU's and set freshwater objectives for each attribute. Communities also need to identify the 'attribute states' they want to achieve as a community. If an attribute state in an FMU is below the national bottom line, the council is required to improve the attribute state or have a plan for how this will be achieved over time.

"Fully populating a National Objectives Framework for every value and water body type is not possible today. It will be populated progressively over time as information becomes available. It may also change over time as science evolves and our understanding improves."

In September 2017, the NPS-FM was amended to support the Government's target to make 90% of New Zealand's rivers and lakes swimmable by 2040. As of September 2017, schedule 3 in the RMA which related to different water quality classes, no longer applies to freshwater. The key instrument now used for managing freshwater in New Zealand is the NPS-FM, which directs Councils on how to manage freshwater. Below is a summary of some key changes resulting from this amendment:

Monitoring requirements

- Regional Councils now required to monitor macroinvertebrates, indigenous flora and fauna, and mātauranga Māori and make this information publicly available.

Managing nutrients in rivers

- Regional Councils are now required to specify the nutrient levels (N and P) they are aiming for in their regional plans.

Te Mana o te Wai

- Recognises freshwater as a natural resource that is integral to the social, cultural, economic and environmental well-being of communities.

Economic well-being

- Regional councils should consider the economic well-being of communities at all stages of decision-making under the Freshwater NPS, as well as the environmental, social and cultural well-being.

Maintaining or improving freshwater quality

- New provisions clarify requirements for Regional Councils about maintaining or improving overall water quality, to make the requirements clearer.

Although the national policy statement was initially criticised by some people for not (in their view) going far enough or identifying specific water quality standards, recent amendments in 2017 have provided further clarification and clearer direction for councils. Some key extracts relating to water quality are listed below.

Objective A1

To safeguard:

a) the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems, of fresh water; and

b) the health of people and communities, as affected by contact with fresh water;

in sustainably managing the use and development of land, and of discharges of contaminants.

Objective A2

The overall quality of fresh water within a freshwater management unit is maintained or improved while:

a) protecting the significant values of outstanding freshwater bodies;

b) protecting the significant values of wetlands; and

c) improving the quality of fresh water in water bodies that have been degraded by human activities to the point of being over-allocated.

Objective A3

The quality of fresh water within a freshwater management unit is improved so it is suitable for primary contact more often, unless:

a) regional targets established under Policy A6(b) have been achieved; or

b) naturally occurring processes mean further improvement is not possible.

Objective A4

To enable communities to provide for their economic well-being, including productive economic opportunities, in sustainably managing freshwater quality, within limits.

Policy A1

By every regional council making or changing regional plans to the extent needed to ensure the plans:

a) establish freshwater objectives in accordance with Policies CA1-CA4 and set freshwater quality limits for all freshwater management units in their regions to give effect to the objectives in this national policy statement, having regard to at least the following:

i. the reasonably foreseeable impacts of climate change;

ii. the connection between water bodies; and

iii. the connections between freshwater bodies and coastal water; and

b) establish methods (including rules) to avoid over-allocation.

Policy A2

Where freshwater management units do not meet the freshwater objectives made pursuant to Policy A1, every regional council is to specify targets and implement methods (either or both regulatory and non-regulatory), in a way that considers the sources of relevant contaminants recorded under Policy CC1, to assist the improvement of water quality in the freshwater management units, to meet those targets, and within a defined timeframe.

Policy A2

By regional councils:

a) imposing conditions on discharge permits to ensure the limits and targets specified pursuant to Policy A1 and Policy A2 can be met; and

b) where permissible, making rules requiring the adoption of the best practicable option to prevent or minimise any actual or likely adverse effect on the environment of any discharge of a contaminant into fresh water, or onto or into land in circumstances that may result in that contaminant (or, as a result of any natural process from the discharge of that contaminant, any other contaminant) entering fresh water.

The important point to note from this national policy statement is that Objective A2 requires that "*The overall quality of fresh water within a freshwater management unit is maintained or improved while ……*". There is some debate about the meaning of the word "*overall*" in this context, but the take-home message is that Regional Councils must at least maintain the current state of water quality in their regions, and where possible improve it. They cannot allow water quality to be further degraded. This requirement will have a significant impact on future regional plans in many areas of New Zealand.

Setting limits

The following extract is from Section 5.5 Part A. Water quality in A Guide to the National Policy Statement for Freshwater Management 2014.

> *In most cases, setting a water quality limit involves identifying the quantifiable total of a contaminant entering the FMU from all sources. The background component (the amount of contaminant that comes from natural processes or sources, or from historic activity rather than from current resource use) will also need to be established but is not part of the limit itself (not part of the total amount that could be allocated to users). However, not all contaminants can be measured in a way that allows them to be expressed as a quantifiable total load which can then be allocated. Other types of limits to resource use (eg, limits on stock access) may be appropriate for meeting some freshwater objectives.*
>
> *A limit should, where practicable, specify an actual amount that can be measured or modelled with statistical confidence. The NPS-FM is not prescriptive about how a limit is expressed; (eg, whether as a source load, catchment load, loading rate, loss rate, or concentration). However, the intent of the policy is that a limit will be allocable (that is, an allocation to a particular user, activity or sector can be determined within the total for the FMU) where practicable.*
>
> *A limit is not simply the maximum resource use an FMU can withstand; it is the maximum use of a resource that will allow the relevant freshwater objective to be achieved. Therefore, limits on resource use should ensure specific freshwater objectives can be met, rather than reflect more generic aspirations. If time shows that the freshwater objective can be met within more relaxed limits, the limit and objective combination will need to be reviewed during the next plan change, to decide whether to aim for a more aspirational objective or to increase the limit to allow more use of the resource.*
>
> *To define the limit, regional councils will need to identify:*
> - *the current state of water quality*
> - *the quantity of water available and how it fluctuates seasonally and over time (as concentrations of contaminants will be influenced by the quantity of water present)*
> - *the attribute(s) and objective(s) that the setting of a limit is intended to manage*
> - *inputs and outputs (freshwater accounting). In the case of water quality, that includes identifying the sources of relevant contaminants (eg, sediment, nitrogen, phosphorus)*
> - *the limit for each relevant contaminant, taking into account any possible interactions between contaminants and possible lag effects*
> - *the timeframes over which the limit can be achieved, and targets that may be required to reach the limit (discussed further in the section on Policy A2)*
> - *the scale at which the limit is to be applied (eg, to the input into a lake itself, the streams feeding into the lake, or by managing nutrient inputs to the land in the catchment). Some limits may not be allocable at anything smaller than a catchment scale.*
>
> *In many cases limits for both water quantity (eg, environmental flows/levels) and water quality will be necessary to meet freshwater objectives.*

The Role of Regional Councils

A key philosophical approach of the original Resource Management Act was the devolution of much of the responsibility for water quality management to the regions. Local communities could decide on the level of water quality that was most appropriate for their region - although the Act did specify some irreducible quality minima. For example, Section 70 of the Act specifies:

SECTION 70 RULES ABOUT DISCHARGES

(1) Before a regional council includes in a regional plan a rule that allows as a permitted activity—

(a) a discharge of a contaminant or water into water; or
(b) a discharge of a contaminant onto or into land in circumstances which may result in that contaminant (or any other contaminant emanating as a result of natural processes from that contaminant) entering water,—
the regional council shall be satisfied that none of the following effects are likely to arise in the receiving waters, after reasonable mixing, as a result of the discharge of the contaminant (either by itself or in combination with the same, similar, or other contaminants):
(c) the production of conspicuous oil or grease films, scums or foams, or floatable or suspended materials:
(d) any conspicuous change in the colour or visual clarity:
(e) any emission of objectionable odour:
(f) the rendering of fresh water unsuitable for consumption by farm animals:
(g) any significant adverse effects on aquatic life.

As we read this section of the Resource Management Act we note that the effects listed in points (c) to (g) all seem to make good sense. We would not want any discharge into a river to have these undesirable effects. But while we would probably all agree with these requirements, we note that they are all written in general or "narrative" terms. They would be difficult to define in a court of law. It is up to Regional Councils to specify more quantitative criteria that will achieve the outcomes described in the Resource Management Act 1991 and in the NPS-FM 2014.

The Resource Management Act 1991 states that each Regional Council must produce a regional policy statement which sets out the objectives for managing all resources of the region in an integrated manner.

The formation of regional policy statements involves substantial public consultation and it is during this process that the community can debate the most appropriate standards that should apply to water quality within the freshwater management units in their region. Importantly however, future regional policy statements will also have to take account of the NPS-FM 2014.

Undesirable biological growths

When people comment on the role of agriculture in degrading water quality it is this production of "undesirable biological growths that they are usually referring to. It is therefore very important to understand what is meant by this term "undesirable biological growths" and what affects their growth.

In 1992 the Ministry for the Environment (1992) produced a booklet entitled "Water Quality Guidelines No.1 (Guidelines for the Control of Undesirable Biological Growths in Water)". This booklet provides detailed information on the problem of undesirable biological growths in New Zealand waters. An edited version of selected sections of this booklet is provided below.

"Undesirable" biological growths are those that have developed to the extent that they have nuisance or otherwise detrimental effects on desirable water uses (Table 1.2). There are two main categories of aquatic organisms which can proliferate in response to discharge of contaminants to the extent that they become undesirable. These respond to different types of contaminants in discharges.

Heterotrophic slimes, commonly referred to as "sewage fungus"' comprise organisms that require an external source of organic material as their source of carbon for growth. These respond primarily to dissolved organic material in discharges.

Phototrophic organisms (plants and some bacteria) obtain their carbon for growth by photosynthesis. These respond to nutrients in discharges.
In healthy ecosystems these organisms play vital roles in food webs and general ecosystem function. This needs to be borne in mind when considering control strategies. In certain situations, however, they can proliferate and interfere with desired water uses. This is most common in stressed ecosystems, particularly those that are enriched by discharge of organic material and/or nutrients.

Table 1.2 Summary of the ecological roles of organisms having the potential to cause nuisances.

Organisms	Main ecological roles
Heterotrophs	• Convert inputs of dissolved organic matter into food available to higher trophic levels (e.g. to invertebrates, birds and fish). • Recycle nutrients. • Purify water bodies by removing organic material and nutrients from the water column.
Phototrophs	• Primary production converts solar energy and nutrients to organic matter that provides food for higher trophic levels and produces oxygen. • Recycle nutrients. • Purify water bodies by removing nutrients from the water column. • Rooted plants stabilise sediments and promote settling of suspended solids hence maintaining water clarity, especially in shallow lakes. • Provide habitat diversity (especially macrophytes) for invertebrates, and fish

The main groups of heterotrophic and phototrophic organisms and their potential undesirable effects on water uses are summarised below.

HETEROTROPHS

Heterotrophic slimes (sewage fungus) are proliferations of bacterial and/or fungi that may form feathery, cotton-wool-like growths in streams and rivers that have high concentrations of dissolved organic compounds. The main organisms are filamentous bacteria (e.g. white growths of *Sphaerotilus natans* and pink growths of *Flavobacterium*), and fungi (e.g. white growth of *Leptomitus lacteus*). In New Zealand the filamentous bacteria *Sphaerotilus natans* is usually dominant (Cooper, 1983).

The main undesirable effects of sewage fungus on water uses are summarised in Table 1.3.

Table 1.3 Potential nuisance effects of sewage fungus.

Water uses	Nuisance effects
Water supply	• Blockage of intake screens, filters and irrigation pipes.
Aesthetic appeal	• Reduced clarity due to sloughed material. • Unnatural white, pink or grey growths on river bed. • Strandings on shoreline during flow recessions cause odour and unpleasant appearance.
Recreation	• Water based recreation degraded due to slimy bed and degraded aesthetics. • Sloughed material fouls fishers' boats lines and nets. • Dense mats restrict invertebrates preferred as food by game fish.
Ecosystem protection	• High respiration rates reduce dissolved oxygen, stressing or eliminating sensitive species. Anaerobic conditions may lead to a release of nutrients from sediments. • Dense mats covering the bed reduce intragravel flow and degrade habitat quality for benthic invertebrates and fish spawning. • *Sphaerotilus* growths accumulate heavy metals.

PHOTOTROPHS

Phototrophs include most plants and some bacteria.

Planktonic algae

These are microscopic plants, most of which drift freely in the currents. Nuisance effects (Table 1.4) can occur in standing waters such as lakes, impoundments and estuaries. They respond to nutrients in discharges. Some of the major types of planktonic algae and their effects on water quality are summarised below.

- **Green algae** can range from small individual round cells to large filamentous colonies (Figure 1.1), e.g. Waternet. These are not generally taste or colour producers except when large populations decay rapidly.
- **Diatoms** are usually brown or yellow in colour. Cells may exist singly, in filaments or in variously shaped colonies. Diatoms do not seriously affect the taste or smell of water, but can affect colour and clarity and cause water filtration problems when their biomass is high.

- **Cyanobacteria** (Blue-green algae) occur either as clumps or filaments and have a tendency to form surface blooms. Some (e.g. *Anabena*) are known to produce toxins under certain conditions, and are associated with a "musty" smell when abundant (Pridmore and Etheredge, 1987).
- **Flagellates** come in all shapes, sizes and colours and are capable of independent movement using flagella. In large numbers, flagellates can cause severe taste and odour problems (Sullivan, 1990) and high dinoflagellate densities in coastal waters cause "red tides" that can result in fish and shellfish poisoning.

Figure 1.1. An example of green algae in a stream in the Manawatu catchment. (Photo reprinted with the kind permission of Horizons Regional Council).

Table 1.4 Potential nuisance effects of excessive phytoplankton growth.

Water uses	Nuisance effects
Water supply	• Taste and odour problems. • Production of toxins (e.g. by blue-green algae). • Blockage of intake screens and filters. • Disruption of floculation and chlorination processes in water treatment plants.
Aesthetic appeal	• Reduced clarity and altered colour. • Surface scums (including "red tides") and floating mats.
Recreation	• Boating, swimming, water skiing and other water based recreation restricted or degraded.
Aquaculture	• Fish kills (via toxicity) e.g. salmon farming. • Shellfish contamination resulting in human poisoning.
Ecosystem protection	• Diurnal fluctuations in pH and dissolved oxygen that can stress or eliminate sensitive species. • Oxygen depletion in lake bottom waters through decay of organic material eliminates sensitive species and releases phosphorus from sediments. • Reduced light penetration may cause macrophyte decline.

BENTHIC ALGAE

Benthic algae grow on the bed and solid objects such as logs and rocks and are generally referred to as "periphyton" in streams (Figures 1.2 and 1.3), rivers and lakes and "macroalgae" in estuaries and coastal waters. They can cause a variety of nuisance effects in streams and rivers, and in the littoral areas of lakes, estuaries or the coast (Table 1.5). The main taxonomic groups are:

- Green algae (e.g. *Cladophora glomerata* ("blanket weed") in rivers and lakes, and *Ulva* ("sea lettuce") in coastal waters).
- Brown algae (e.g. *Carpophyllum* in coastal waters); diatoms (e.g. dark brown *Navicula* and fawn *Gomphonema* slimes in rivers).
- Red algae (e.g. *Audouinella hermanii* in rivers and *Gracillaria* in coastal waters).
- "Blue-green algae" (Cyanobacteria e.g. filamentous growths of *Phormidium* and *Oscillatoria).*

Green algae and diatoms are predominant in periphyton in New Zealand rivers (Biggs, 1990).

Figure 1.2. An example of periphyton in a stream in the Manawatu catchment. (Photo reprinted with the kind permission of Horizons Regional Council).

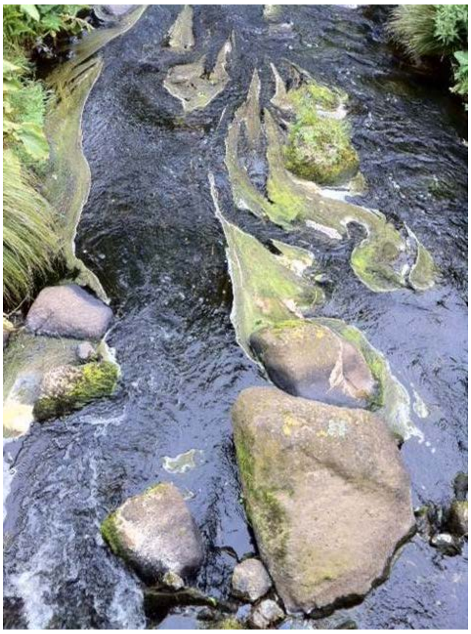

Figure 1.3. An example of periphyton in a Taranaki stream.

Table 1.5 Potential nuisance effects of excessive benthic algal (periphyton and macroalgae) growth.

Water uses	Nuisance effects
Water supply	• Blockage of intake screens.
Aesthetic appeal	• Floating mats. • Reduced clarity and altered colour due to sloughed material. • Strandings on estuary and lake shorelines following storms and river margins during flow recessions cause odour.
Recreation	• Swimming and other water based recreation restricted of degraded due to aesthetic degradation. • Slippery bed makes wading dangerous. • Sloughed material fouls fishers' lines and nets. • Dense algal mats restrict invertebrates preferred as food by sports fish.
Ecosystem protection	• Smother existing communities. • Diurnal fluctuations in pH and dissolved oxygen that can stress or eliminate sensitive species. • Dense mats covering the bed reduce water flow through the sediment and sediment chemistry, degrading the habitat for benthic invertebrates and fish spawning. • Reduced light penetration may cause macrophyte decline.

MACROPHYTES

These are rooted plants (Figure 1.4) that respond to nutrients in discharges. Introduced flowering plants (e.g. oxygen weed) are the main group causing the nuisance effects listed in Table 1.6.

Figure 1.4. Examples of macrophytes (rooted plants) in a stream in the Manawatu catchment. (Photo reprinted with the kind permission of Horizons Regional Council

Table 1.6 Potential nuisance effects of excessive macrophyte growth.

Water uses	Nuisance effects
Water supply and power generation	• Blockage of intake screens and filters
Land drainage	• Clog stream channels reducing drainage and increasing risk of flooding adjacent land by reducing conveyance and increasing sedimentation.
Aesthetic appeal	• Strandings on estuary and lake shorelines following storms cause odour and reduce access.
Recreation	• Boating, swimming, water skiing and other water based recreation restricted or degraded. • Sloughed material fouls fishers' lines and nets.
Ecosystem protection	• Diurnal fluctuations in pH and dissolved oxygen that can stress or eliminate sensitive species. • Exclusion of desirable native species such as low-growing Charophytes and tall-growing native pond weeds. • Physical barrier to fish migration when they choke stream channels.

Factors influencing growth

The biomass of bacteria, fungal and plant communities in a water body results from the balance of growth and loss processes. Many factors in addition to the discharge of contaminants influence the development of biological growths by either limiting growth rates or causing biomass loss. This is the reason that the type and severity of water quality degradation varies from region to region and an understanding of these factors is required to decide whether the discharge of contaminants is the cause of any undesirable growths and to develop effective control measures.

Growth of the bacteria and/or fungi that can form "sewage fungus" is primarily dependent on the supply of suitable dissolved organic compounds. Growth of plants requires inorganic carbon (carbon dioxide and bicarbonate) and the variety of trace elements which are usually available in adequate amounts. Light input or the supply of biologically available nitrogen (N) and/or biologically available phosphorus (P) often limit biomass production. Other physical factors, such as a lack of a suitable river bed, can also limit proliferation of biological growths to nuisance levels, despite suitable levels of nutrients. The "growth limiting factor" often changes with the season and the river flow. For example, in many streams nutrients probably limit periphyton biomass only under summer low flow conditions, with physical factors (light, temperature, scour by floods) limiting growth at other times.

Loss processes may involve grazing (i.e. consumption by invertebrates, fish and birds), flooding or wave-induced sloughing of attached growths, senescence, and (for phytoplankton) flushing and settling out.

FACTORS CONTROLLING HETEROTROPHIC GROWTHS

Organic compounds

The heterotrophic bacteria and fungi that are the main components of sewage fungus grow in response to readily degradable organic compounds. Sewage fungus organisms also require a range of nutrients, particularly N and P. However nutrient limitation of growth is not likely. This is because most of the minimally treated effluents that promote growth of sewage fungus contain adequate nutrients to augment the receiving water concentrations.

Stability of the riverbed substrate

Unstable sands and fine gravels generally restrict biomass development compared with larger stones, bedrock, large woody debris (fallen trees and logs), filamentous algae and macrophytes on which obvious growths can form.

Current velocity

The growth of sewage fungus benefits from some current velocity – presumably due to increased transport of dissolved organic materials to the organisms. Sewage fungus growths are however, quite fragile and are easily dislodged by increased drag associated with marked increases in current velocity.

Temperature

Sewage fungus can develop across the seasonal range of temperatures experienced in rivers throughout New Zealand. However microbial growth and metabolic rates do increase with increasing temperature. Hence, at higher temperatures the time for development of slimes declines, the downstream extent of growths below discharges decreases (due to higher rates of uptakes of organics from the water column), and effects on water quality increase (Gray, 1985).

FACTORS CONTROLLING PHYTOPLANKTON

Nutrients

The supply of biologically available forms of N and P often limits the growth of phytoplankton. It is very important to establish which of these two nutrients, (if indeed it is either of them), is limiting phytoplankton yield before instigating nutrient control programmes. Addition or removal (up to a point) of N alone to a P-limited lake will not affect phytoplankton growth, and vice versa.

Light

The main factor, other than nutrients, influencing phytoplankton in New Zealand lakes is light (Viner and White, 1987), and light may also limit growth in turbid estuaries.

Temperature

Temperature influences maximum rates of photosynthesis and growth and the species composition of the phytoplankton community. Generally however, the warmer the temperature the higher the growth rate.

Grazing

Phytoplankton growth can be reduced by grazing by a number of species – including filtering shellfish.

Flushing

In estuaries of short residence time (<2 weeks), phytoplankton may be removed from the system before the standing crop reaches the maximum level expected on the basis of the limiting nutrient.

FACTORS CONTROLLING PERIPHYTON AND MACROPHYTES

Nutrients

Periphyton

The key nutrients controlling periphyton growth are dissolved N (in the form of nitrate and ammonium) and dissolved P.

Macrophytes

Relating nutrients to macrophyte biomass is not so straightforward. Macrophytes are able to acquire their nutrients from both the water and the substrate sediment. High biomass can develop despite low nutrient concentrations in the water column if the sediments contain adequate nutrients.

Light

Sunlight is the source of energy for growth of benthic algae, phytoplankton and macrophytes. Hence, controlling the light input (e.g. by riparian planting in small-medium sized stream and rivers) provides a powerful tool for limiting rates of growth and metabolism of periphyton and macrophytes to prevent undesirable growths. However, once macrophytes reach the surface they are not often limited by light.

Temperature

As with phytoplankton, temperature influences the maximum rate of photosynthesis and growth and the species composition of the periphyton and macrophytes.
The increased metabolic rates of periphyton and macrophytes with temperature result in their effects on water quality (particularly pH and dissolved oxygen) increasing. In the case of dissolved oxygen, this effect is exacerbated by the naturally lower saturation concentration of dissolved oxygen in warmer water. Temperature is manageable to some extent in streams and rivers by riparian shade management.

Current velocity and sediment stability

Where growth is limited by nutrients, moderate current velocities can increase periphyton biomass by increasing the nutrient supply to the cell surfaces. However, as current increases further, this advantage becomes outweighed by the increase in loss processes due to current drag. Floods in rivers dislodge periphyton due to the increased frictional drag with increased current velocities, the abrasion of stone surfaces by suspended sand and course silts in the bed load, and movement of the dominant bed particles. In lakes and estuaries wave action during storms has a similar scouring action to that of floods in rivers.

Macrophytes grow best in rivers and lakes in areas of fine sediments. Thus submerged macrophytes generally occur where the net effects of sediment availability, gradient and exposure to waves and tide permit the accumulation of fine particles on the bed surface.

Grazing

Grazing by a number of organisms can reduce the quantity of periphyton and macrophyte biomass in waterways. In New Zealand rivers and lakes, invertebrates (primarily insect larvae and snails) are the main periphyton grazers (Winterbourn, 1987). Browsing and mechanical damage by freshwater crayfish is an important macrophyte control in those lakes in which they occur in New Zealand (Coffey and Clayton, 1988). Grass carp have been shown to be capable of eradicating nuisance plant growths in standing water bodies, although there has been some debate about risks associated with their introduction.

High nitrate concentrations in drinking water

For many years there has been concern about the possible impact of high concentrations of nitrate on human and animal health. High levels of nitrate in drinking water have been connected with the occurrence of a disorder called `*methaemoglobinaemia*' or `blue-baby syndrome' in young infants. It was thought that nitrate was reduced to nitrite in the stomach of the infants and the subsequent adsorption of nitrite into the blood stream caused a reduction in the oxygen carrying capacity of the blood and possibly death. In recent years the actual role of nitrate in this syndrome has been questioned, but still at this time, high concentrations of nitrate in drinking water are considered undesirable and the World Health Organisation has recommended 11.3 mg 1^{-1} NO_3-N (11.3 ppm) as the maximum safe level in drinking water.

Nutrients and Agriculture

From the preceding sections it is apparent that nutrients entering waterways can have a major impact on the quality of surface and ground waters. Agriculture has been identified as a major source of these nutrients.

When land is cleared of native forest and developed for agriculture, forestry and urban development, there is an increase in the quantities of nutrients and sediment entering rivers, streams and ground water via surface runoff and drainage. In other words, agricultural land use increases the transfer of N and P to waters compared to other forms of land use. Historic catchment studies by Cooper and Thomsen (1988) showed that 17 times more P and about 9 times more N was exported from grazed pasture catchments than pine forest catchments. The total P and N exports to surface freshwaters in several early studies (see Cooper and Thomsen, 1988, Wilcock, 1986; Cooke, 1980), indicate that agricultural runoff is likely to contribute between 47-81% of the total P and N entering New Zealand fresh waters annually. Although these studies were conducted 30 to 40 years ago, the recent OECD Environmental Performance Reviews: New Zealand 2017 (OECD, 2017) stated the following:

> *Achieving water quality improvements in many New Zealand catchments will likely require significant manipulation of existing land management, given the intensive nature of the country's agricultural sector and good regulation of point source pollution in most places. Water quality in some regions (Canterbury, Otago, Southland, Waikato, Taranaki, Manawatu-Wanganui and Hawke's Bay) has suffered from diffuse pollution associated with the steady expansion of intensive farming (most notably dairy farming) and urbanisation (PCE, 2015). The pollutants of most concern are nutrients, pathogens and sediments. In particular, nitrogen levels from diffuse agricultural sources have continued to increase; between 1998 and 2009, the nitrogen balance worsened more than in any other OECD member country (OECD, 2013). Over 1990-2012, nitrogen leaching into soil from agriculture increased by 29% and total nitrogen levels in rivers by 12% (MfE and Statistics NZ, 2015). Contamination of groundwater with nitrates and microbial pathogens is recognised as a human health risk. For example, New Zealand has relatively high rates of largely preventable enteric or gastro-intestinal disease in comparison to England, Australia and Canada (Ministry of Health, 2016).*
> *Deteriorating water quality remains one of the biggest threats to native freshwater species, alongside habitat loss and predation from introduced species. New Zealand has some of the highest levels of threatened freshwater species in the world, with almost three-quarters of native fish threatened with extinction. Macroinvertebrate Community Index scores are poorest in rivers located downstream of catchments where agricultural intensity and urban land cover are high (Larned et. al. 2016).*
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> *The full impacts of past and present agricultural land-use practices on water quality have yet to materialise; the time lag between improved land-use practices and improved water quality can be long (up to decades), particularly for groundwater resources. There are concerns, that even with best mitigation, recent elevated inputs from continued large-scale conversion of land to dairy farming, coupled with time lag effects, will result in more freshwater degradation.*

During this course we will look in more detail at why and how these nutrients move from agricultural land into New Zealand's waterways.

Test Your Knowledge

1. How would you define the concept of 'water quality'?
2. What initiatives are in place at central government level to address the issues of freshwater quality in New Zealand?
3. What are undesirable biological growths in the context of water quality? What sort of undesirable biological growths are important in your own local area?
4. Describe the effect of the major nutrients P and N and water temperature on the growth of undesirable biological growths?
5. Why are high concentrations of nitrate in ground waters a particular concern?

References

Biggs, B. J. R., 1990. Periphyton communities and their environments in New Zealand rivers. New Zealand Journal of Marine and Freshwater Research 24: 367-386.

Coffey, B. T. and Clayton, J. S., 1988. Contrasting deep-water macrophyte communities in two highly transparent New Zealand lakes and their possible association with freshwater crayfish, *Paraephrops* spp. New Zealand Journal of Marine and Freshwater Research 22: 225-230.

Cooke, J. G., 1980. The effect of land use on water quality in New Zealand pp. 40-60. In Land use in relation to water quantity and quality. Nelson Catchment Board and Regional Water Board, Nelson.

Cooper, A. B., 1983. Slimes in our streams. Soil and Water 19: 13-18.

Cooper, A.B. and Thomsen, C.E., 1988. Nitrogen and phosphorus in stream waters from adjacent pasture, pine and native forest catchments. New Zealand Journal of Marine and Freshwater Research 22: 279-291.

Gray, N. F., 1985. Heterotrophic slimes in flowing waters. Biological Review 60: 499-548.

Land and Water Forum, 2012. Third Report of the Land and Water Forum: Managing Water Quality and Allocating Water.

Larned, S. T., Snelder, T., Unwin, M. J., McBride, G. B., 2016. Water quality in New Zealand rivers: current state and trends. New Zealand Journal of Marine and Freshwater Research 50: 389-417.

MfE and Statistics NZ., 2015. New Zealand's Environmental Reporting Series: Environment Aotearoa 2015. Ministry for the Environment and Statistics New Zealand, Wellington.

Ministry of Health., 2016. Drinking water legislation. www.health.govt.nz/our-work/environmental-health/drinking-water/drinking-water-legislation. Accessed Dec 2017.

OECD., 2013. OECD Compendium of Agri-environmental Indicators. OECD Publishing, Paris.

OECD., 2017. OECD Environmental Performance Reviews: New Zealand 2017. OECD Publishing, Paris.

Parliamentary Commissioner for the Environment., 2015. Water Quality in New Zealand; Land Use and Nutrient Pollution, Update Report. Parliamentary Commissioner of the Environment, Wellington.

Pridmore, R. D. and Etheredge, M. K., 1987. Planktonic cyanobacteria in New Zealand inland waters: distribution and population dynamics. New Zealand Journal of Marine and Freshwater Research 21: 491-502.

Ministry for the Environment, 1992. Water Quality Guidelines No. 1 – Guidelines for the Control of Undesirable Biological Growths in Water.

Sullivan, C., 1990. Phytoplankton. In: The Murray, MacKay, N. and Eastburn, D. (eds), Murray Darling Commission, Canberra, Australia, p. 251-264.

Viner, A. B. and White, E., 1987. Phytoplankton growth. In: Inland Waters of New Zealand, Viner, A. B. (ed.). DSIR Bulletin 341 pp. 191-224. Department of Scientific and Industrial Research, Wellington.

Wilcock, R. J., 1986. Agricultural run-off: a source of water pollution in New Zealand. New Zealand Agricultural Science 20: 98-103.

Winterbourn, N. J. 1987. Invertebrate communities. In: Inland waters of New Zealand, Viner, A. B. (ed.). DSIR Bulletin 341 pp. 167-190. Department of Scientific and Industrial Research, Wellington.