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Environmental indicators for the sustainable management of fresh water.

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Signposts for sustainability

Environmental Indicators for the Sustainable Management of Freshwater

MINISTRY FOR THE ENVIRONMENT

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DEFINITION OF TERMS

Some terms are used differently in the literature resulting in confusion. The following definitions apply to this report:

Benchmark site is a reference site that is as pristine or as unimpacted as possible and allows environmental change to be measured against a desired or attainable state;

Ecosystem components are parts of the ecosystem grouped into convenient blocks;

Environmental indicators reflect measurable changes in some aspect of the environment;

Index is a computed function of indicators that integrates the data in some way;

Wetlands are non-tidal wet areas with emergent vegetation (pallustrine).

1 INTRODUCTION

The Ministry for the Environment is developing a core set of nationally standardised environmental indicators that will help to assess the state of the environment and help to monitor the effectiveness and suitability of regional and national environmental policy and legislation including the Resource Management Act (RMA) 1991 and the Government's Environment 2010 Strategy (MfE, 1995). Indicators will also help to monitor the effectiveness and suitability of regional policies and resource management methods. The purpose of this report is to suggest an approach to and some examples of indicators for the sustainable management of freshwater.

Indicators that are developed need to take account of the Purpose and Principles of the RMA under which regional councils operate. The goal is to develop a set of environmental indicators for sustainable management of freshwater (s5[1]) so that the needs of future generations are observed (s5[2][a]), life supporting capacity of water and ecosystems are safeguarded (s5[2][b]) and adverse effects are avoided, remedied or mitigated (s5[2][c]).

Sections 6 to 8 are also relevant to the development of freshwater indicators as they provide further clarification of Section 5 with respect to natural character, outstanding natural features, indigenous vegetation, habitats of indigenous fauna, access to water, the relationship of Maori to water, kaitiakitanga, amenity values, intrinsic values, quality of the environment and protection of the habitat of trout and salmon.

The E2010 goal for managing water resources (MfE, 1995) includes:

- *Maintaining sufficient water in water bodies to meet current and future needs;*
- *Ensuring surface freshwaters are of a quality suitable to meet community needs and that aquatic life is not significantly affected by discharges and abstractions;*
- *Restoring and preventing further degradation of groundwater quality and quantity;*
- *Preventing degradation of quality and flow of water resources that are identified as having national significance to New Zealanders for recreational, scenic, scientific or cultural reasons.*

Based on the RMA sections 5, 6 and 7, and on Environment 2010 section 6.2, the objectives to develop a draft set of national indicators for freshwater are to measure:

- Life supporting capacity (RMA s5[2][b]);
- Suitability for human uses and values (E2010, s6.2).

Indicators to measure suitability for human uses and values include indicators already measured by most regional councils such as microbiological organisms in water used for contact recreation. However, life supporting capacity is difficult to define and therefore hard to measure. The term "ecosystem health" is used as a surrogate in this report but even this term has problems of definition and anthropocentric overtones (see further discussion in Section 3).

In this report, the emphasis is on indicators of life supporting capacity/ecosystem health because the indicators of human uses and values are relatively well established. It is recognised that indicators of ecosystem health will overlap with other groups of indicators to be developed later as part of the Ministry for the Environment's indicator programme. These include indicators of indigenous habitat and biodiversity and indicators of pests, weeds and diseases. Since local authorities have a statutory obligation to monitor the state of the environment as a whole, the overlap between different groups of indicators provides an holistic approach to monitoring.

Indicators of ecosystem health that are very specific to a region, very rare or otherwise very interesting but do not apply nationally are developed under the biodiversity indicators programme, eg endangered plant and animal species.

The Ministry for the Environment has provided criteria for the selection of indicators (MfE, 1996) including the following:

Indicators need to be:
- Simple and robust
- Policy relevant with a clear purpose justifying their use
- Scientifically credible (methods chosen can influence accuracy and credibility of an indicator)
- Responsive to environmental change
- Repeatable
- Cost effective, using existing data and information wherever possible
- Easily understood

Freshwater ecosystems include rivers and streams, lakes and ponds, wetlands, geothermal water, and groundwater. Each system may require a different core set of indicators. Some type of framework is needed to distinguish the different types of lakes, rivers and wetlands so that indicators can be developed for specific types of freshwater ecosystems. For example, we need to measure different attributes in headwater streams and lowland rivers.

A Pressure-State-Response framework is proposed for the indicators programme (MfE, 1996) because it:

- Can reflect environmental issues of concern;
- Is widely used for national and international state of the environment reporting;
- Can incorporate sustainable resource management concerns identified in the RMA 1991, national and regional policy statements, national environmental standards, regional and district plans;
- Can incorporate resource management functions of local government under the RMA.

Indicators of Environmental Pressure can be thought of as forcing functions. They are actions or impacts that contribute, directly or indirectly, to environmental stress. Direct pressures are biophysical stresses while indirect pressures include human activities or natural events. *Indicators of Environmental State* or condition include the ambient condition of natural and physical resources and ecosystems. They are the focus of this report. *Indicators of Management Response* are the actions taken to address the observed or predicted environmental changes or adverse effects.

In order to monitor agency or societal Responses, clear statements of the intended outcomes of the policies implemented are required so that achievement of these can be measured objectively. National policies such as the RMA goal of preserving the natural character of water bodies and margins have provided a framework for agency performance monitoring (Parliamentary Commissioner for the Environment, 1996).

Management objectives of the agencies responsible for monitoring may vary with the site to be monitored and the region. Therefore the indicators selected for monitoring will be influenced by particular waterbody and the objectives for management.

2 OVERSEAS APPROACHES

Several countries are developing national indicators of freshwater and different approaches reflect the specific problems of that country. For example, Canadian national indicators focus on discharge of toxic chemicals to water while in the US national indicators focus on designated use of water. A very brief overview is provided here of the indicators developed in a few countries.

United States Environmental Protection Agency (USEPA) has developed a national set of indicators of water quality based on the Pressure, State, Response system (USEPA June 1996). They have 13 freshwater indicators with targets set for the year 2005. Ten indicators are State indicators, two are Pressure indicators and one is a Response indicator. The indicators are listed in Appendix I.

Canada has also developed a national set of State indicators for freshwater quality (Environment Canada, 1991) and indicators of ecosystem health are also being developed (see Appendix I). Managers use objectives for ecosystem management when selecting indicators to determine whether changes in structure and function are acceptable (Canadian Council of Ministers of the Environment, 1994). Ecosystem objectives therefore become critical elements to the indicator selection process. The Canadian Water Quality Guidelines Task Group suggests a participatory multi-stakeholder process to establish ecosystem goals and objectives which describe the desired state of ecosystem health in broad terms. Indicators are selected or developed that will measure the progress towards the attainment of each ecosystem objective. Any data gaps can then be targeted towards research and monitoring to meet decision makers' needs.

Australia is in the process of selecting national indicators. Australian water managers are having difficulty choosing indicators at the appropriate scale because Australia is a vast country with a wide variety of ecosystems and impacts occur at very different scales. For example, Lake Eyre in central Australia fills with water three times a century - a vastly different time scale to what we are used to in New Zealand.

Australian water managers recognise that they do not have an adequate set of water management tools to effectively manage water resources. They have set up a "Monitoring River Health Initiative" to develop further tools and some of these tools are likely to be used as National Environmental Indicators. One such tool is a RIVPACS (River Invertebrate Predication and Analysis Computer System), which is a British invention (see below).

The State of Queensland has developed a "state of the rivers" project (Anderson, 1993) which includes an assessment of habitat condition rather than surveys of flora or fauna or assessment of community structure or integrity. It also establishes a baseline or benchmark against which to assess change and a sampling strategy. A preliminary system of classifying catchments and sub-catchments has been developed.

Great Britain has developed RIVPACS (River Invertebrate Predication and Analysis Computer System) as a water management tool and a number of other countries, including Australia, have started to develop RIVPACS or are considering doing so. RIVPACS develops an expected score for the invertebrates at a particular site on a particular river and then compares the observed score with this expected score. The UK is also in the process of developing statutory water quality objectives and is developing protocols for assessing the ecological condition and amenity values of river corridors.

Since the mid 1980s the National Rivers Authority (NRA) has produced a colour coded map every five years showing chemical water quality across the country. This is effectively a national State of the Environment Report based on chemical water quality parameters. Water quality is divided into five classes and each class has a different colour on the map. The classification is generated using a statistical protocol.

In the early 1990s the NRA published the first biological map showing river health in the UK. The RIVPACS generated the data for this map. The NRA aims to produce a biological map every five years.

3 CONTEXT OF FRESHWATER MONITORING IN NEW ZEALAND

Fragmented statutory provisions in relation to water and concern over its administration and regulation led to the introduction of the Water and Soil Conservation Act in 1967. The Act was implemented at the national level through the National Water and Soil Conservation Authority (NWASCA). The Authority and three subsidiary councils were serviced by the Ministry of Works. When NWASCA was abolished in 1988, the functions and powers of the catchment boards and regional water boards were changed to include most of those previously under the Authority (Ward and Scarf, 1993). The Ministry of Works, in its resource management role, failed to integrate the management and operation of the Town and County Planning Act with the Water and Soil Conservation Act and the Rivers Control Act.

With the introduction of the RMA in 1991, the focus was on the integration and sustainable management of land, air and water resources. At the regional level, the requirement changed from planning for development to one of planning to avoid, remedy and mitigate adverse effects on the environment. The Act also requires local authorities to monitor the state of that part of the environment relevant to their policy functions or affected by their policy statements or plans or consents. The emphasis has therefore changed for local authorities from monitoring water quality to monitoring environmental quality, ie life supporting capacity or ecosystem health. In addition, there has been a policy shift from preserving the natural character of the margins of lakes and rivers (Town and Country Planning Act s3 and Reserves Act s3[c]) to include preserving the natural character of the water body as well so that a more integrated and useful approach to monitoring land use, riparian condition and water quality is possible. In addition, New Zealand has obligations under the international RAMSAR Convention on Wetlands (1971) to protect and monitor the (natural) ecological character of lakes, rivers, wetlands and estuaries.

Life supporting capacity is difficult to define and the term ecosystem health is used in this report for indicator development but this term is an equally anthropocentric surrogate. Changes in natural character may be easier to assess than changes in life supporting capacity, of which it is a part as set out in sections 5 and 6 of the RMA where s6 is seen as a further elaboration of s5. There is also much debate about the definition of natural character as discussed by Urlich and Ward (1996) but "preserving natural character" (s6[a]) is seen as protecting the existing degree of naturalness. Natural character has two primary dimensions, the objective natural ecological character (the ecological processes and structures defined by RAMSAR) and the subjective natural aesthetic character (landscape elements). Until recently, emphasis has been placed on the latter dimension. However, assessment of natural character can be very useful in developing national indicators for rivers, lakes and wetlands because it can provide a baseline against which to assess change.

Richmond (1996) has identified some key elements of ecological structure and processes for monitoring ecological natural character of waterbodies. These are grouped into eight "domains" with several structural and process elements for each. The domains are: geomorphic, hydrologic, energetic, physico/chemical, trophic, biotic, ecologic and extrinsic (anthropocentric). The geomorphic domain is usually unaffected by people while the hydrologic and energetic domains can be affected by human interference and the physico/chemical, trophic, biotic and ecologic domains form the basic ecosystem components from which indicators have been developed (see Figures 3.1, 4.1, 5.1 and 6.2).

Under the Water and Soil Conservation Act, only physical and chemical indicators were usable to monitor water quality. In the 1970s and 1980s, NWASCA's Water Quality Research Committee encouraged and funded the development of indicators including indices for macroinvertebrates and periphyton. At first, the use of indices failed because the techniques used had been developed for northern hemisphere species. Later, techniques applicable to New Zealand species were developed.

The changes in water management under the RMA require the use of new tools from those developed under NWASCA because of the different legislative requirements and different monitoring activities such as the need to monitor the state of the environment (s35) instead of discharges into water. For example, the macroinvertebrate community index (MCI) was originally developed to reflect changes in water quality. Now this tool is used as an index of changes in ecosystem health although it may never have been rigorously assessed for this purpose. Other tools need to be developed to measure change in ecosystem health and/or the natural character of aquatic ecosystems. This may not necessarily mean more monitoring if the indicators are chosen carefully. For example, it may not be necessary to monitor both aquatic macrophytes and periphyton. A broader emphasis on biological monitoring would reduce the emphasis on physico-chemical monitoring and, therefore, reduce the costs associated with this type of monitoring.

Freshwater indicators are already being employed in monitoring by many regional councils as part of their state of the environment reporting procedure (see Appendix II). Any additional monitoring carried out by councils may incur considerable costs and an effort will be made to build on the use of existing data and information wherever possible. This will be done by incorporating traditional indicators into the indices and hence will allow the use of historical data sets.

The end result of the freshwater indicators programme is to develop an index for a particular river, lake or wetland by integrating the values for the different State indicators that are appropriate to that site. These indicators will come from some of the ecosystem components such as physical and chemical parameters, indicators for biota, and an assessment of the riparian or margin condition as shown in Figure 3.1. Hydrology may affect these components and may need to be considered as a component in its own right in some systems. This method should provide an understanding of the overall life supporting capacity/ecosystem health/natural character for that particular system as well as an assessment of the water quality or riparian condition alone and therefore is in accord with sections 5 and 6 of the RMA. However, the development of indices is a very precise activity that will require care and a good understanding of the theoretical aspect of environmental indices as well as the purpose or intended use.

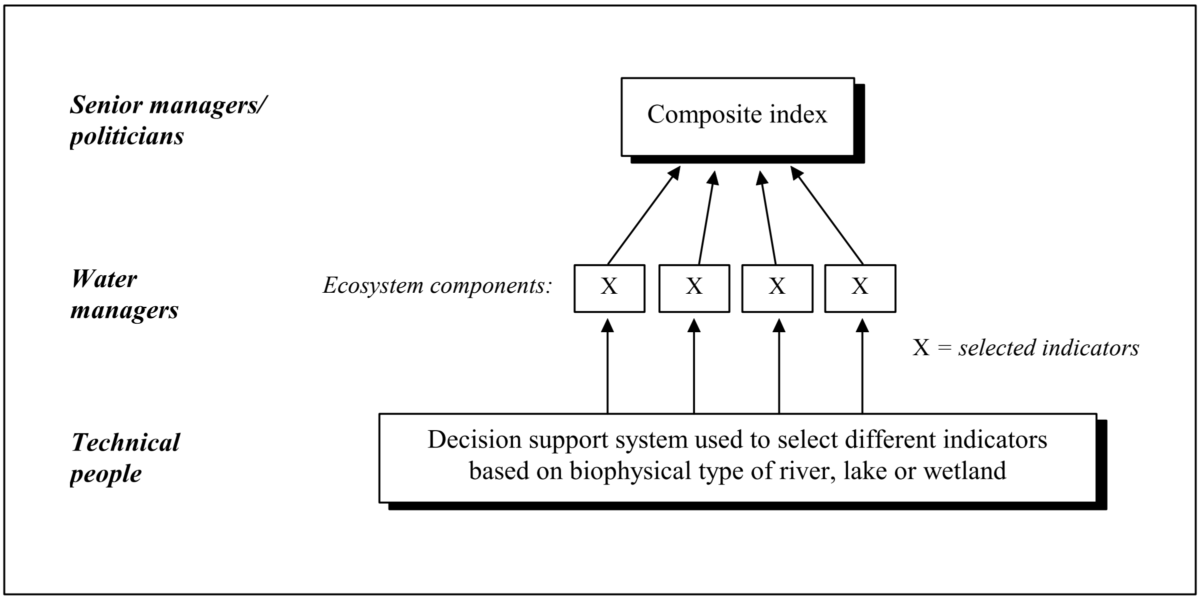

Figure 3.1: Diagram showing a suggested process for developing an index of ecosystem health of freshwater systems

A decision support system (DSS) will need to be developed to guide councils to measure the appropriate ecosystem components and relevant indicators. For example, it may be possible to measure 20 indicators in a wetland but the DSS will guide councils to the most appropriate three or four to measure. The development of a DSS will require a good understanding of the system under study. There is a strong spatial component to the DSS which will depend on the region of the country being considered. For example, streams in the Waikato are different from streams on the West Coast.

It is useful to have an overall index of the health of a waterbody that is relevant to politicians and senior management. The composite index will give an overall picture at the political and community level. Water policy managers will be most interested in the "indicator" level where indicators will give the condition or health of different components of the ecosystem. Technical people will be measuring at the level below this where the DSS is used to determine which components and indicators should be measured in any particular freshwater system. This works in practice because different levels in a regional council want different types of information. Politicians may simply want to know that the life supporting capacity of a river is good. Managers need to know that while the water quality may be satisfactory, the riparian zone needs more management.

In order to measure trends and where a system is relative to a standard or desired state, there is a need for benchmark sites against which change can be measured (Figure 3.2). Benchmark sites need to be as unimpacted or as pristine as possible so change can be assessed relative to a baseline or desired state. In well developed catchments, sites with the best management practices in the catchment may need to be selected as the benchmark. Benchmark sites will be needed on each type of river, lake or wetland.

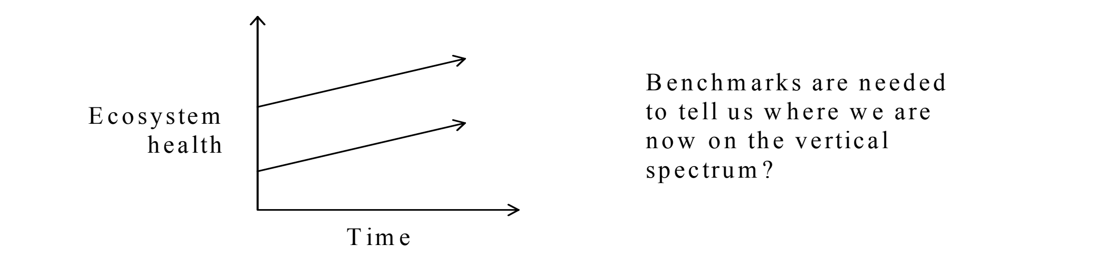

Figure 3.2: Change in ecosystem health with time

Philosophy of approach to freshwater indicators:
- observed/expected values for indicators will be used
- integrated indices of indicators or parameters will be used where helpful
- benchmark sites will be used

Under the Pressure-State-Response framework, it is easier to develop State indicators for water than Pressure indicators because pressures such as land use changes, weed invasions or fire are generally more difficult to measure. At the larger scale, the area of land and the type of land use involved are generally a reflection of the amount of the pressure on the system, and this could be aggregated up to the national level. However, at the smaller scale, the amount of the pressure such severe impacts at the reach level of a river due to a variety of possible causes are not so easy to aggregate up to give a national picture.

Freshwater indicators of ecosystem health/natural character for rivers, lakes, wetlands, groundwater are discussed in Sections 4 to 7. Indicators of suitability for human uses and values are discussed in Section 8.

4 INDICATORS OF ECOSYSTEM HEALTH/ NATURAL CHARACTER FOR RIVERS

4.1 Background

River ecosystems can be divided into various components:

- Physical/chemical parameters including water clarity
- Periphyton
- Aquatic macrophytes
- Macroinvertebrates
- Fish and birds
- Riparian zone
- Instream habitat including substrate

These components are useful for indicators of river ecosystem health/or and natural character because they provide a basis from which to the indicators can be developed.

A core set of ecosystem components has been selected by the Australian State of Victoria where an "Index of Stream Condition" is being developed as a tool to aid water management (Department of Conservation and Natural Resources, 1995). The tool is to be used as a benchmark of stream condition, throughout the State, to judge the long term effectiveness of management, and to aid objective setting. The elements of a stream are aggregated to give an overall index of condition. The particular elements chosen by the State of Victoria are:

- Hydrology (change in volume and seasonality of flow)
- Physical form (bank stability, bed erosion/aggredation, barriers, debris)
- Riparian vegetation (species, extent, width, intactness, regeneration, conditions of wetlands and billabongs)
- Water quality (phosphorus, turbidity, conductivity, pH)
- Aquatic life (number and type of macroinvertebrates)

We intend to develop a similar approach in New Zealand because it allows comparison between different components of an ecosystem. For example, there may be excellent water quality in a concrete lined channel but the life supporting capacity is low because the channel can't sustain life. An index provides an easy to understand total picture of the health of a river system which may be useful for decision makers and the general reader. However, the use of an index may suggest that the picture is far more simple than in fact it really is and may not always be useful for management where the root of the problem needs to be explicit. So the health of the individual ecosystem components that are used to create the index are very important for management. The index could be developed in a number of ways. For example, it could be a simple display based on robust methodology underlain by good science.

There are different types of rivers in New Zealand based on the source of flow and the country through which the river travels, including geological history, soils and climate. The indicators of ecosystem health⁄natural character of a particular river will therefore vary so some form of river typing is needed as a framework for the indicators. This would have significant advantages for water managers because they could choose the data they want to collect and reduce the costs of collecting less important data. Some attempts have been made at river typing for New Zealand but they need further adaptation to be useful for monitoring environmental indicators. Different broad categories will be relevant in different ecoregions.

For example, Collier (1995) has suggested one river typing system based on the geomorphic origin of the river, assuming the source of flow is the key determinant of the biota. Rivers are grouped into seven types:

- Glacial fed inland mountain origin
- Non-glacial fed inland mountain
- Spring or lake fed origin
- Inland hill country origin
- Inland plateau origin
- Lowland origin
- Coastal high country origin

Each of these can be divided into the main stem and headwaters, into different channel types and into different reaches. Rivers and streams can be permanently flowing or temporary/ephemeral.

The position on the river continuum will determine the indicators to be selected since indicators that are applicable for the upper catchment of a river may be inappropriate near the river mouth. For example, in the upper catchment macroinvertebrates may be the most appropriate ecosystem indicator to monitor, while in the lower reaches of a heavily silted river, water clarity may be the most appropriate indicator. In addition, because different types of rivers exist, the relative importance of ecosystem components and indicators will vary from river to river.

Therefore the expected values of the indicators to be measured for each ecosystem component (Figure 3.1) would depend on the river type and position on the river continuum. For each indicator there will be an expected value for that river type so councils know what value to expect.

Much of the research on rivers in New Zealand has concentrated on upland rivers while the problems with urban and agricultural development lie in the lowland rivers or reaches where lack of water clarity and riparian cover have severe implications for some biota such as the migration of native fish. The 100 rivers programme, for example, monitored most rivers from catchments with tussock grassland, native forest and developed pasture land use (Biggs *et al*, 1990). The hydrological recorder sites were mostly located in the middle or upper parts of catchments above 350 m mean catchment elevation (range from 111-1288 m elevation), so reaches affected by lowland point-source pollution are under-represented. The objectives of the programme were to “characterise the catchments, flow regime, water chemistry, optical properties, periphyton, benthic invertebrates, and trout of sites in a large sample of New Zealand rivers; characterise this sample of rivers according to the above characteristics; develop models relating the various river characteristics to environmental factors”. This study has laid the foundation for scientific understanding but in future more attention needs to be given to lowland, more impacted rivers and streams.

4.2 State Indicators for Rivers

A process for aggregating the data to give an index of the state of New Zealand rivers is suggested as shown in Figure 4.1 where the indicators are grouped into seven ecosystem components in the boxes. The importance of the ecosystem components is discussed in Section 4.2.1. In any one river type not all the components in Figure 4.1 need to be measured. Also within each component, only some of the indicators will need to be measured. A decision support system will determine which are the important ecosystem components and indicators to measure in certain types of rivers. This process can therefore used as a management tool to determine indicator requirements and develop scores.

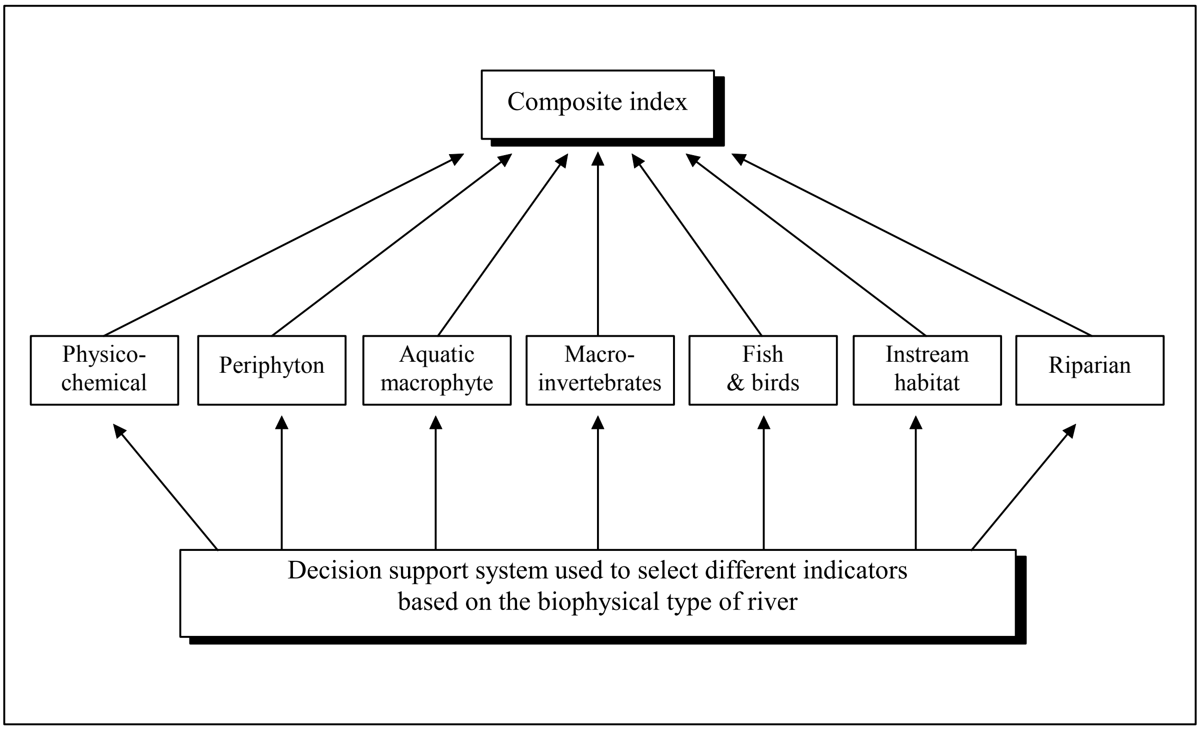

Figure 4.1: Diagram showing a suggested process for developing state environmental indicators for rivers

Rivers need to be divided into similar reaches which can usually be defined by the inflow of major tributaries, change in character due to geological changes, inflow of major discharges, etc. A sampling site towards the lower end of the reach would be assumed to represent the conditions in that reach and give information about it. Some reaches will be quite long while others will be very short.

The reaches need to be put onto a GIS system so that a spatial framework is provided for water managers and data can be collected at a single sampling site and given meaning in a spatial context for that particular reach. Data from separate reaches could be mapped and colour coded to show how the index varied spatially along the length of the river. A decision support system (DSS) would guide the councils to measure the appropriate indicators in a particular river type. Regional councils will need to define reaches on all main stem rivers with representative minor rivers to be decided by DSS.

Benchmark sites will need to be identified to give an expected value of the health of the river or reach, based on a pristine site or the best available land management practice. An integrated index of observed/expected would give an indication of the biological health of the river/reach. The range could be from pristine through to very poor (A to E).

Trends could be presented such as the % river length in each state of health in each ecoregion (Figure 4.2). To provide a national picture, deviations of observed/expected values from each region could be summed.

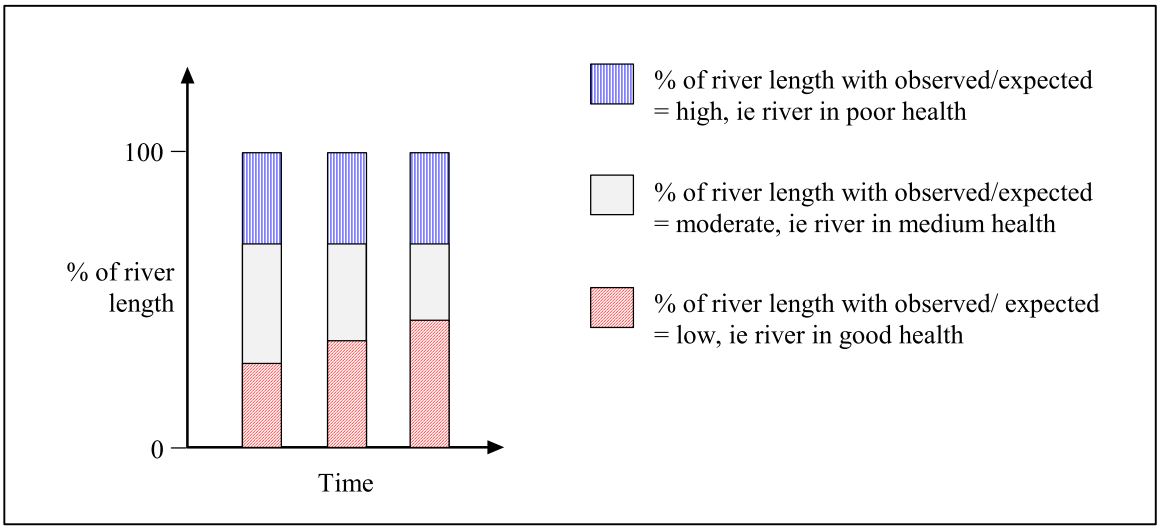

Figure 4.2: Graph showing change over time in observed/expected values for ecosystem health of rivers or reaches monitored in a region

4.2.1 Ecosystem components

The components in the boxes in figure 4.1 contain the indicators. Only some components will need to be used in any one situation and only some indicators within a component will need to be measured.

Primary core indicators would be those measured in the first instance; second tier indicators may need to be measured for more detailed understanding of the situation. Not all primary core indicators will need to be measured at each site.

- ***Physical and chemical parameters --*** These are monitored by most regional councils. These include parameters such as pH, temperature, conductivity, clarity/turbidity, dissolved oxygen, biochemical oxygen demand and nutrients. Data handling protocols need to be developed so that the results can be interpreted and related to standards and guidelines or to data gathered from benchmark sites.

However, for the ecosystem health of a river it may not be necessary to measure all these parameters that provided rather coarse information in the 1970s. Now we have other information and more precise tools to reflect ecosystem health. For example, it may be less important to measure nitrogen, phosphorus and biochemical oxygen demand than some biological aspects of the water that reflect these qualities such as macroinvertebrates and fish.

All parameters need protocols for statistical analysis. The use of 90 or 95 percentiles may be appropriate for the data, but this would only need to be done about every five years for each river.

Examples of primary core indicators:

pH or hydrogen ion activity of the water indicates the degree of acidity or alkalinity of the water. Biological processes are influenced by pH and can themselves affect pH. Therefore some processes are inhibited when the water becomes too acidic or alkaline and therefore the natural character/health of the aquatic ecosystem is affected. In acid streams, pH needs to be measured to put other indicators in context. In streams with periphyton, pH needs to be measured because high pH will affect the health of other organisms.

An indicator of pH could be the amount of time the pH varies from the expected value for that river.

Water clarity is a particularly good indicator for rivers because high levels of suspended solids in water can be detrimental to the health of the ecosystem, reducing light levels, smothering plants and animals, clogging the gills of fish and invertebrates. Fish that feed by sight are also affected. Most organisms can only tolerate high levels of suspended solids for short periods but it is important to measure clarity when the catchment characteristics produce high sediment loads eg mudstone streams. Water clarity is measured using a black disc and a viewing box.

An indicator of water clarity might be the per cent of time that the sample exceeds a certain clarity value expected for that river.

pH indicator	- Amount of time the pH varies from the expected value for that river
Reason for measuring	- Particularly relevant where acid soils are exposed to the atmosphere by mining or urban development, and where high nutrients levels cause excessive plant growth.
Status	- Further work required to develop protocols of when to monitor and statistical analysis
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Water clarity indicator	- Per cent of time that the sample exceeds a certain clarity value expected for that river
Reason for measuring	- Particularly relevant where high levels of suspended solids reduce clarity for more than a short period
Status	- Need protocols of when to monitor and statistical analysis

- ***Periphyton*** (predominantly attached algae) **--** This is another important indicator of the health of rivers. They are the most successful primary producers to exploit rivers as habitat and are a very important component of aquatic ecosystems in New Zealand. They form the basis of the foodchain and purify stream waters, but can proliferate during low flows in enriched rivers to cause aesthetic and habitat degradation. Periphyton is sensitive to contamination and responds more quickly to changes in the environment than the more "standard" indicator of macroinvertebrates. The nature of the response also provides guidance on the type of contamination.

Periphyton growth can be a major problem in New Zealand gravel streams. It will not be necessary to measure periphyton in every stream or river but only those where there is likely to be a problem such as gravel streams draining pasture. The DSS will aid the decision whether to monitor a particular stream.

New Zealand is a world leader in periphyton research and NIWA have an extensive research programme almost ready to be used for an indicator. Assessment protocols for periphyton cover are currently being developed by NIWA as part of an on-farm stream health monitoring and assessment kit. These should be available in early 1997 and will be assessed for their applicability to indicators for rivers in consultation with water managers. The scoring programme will be very useful for the indicator programme as a whole.

Periphyton indicators will probably be very simple and based on a visual estimate following a period of low flow. In certain river types periphyton may be easier and cheaper to monitor than benthic invertebrates, yet provide equally robust data for significantly less effort. The DSS will help councils decide when to measure periphyton.

Further research on periphyton is required to define the level of biomass/cover at which periphyton growths become a problem. This relates to aesthetics, water quality degradation and displacement of higher trophic levels, ie effects on the life-supporting capacity of aquatic ecosystems.

Periphyton indicators	- Presence/absence/% cover of heterotrophic slimes (sewage fungus) - Presence/absence/% cover of benthic algae (blanket weed, dark brown slimes, green filamentous growths in rivers)
Reason for measuring	- Cause habitat degradation in nutrient enriched waters
Status	- Need protocol on when periphyton assessment becomes necessary, ie when it becomes a problem to ecosystem health.
Research needs	- Ongoing research to underpin the protocol

- ***Aquatic macrophytes --*** These form an important component of aquatic ecosystems, providing habitat for other organisms in terms of food and shelter, aiding sediment and bank stability, and participating in nutrient re-cycling. They can be submerged, emergent or floating. Emergent plants in particular assist bank and margin stability and provide important habitat for birds (see riparian).

  Macrophytes are very obvious ecosystem components in some rivers and almost non-existent in others. The DSS will be used to guide councils on whether it is important to measure macrophytes in a particular river reach. The abundance of macrophytes may also determine which other parameters, such as dissolved oxygen, need to be measured. This type of information could be incorporated into a DSS and could be used until a good indicator of macrophytes is developed. A good assessment protocol for macrophytes is also needed.

  Invasion of freshwater systems by introduced macrophyte species can cause smothering of native communities and therefore affect the health and natural character of the whole ecosystem. Luxuriant growths of some species block drains and affect the flow of water in streams and rivers. They have the potential to block hydro-electric power intakes but relatively few species interfere with power generation. Excessive macrophyte growths can increase water levels which flood riffles that are the preferred habitats of young brown trout and some galaxiids.

  Research in Europe has shown that some macrophyte species are associated with organic enrichment. Other species cannot tolerate the algae that grow on them and subsequently die. The trophic status of water bodies has been classified according to the macrophyte species growing in rivers and streams. Further work is needed in New Zealand in this area.

Aquatic macrophytes indicators	
	- Floating plants: % cover; % cover of introduced/native sp. - Submerged plants: % cover; species, height/biomass with water depth; % cover introduced sp. - Emergent plants: % cover, biodiversity, % cover introduced/native sp.
Reason for measuring	- To assess the observed species/biomass/cover in relation to the expected in a particular river so that potential problems can be anticipated
Status	- Need protocol on when to assess macrophytes
Research needs	- % cover/species presence etc that constitutes a problem in that river type

- ***Aquatic macroinvertebrates --*** These animals are good indicators of ecosystem health in most rivers because some species can be associated with high, moderate or low water quality.

There are a variety of methods for the analysis and presentation of monitoring data on macro-invertebrates (Stark, 1985). Communities of benthic macroinvertebrates are thought to provide a more reliable assessment of water pollution than the presence or absence of specific taxa. The macroinvertebrate community index (MCI) was developed specifically for New Zealand for nutrient enriched water in Taranaki and has been applied across the country. Although to our knowledge, there has been no rigorous assessment as to whether MCI is applicable to other rivers and other problems.

Calculating the MCI involves the allocation of scores to taxa with pollution tolerant taxa receiving the lowest scores and pollution sensitive taxa receiving the highest scores (Stark, 1985). The scores are summed for each taxon at a site to give a site score, divided by the number of taxa and multiplied by a scaling factor of 20 to give the index for that site. The index varies from 20-200 where sites scoring 120 or over are considered clean and unpolluted. Sites with values less than 100 are considered moderate to grossly polluted. However, low MCI values may be natural at some sites in certain river types/ecoregions and not reflect low ecosystem health.

Variants of the MCI, such as Quantitative MCI (QMCI) and Semi-quantitative MCI (SQMCI), may be required for different purposes, such as investigating the effects of sedimentation or toxic discharges, and these need further investigation. A critical look needs to be given to developing a River Invertebrate Prediction and Analysis Computer System (RIVPACS) for New Zealand**.** It may be sensible to ensure that a national macro-invertebrate database (if one was set up) could be used to develop a RIVPACS.

Methods of assessing macroinvertebrates using techniques such as MCI require resources for collection and identification of taxa and preferably with nationally consistent sampling techniques. Sampling experience is also an important factor as found in Northern Ireland recently with the introduction of kick sampling which lead to an apparent gradual improvement of water quality over time as the sampling team became more experienced. There was no actual improvement of water quality.

A national macroinvertebrate database would be a very useful asset for water managers. The database would form the basis for developing more effective macroinvertebrate assessment protocols, for example, those that relate to particular ecoregions.

A national database of macroinvertebrates is an essential tool for managing biodiversity (see Biodiversity Indicators).

Currently there is a range of techniques available for sampling macroinvertebrates. For national consistency it is necessary to have a protocol setting out which technique should be used and where it is appropriate. It is currently difficult to establish significant differences between sites using macroinvertebrates as a tool in relation to discharges unless the discharge is having a gross effect.

Macroinvertebrate indicator	
	- Invertebrate community index scores observed/expected for that river type exceeds 0.75
Reason for measuring	- Good indicator of ecosystem health
Status	- Need protocol of which technique to use and where appropriate
Research needs	- National macroinvertebrate database - Assess the need for a RIVPACS - Standardised sampling techniques - Standardised scoring system

- ***Fish --*** These may be important indicators of river ecosystem health because they are at the top of the food chain and reflect the state of the lower levels such as food availability. In addition to food supply, their presence indicates that the instream habitat and cover are suitable for survival of the species. In lowland areas, sediment loads and urban and agricultural development may strongly influence fish populations. In these areas, fish could be used as habitat/water quality indicators, but more work needs to be done. Data on fish populations including trout, salmon and some native species, are collected by Fish and Game Councils and may be appropriate to use for the development of indicators of ecosystem health (see Section 8.3 for details). Productivity and biomass of trout could be useful indicators of ecosystem health, but more research is needed.

Native fish may be useful as indicators of ecosystem health because they integrate many qualities of the instream habitat and riparian zone. About half the species of these fish are diadromous, with an obligatory migration to the sea. They are therefore sensitive to barriers blocking access to and from the sea and to habitat quality and are good indicators for these. Barriers to movement and habitat quality become pressure indicators. Within diadromous fish, different species have differing abilities to migrate and the drive to do so. This means that, although there are often consistent and predicable groups of species in particular types of habitat, there are also downstream/upstream gradients in species richness and abundance, with various species dropping out of communities with increasing distance from the sea, elevation and stream gradient (McDowall, 1996). In non-migratory species, relative abundance and growth rates may be useful indicators of habitat quality in addition to instream habitat and riparian vegetation.

In the early stages of this project we realised that we had little information on whether we could develop useful indicators around native fish. In a joint project for Ministry for the Environment and Department of Conservation, NIWA has been contracted to prepare a report on the use of the native fish as indicators of ecosystem health. This report (McDowall, 1996) discusses the following indicators of environmental health:

- *Upstream dispersion as an indicator for diadromous species.* Trajectories of occurrence with increasing inland penetration are shown for several native fish species. These show a general, but variable, decline in frequency of occurrence of nearly all diadromous species with increasing elevation and distance inland. *".... comparisons made within a common time interval, between designated areas, will provide some measure of geographical variability in habitat suitability/quality across the country, while comparisons within a geographical area, across time, will provide a measure of temporal variation in habitat suitability/quality, and enable an assessment of change ...."* (McDowall, 1996).
- *Presence/absence and habitat suitability.* Semi-quantitative assessments of the characteristic habitats of species, based on some experienced observers and the New Zealand Freshwater Fish Database, would provide catchment managers with some ability to determine what species would be expected to be present in a particular waterbody, including elevations and distance from the sea.
- *Access* or the freedom of fish to migrate up and downstream is a key indicator of ecosystem health but needs to be interpreted with care because of the high variation in migratory ability among species and between different life stages. Absence from a site could be due to a variety of causes including presence of barriers, unsuitable habitats or perturbations due to changes in land use.
- *Species diversity.* High diversity of migratory species at a site is a potential measure of ecosystem health. However, an analysis of species diversity must involve an understanding of the gradient imposed by rivers (distance from sea, elevation, slope) on migratory species.
- *Species demography: age structure and recruitment process.* The presence of the complete age structure of a population with no obvious recruitment failures in any year class could be used as an indicator of ecosystem or habitat health. This would require an understanding of the species demography so that an expected age/size frequency relationship could be used for comparison with the observed situation. It would also be necessary to know whether the various age classes are expected to be present together in a particular waterbody. Also, sex ratios may not be equal and in some species sex changes with location.
- *Instream habitat.* It is probable that species will differ in their responses to water quality parameters, substrate coarseness, flow velocity, etc. Some species are more tolerant to a range of natural habitat variation than others.

This discussion suggests that while native fish seem to reflect habitat quality, there is a need for considerable understanding of the individual species for them to be used as indicators of ecosystem health. Using the NIWA New Zealand Freshwater Fish Database (NZFFD), McDowall (1996) has generated trajectories or curves of occurrence of each native fish species based on altitude and distance inland. The slope of the trajectories depend on the ability of each species to migrate upstream and its instinctive drive to migrate. There are therefore gradients in community/species richness and probably abundance. A high quality habitat that is low elevation or close to the sea will generally have a higher species richness and number of individuals of each species than a similar habitat at higher elevation or further inland.

For example, Figures 4.3 and 4.4 show the percentage occurrence of giant kokopu and shortjawed kokopu at high quality sites on the South Island West Coast rivers and streams, compared with other river and stream sites in New Zealand where habitat, particularly at low elevations, is of much lower quality.

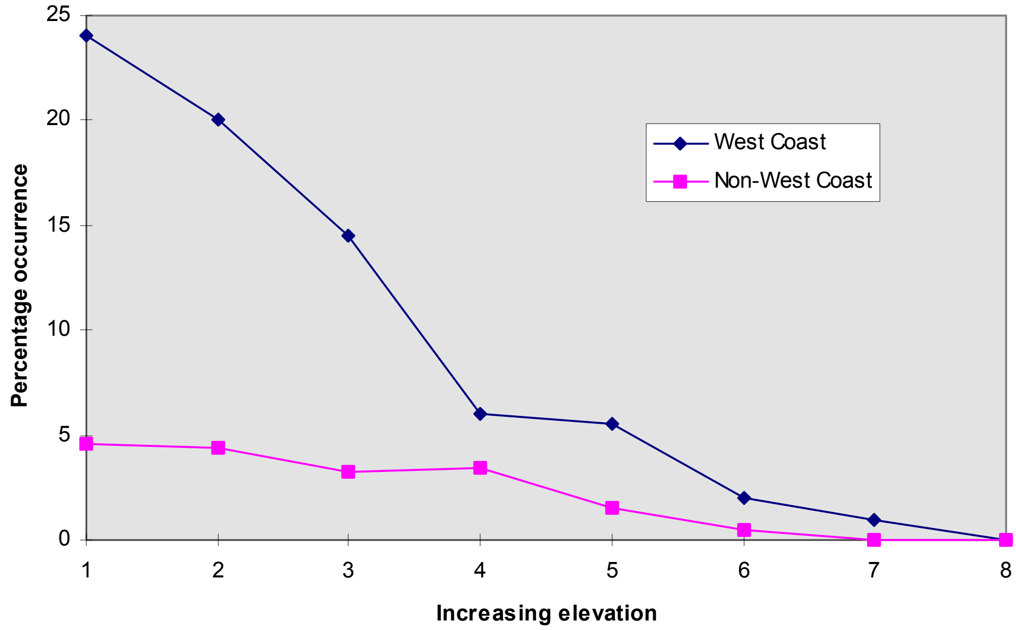

Figure 4.3: Percentage occurrence of giant kokopu with increasing elevation at West Coast and non-West Coast sites (data provided to MfE by McDowall, NIWA; data source from Freshwater Fish Data Base)

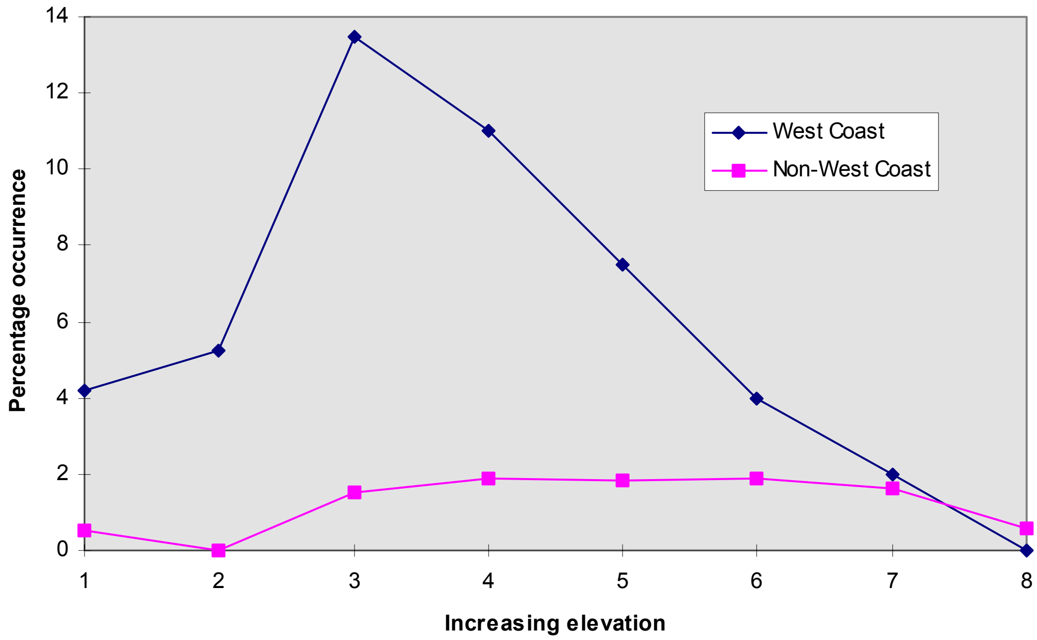

Figure 4.4: Percentage occurrence of shortjawed kokopu with increasing elevation at West Coast and non-West Coast sites (data provided to MfE by McDowall, NIWA; data source from Freshwater Fish Data Base)

McDowall (1996) states that the trajectories can be used as standards for each species against which future data can be compared. A change in trajectory indicates an increase or decrease in the frequency of occurrence of a species which can be interpreted as a decline or improvement in the quality of the habitat. Trajectories can also be used to compare time series of past data with the present. Regional trajectories can be calculated for assessment of habitat quality at the regional level but they cannot be used for comparison of habitat conditions because at the catchment level species' distributions are catchment specific.

McDowall has selected species that may be suitable as indicators of environmental health based on:

- whether a species is sufficiently widespread in the country to be relevant;
- whether it is abundant enough to provide a relevant standard of relative abundance;
- whether enough is known about habitats and behaviour to allow consistent decisions to be made on it status;
- whether the species is sufficiently sensitive to environmental change to provide useful information on habitat quality.

Table 4.1 shows the habitat and distribution characteristics of four native fish species that could be used as indicators.

Table 4.1: Habitat/distribution characteristics of species with potential as national environmental indicators (Source: after McDowall, 1990 and 1996)

Giant kokopu (*Galaxias argenteus*)	The largest species of the galaxiid family growing to at least 580 mm in length and 2.7 kg in weight. Mostly low elevation in overgrown streams, lagoons and lakes; now lost from many areas of the country; possibly sensitive to presence of brown trout; a weak climber.
Banded kokopu (*Galaxias fasciatus*)	Grows to about 260 mm long and frequently to about 200 mm. Low to middle elevations, most often in very small steams and sometimes in associated backwaters/pools; needs overhanging vegetation and sensitive to forest loss; a very vigorous climber that climbs high falls.
Koaro (*Galaxias brevipinnis*)	A slender fish that grows to 271 mm and is commonly 160 to 180 mm. Widely present from low to higher elevations in moderate-sized, swiftly flowing, bouldery streams; mostly in forested streams and sensitive to loss, though this does not apply always to lake tributaries; many lake-limited populations in submontane lakes; a very vigorous climber that climbs high falls.
Redfinned bully (*Gobiomorphus huttoni*)	A stout fish; the length of the largest recorded male is 122 mm. Widely present at low to middle elevations in rocky/bouldery small streams to larger rivers; a moderate climber.

These indicator species tend to occupy more lowland than high elevation habitats but we need to have more lowland species for indicators of ecosystem health because that is where the pressures from humans occur. Upland species do not receive the same amount of human impact.

These are presence/absence indicators rather than abundance indicators and they could not have been developed without the NZ Freshwater Fish Database. Without this database, it would be impossible to use native fish as indicators of ecosystem health.

Fish indicators	- Presence/absence of native species that are widespread, abundant and sensitive to environmental change : giant kokopu : banded kokopu : koaro : redfinned bully
Reason for measuring	- Useful indicators of ecosystem health of instream habitat and riparian vegetation
Status	- Ready to use
Research needs	- More research required to define the relationship between pressure and state indicators

- ***Birds --*** These may be key indicators in certain areas because they are at the top of the food chain. For example, there used to be many black shags on the Wanganui River; now there are very few. There has been no research to suggest the reason for the decline. More work needs to be done on birds.

Birds indicator	- Presence/absence of expected bird species
Reason for measuring	- Top of the food chain; reflect natural character and health of the habitat
Status	- Not ready to use
Research needs	- More work required

- ***Instream habitat --*** Characterisation of the habitat is needed to assess the ecosystem health of a river. The quality of the instream habitat, riparian habitat and physical and chemical parameters of the water itself allow for a consistent assessment of the quality of the habitat as a whole. These components have been used as part of the USEPA Rapid Bioassessment Protocol (1989) and are also being used in New Zealand.

The first three components are considered “primary” by the USEPA in that they characterise the “microscale” habitat and have direct influence on the structure of the animal and plant communities. The three secondary components measure the “macroscale” of the habitat. Instream habitat indicators of the USEPA protocol include:

- *Bottom substrate and available cover* to provide habitat for aquatic animals and plants. Gravel bottom rivers and streams are considered to be good habitat but submerged logs, tree roots and undercut banks also provide good habitat. Bottom substrate is visually assessed.
- *Embeddedness* is the degree to which boulders and gravel are surrounded by fine sediment that provides habitat for benthic invertebrates and fish. This parameter is assessed visually.

– *Velocity and/or flow* of a stream or river relates to the ability to provide and maintain a stable aquatic environment. Stream flow is the critical parameter to monitor when low flows are an issue; in larger streams and rivers velocity in relation to depth has a more direct influence on the structure of aquatic communities than flow.

The next three indicators are concerned with channel morphology:

– *Channel alteration* is an indication of watershed disturbance and can be assessed by the *appearance and growth of sediment bars and sediment deposition inside bends, below channel* constrictions, and with a reduction in gradient. Channelisation increases river velocity and the potential for scouring.

– *Bottom scouring and deposition* destroy aquatic habitats due to watershed disturbance including channelisation. This parameter is assessed by the percentage of a reach that is scoured or silted.

– *Pool/riffle or run/bend ratios* are assessed on the assumption that a stream or reach with pools and riffles provide more diverse habitat than a straight or uniform depth stream.. Bends provide additional habitat by the cutting action of the water.

The USEPA scores each indicator and adds the scores together to give total instream habitat assessment score. More work is needed in New Zealand to assess the relevance of these indicators and the US scoring. A reference or baseline is required to determine how the observed conditions vary from the expected.

Instream habitat indicators	
	- Bottom substrate and available cover - Embeddedness - Velocity and/or flow - Pool/riffle or run/bend ratios
Reason for measuring	- Influence of the structure of the habitat on the instream biota - Assess the channel morphology as affecting instream habitat
Status	- Ready to use although needs scoring system
Research needs	- Relevance of USEPA scoring system to New Zealand conditions

Riparian zone -- Part of the health of a river ecosystem is related to the effectiveness of the riparian zone in the functioning of the ecosystem. It is now widely recognised that the riparian zone acts as a nutrient buffer and sediment trap, temperature buffer and provider of shade. It may also be important to bank stability and erosion control, as a wildlife corridor for fish, birds etc and in relation to barriers that restrict access for fish, river re-alignment, the presence of weed species, and its aesthetic appeal.

The USEPA Rapid Bioassessment Protocol (1989) uses bank stability, bank vegetation and streamside cover as riparian parameters that are scored and added together to give an index of riparian and bank structure. These parameters are relevant to some New Zealand riparian zones and the USEPA protocol could be used as a basis for a New Zealand protocol. However, unstable banks are characteristic of New Zealand braided rivers and provide habitat for some birds such as pied stilts, plovers and dotterels and some aquatic macroinvertebrates such as some mayfly larvae and beetles.

- *Bank stability* is assessed as the proportion of the reach with eroded or collapsed banks. Steeper banks are usually more prone to erosion and failure and do not support stable vegetation. Instream habitat is often poor where banks are unstable. Bank stability is not an appropriate indicator for gravel bed rivers.
- *Bank vegetation* holds the soil in place, preventing erosion and sediment and nutrient loss to the water.
- *Streamside cover* assesses the provision of shade of the waterway. Some vegetation types provide cover and refuge for fish and birds near the bank while taller vegetation may shade the whole waterway modifying the effect of temperature fluctuations for instream plants and animals. Deciduous (introduced) vegetation frequently results in a large amount of leaf litter to fall into the water in Autumn, thereby increasing the organic matter component of the aquatic system. Native vegetation as shade provides greater natural character to the ecosystem and may be more suitable for native birds. To effectively reduce temperature fluctuations, long stretches of water need to be shaded. Short sections of a few hundred metres have no effect.

While information is available on the management of riparian areas for different purposes (Collier et al., 1995), the choice of a set of national indicators requires a good protocol including the use of aerial photos and ground truthing.

Aerial photographs need good resolution. The less resolution, the harder to ground truth and the higher the error factor. Normal statistical sampling methods are used for ground truthing. Areas of dense riparian vegetation on a photo can be walked and species recorded. Similar densities can be assumed to have the same species. Bare riparian areas on the photo can also be walked and the species recorded. The scale of the photo can be confirmed by measuring the actual distance of the active river bed to the outside of the riparian zone and comparing this with the distance on the photo. The same scale can then be applied to the length of the reach as well. Similarly where the crowns of trees cover the river providing shade, ground truthing can be used to identify the distance between trees. Where there is a similar canopy on the photo, the trees can be assumed to be a similar distance apart. Unless damaged, similar age trees have a similar canopy.

Assessment of riparian condition is included in the on-farm stream health monitoring kit currently being developed by NIWA.

Primary indicators of the riparian zone at the reach scale	
	- % cover of riparian zone with vegetation along the length of the reach - % shade of waterway - % reach with eroded or collapsed banks in non-gravel bed rivers
Additional indicators include	
	- % naturalness of riparian cover - % naturalness of shade cover
Reason for monitoring	- Riparian zone affects the health and natural character of the aquatic ecosystem
Status	- Almost ready to use
Research needs	- Good assessment protocol

Second tier indicators of riparian conditions at the reach scale could include:

– width of riparian zone (may affect buffering capacity)
– stock access to channel/unbridged stock crossing
– % invasion of riparian zone by introduced plant species
– frequency of wastes discharged to channel
– presence of structures in river channel (dams)
– length of river re-alignment
– periodic instream weed clearance

4.3 Indicators of Environmental Pressure on Rivers

Indicators of environmental pressure are actions or impacts that contribute, directly or indirectly to environmental stress. We need to know what these factors are so that we can direct our management responses to avoid, remedy or mitigate these pressures wherever possible.

- ***Change in catchment/riparian land use*** may affect:

– sediment, nutrients, micro-organisms, pesticides, contaminants
– stability of margins (stock trampling, removal of vegetation)
– aquatic plant communities and habitat for invertebrates, fish and birds by removal of shade and increased temperature
– functioning of river corridor

Trends in land use change over time provide an indication of potential sources of environmental stress. Increase in urban development produces the most stress, while dairying produces more stress on the environment than sheep farming (Figure 4.5). National statistics such as fertiliser use also provide an estimate of the magnitude of environmental impact.

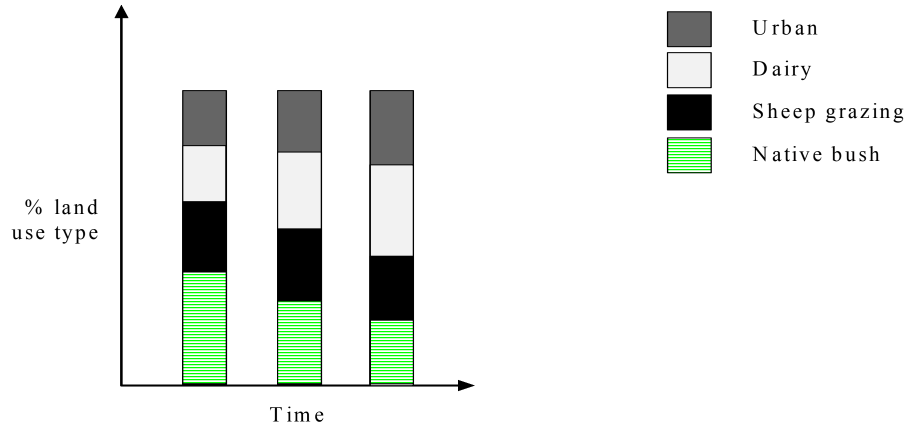

Figure 4.5: Change in land use over time

Change in land use indicators	
	- % area of urban development in river catchment
	- % area of agriculture/forestry in river catchment
	- Proportion of length of waterway accessible to stock
Status	- Ready to use

Important links to land indicators here

- ***Significant change in flow --*** Impacts of significant change in flow due to water abstraction or discharge are important stressors on the environment. There is a trend towards increased water extraction for agricultural and horticultural activities through the consent process. Significant changes in flow over long periods affect periphyton growth, native fish habitat, and potentially the whole aquatic ecosystem although it is difficult to aggregate up the various effects.

Indicator	- Amount of water abstracted for out of stream purposes
Status	- Ready to use

- ***Point source discharges --*** These are important sources of environmental stress that may affect water quality and therefore ecosystem health and natural character in a number of ways depending on the nature of the discharge. Rutherford *et al* (1987) have summarised the point sources of nutrients and organic matter as shown in the Table 4.2.

Table 4.2: Summary of point sources of nutrient and organic matter (Rutherford et al., 1987)

	Total Produced				Discharged to Lakes/Rivers			
	Number	BOD_5	N	P	Number	BOD^5	N	P
Sewage	* 197	** 4	** 4	** 4	* 96	0.2	0.6	0.7
Cowsheds	14317	1.8	1.7	1.6	7800	0.6	0.7	1.0
Dairy factories	50	2	0.4	0.7	23	0.3	0.1	0.2
Meatworks	39	*** 3	*** 2	*** 1.3	18	0.7	0.6	0.6
Pulp & paper	7	0.7	0.4	0.3	6	0.3	0.2	0.1
Piggeries	503	0.6	0.9	1.8	220	0.2	0.4	0.8

BOD_5, N and P figures are million population equivalents.

1 pe = 77 g BOD_5 capita^{-1} d^{-1} = 11 g N capita^{-1} d^{-1} = 1.8 g P capital^{-1} d^{-1}. Data collated from several sources. Uncertainty of load estimates = -50 to +100%.

* Population greater than 1000; ** Includes industry ~ 1 million pe; *** After primary treatment.

Indicator	- Number and type of discharge/river
Status	- Ready to use

- ***Barriers restricting fish access --*** Barriers are a major impediment to migration of many fish species. Some dams have no fish passes and these now have to be considered at the time of renewal of the resource consent. For new dams a resource inventory of existing fish species above the proposed dam is carried out. Where there are diadromous species that are prevented from gaining access to upstream waters by constructed barriers, a fish pass must be installed. The type of installation will depend on the species concerned. Eels, lamprey and juvenile galaxiids can climb fish ladders. Salmonids can jump. Where salmonids are not desirable but a fish pass is required for native fish, climbing fish passes should be installed to give access to native fish but not to introduced salmonids.

An index based on climbing ability might be a useful way of assessing the size of barriers on a stream or river. For a given site an index could be predicted, based on distance from the sea and other relevant parameters, and the fish community measured in relation to this index. Differences could be identified and a score could be given based on observed to expected ratio. The Native Fish Database may contain sufficient information to enable an index to be developed. The index would probably be based on presence/absence. For the index to work, reliable fishing methods are needed. The current methods need to be assessed for their ability to produce repeatable and reliable results.

Indicators	- Type of barrier in relation to fish species - Distance of barrier from the sea
Status	- Further work required

- ***Groundwater contribution to quickflow –*** Groundwater can enter rivers through subsurface flow carrying with it nutrients into the river.

4.4 Indicators of Management Response

These are the actions taken to address observed or predicted environmental change or adverse effects.

- ***Land use controls in place***

Regional policy statements can encourage district councils to provide for public access in their district plans by creating esplanade reserves following subdivisions.

- ***Resource consent management and monitoring programme***

Resource consents are required for discharges to surface water to avoid adverse effects and thus to ensure minimum risk to water quality. Each consent is subject to conditions which need to be monitored. Monitoring water quality for a variety of land uses will provide overall trends in a region.

- ***Environmental education programme***

Advice to the community on management and use of river water can be provided in a variety of ways including freshwater plans and leaflets and informally through advice to landowners and community planting.

- ***Riparian zone management strategy***

A strategy would help councils address management of riparian zones. This might involve protection and enhancement of riparian areas by planting.

- ***Minimum flow requirements set***

See NIWA guidelines to be released shortly.

- ***Consultation with iwi***

Iwi need to be involved at all stages of water management with input into policy statements and plans.

- ***Freshwater plans developed***

Regional freshwater plans may be a management response to address the effects of point and diffuse source discharges on water quality, use and diversion of water, and the discharge of contaminants. These plans can also address issues of maintenance and enhancement of public access to rivers.

4.5 Data Presentation - Storage and Handling

The concept of benchmark sites may be useful where there are good long term data sets that can be used as reference sites such as national hydrological monitoring sites. These benchmark sites may need to be monitored nationally by one agency so that new tools and techniques can be tested by one organisation in a range of river types.

In situations where different methods are used to collect benthic invertebrate data, for example, the range of MCI or other values needs to be grouped into high, medium and low so that the number of reaches with invertebrate communities of high value etc in each region can be collated nationally.

4.6 Summary

- All indicators must conform to the criteria as set out in the Introduction (Section 1) as shown in Table 4.3.
- A reach-based approach will be used.
- Indicators will be aggregated into an index for that particular river type and reach.
- A decision support system will be used to select appropriate indicators for each river type, thereby making data collection efficient.

Key components for the development of State indicators for rivers are:

- Physical/chemical parameters
- Periphyton
- Aquatic macrophytes
- Macroinvertebrates
- Fish and birds
- Riparian zone
- Instream habitat

State indicators for rivers

pH indicator - Amount of time the pH varies from the expected value for that river

Water clarity indicator - Per cent of time that the sample exceeds a certain clarity value expected for that river

Periphyton indicators
- Presence/absence/% cover of heterotrophic slimes (sewage fungus)
- Presence/absence/% cover of benthic algae (blanket weed, dark brown slimes, green filamentous growths in rivers)

Aquatic macrophytes indicators
- Floating plants: % cover; % cover of introduced/native sp.
- Submerged plants: % cover; species, height/biomass with water depth; % cover introduced sp.
- Emergent plants: % cover, biodiversity, % cover introduced/native sp.

Macroinvertebrate indicator
- Invertebrate community index scores observed/expected for that river type exceeds 0.75

Fish indicators - Presence/absence of native species that are widespread, abundant and sensitive to environmental change: eg giant kokopu, banded kokopu, koaro, redfinned bully

Birds indicator - Presence/absence of expected bird species

Instream habitat indicators
- Bottom substrate and available cover
- Embeddedness
- Velocity and/or flow
- Pool/riffle or run/bend ratios

Primary indicators of the riparian zone at the reach scale
- % cover of riparian zone with vegetation along the length of the reach
- % shade of waterway
- % reach with eroded or collapsed banks in non-gravel bed rivers

Table 4.3: Comparison of State indicators of the health of rivers with the MfE criteria for indicators

Indicator	Criteria							
	Simple & robust[1]	**Policy relevant**[1]	**Scientifically valid**	**Responsive to change**	**Repeatable**	**Cost effective**	**Easily understood**	**Comments**
Phys/chem pH, clarity	✓ routinely measured (eg black disc)	✓ lsc, nc (water quality)	✓ techniques available	✓	✓	✓ simple measurement techniques	✓	needs good framework
Periphyton presence/absence	✓ visual assessment	✓ lsc, nc (base of food chain)	✓ techniques needed	✓	✓	✓ simple to measure	✓	needs guidelines for use
Aquatic macrophyte % cover	✓ visual assessment	✓ lsc, nc (base of food chain) influence dissolved oxygen	✓ techniques needed	?	✓	? unknown until protocol developed	✓	needs guidelines for use
Macroinvertebrate observed/expected score	✓	✓ lsc, nc key part of food chain & key water quality indicator	✓ techniques available but not for silty streams	✓ respond to changes over time	✓	? costly	✓	needs guidelines for use
4 Native fish spp. presence/absence	✓ simple curves can be developed	✓ lsc, nc (near top of food chain)	✓	? take time to recover from disturbance	✓	✓ freshwater fish database makes it cost effective	✓ healthy fish = healthy river	species identification essential
Bird sp. Presence/absence of expected sp.	?	✓ lsc, nc (top of food chain)	?	?	?	?	✓	more research needed
Instream habitat substrate, flow, scouring, riffle/pool	✓ easily assessed	✓ lsc, nc important to ecological function	✓ techniques available	✓	✓	? unknown until protocol developed	✓	needs scoring system
Riparian zone (reach scale) % cover, shade, bank erosion	✓ visual assessment	✓ lsc, nc important to ecological function	✓ techniques available	✓ responds to changes over time	✓	✓ simple to measure	✓	needs good assessment protocol

Note: 1 = for relevance to aesthetics, contact recreation, etc, see Section 8
lsc = life supporting capacity (RMA s5)
nc = natural character (RMA s6)

Indicators of environmental pressure

Change in land use indicators

- % area of urban development in river catchment
- % area of agriculture/forestry in river catchment
- Proportion of length of waterway accessible to stock

Significant change in flow indicator

- Amount of water abstracted for out of stream purposes

Point source discharge indicator

- Number and type of discharge/river

Barriers to fish access indicators

- Type of barrier in relation to fish species
- Distance of barrier from the sea

Considerable research is still needed to use most of these indicators effectively. Apart from water clarity, an acceptable methodology is required for all situations. At present different methods are used by different local authorities.

More attention needs to be given to lowland rivers and streams for the development of indicators. We suspect that most indicators apply to upland streams and river reaches but may not be relevant to lowland reaches.

Indicators of management response

Actions taken to address adverse environmental change:

Land use controls in place
Resource consent management and monitoring programme
Environmental education programme
Riparian zone management strategy
Minimum flow requirements set
Consultation with iwi
Freshwater plans developed

5 INDICATORS OF ECOSYSTEM HEALTH OF LAKES

5.1 Background

Traditionally lakes have been looked at from the perspective of trophic state because of concerns about algal blooms and dying fish. Lake eutrophication is studied by the measurement of key parameters such as oxygen, chlorophyll-a and nutrient concentrations. Low oxygen levels in a eutrophic lake cause death of biota while the amount of chlorophyll-a indicates the level of productivity of the phytoplankton in the lake at that time and the nutrient concentrations control the chlorophyll-a levels.

Early research on eutrophication of New Zealand lakes revealed that nutrient levels are different from northern hemisphere temperate lakes. Lakes in the Central Volcanic Plateau are characterised by low levels of inorganic nitrogen with frequent nitrogen limitation of phytoplankton growth compared with most northern temperate lakes. Nutrient inflows tend to be diffuse rather than point source. Lakes mix to relatively greater depths in summer and exhibit a great diversity of optical properties, unusual and often variable timing of planton growth, low productivity and biomass of zooplankton, and sensitivity to invasion by exotic macrophytes (Burns, 1991). So models from northern hemisphere lakes are not directly applicable to New Zealand.

The difference between the three trophic states of lakes (oligotrophic, mesotrophic, eutrophic) is rather coarse for management purposes. Current research is proceeding at NIWA Hamilton to develop a simple way of using regularly monitored parameters to ascertain whether or not the trophic state is changing in a small way so that large changes can be anticipated and mitigating measures put in place.

Oligotrophic lakes are mainly located inland, mostly in the high country, while eutrophic lakes are mainly lowland and coastal. However, widespread agricultural development and inland urban centres have resulted in several inland lakes being in a eutrophic state.

However, the trophic state of lakes is only one aspect of ecosystem health. The condition of the littoral and riparian zones are also important components of lake ecosystems because they reflect the surrounding land uses. The plant communities (submerged, emergent and terrestrial species) provide habitat for a diversity of animals. Indicators needs to be developed that reflect the health of shallow waters and lake margins. Invasion by introduced plant and animal species can severely affect the functioning of native plant communities.

The development of indicators of the ecosystem health of lakes needs to take all these factors into account. Certain aspects of New Zealand lakes are reasonably well understood and relatively good indicators can be developed; other aspects such as ecosystem functioning and the health of lake margin communities need further research

A standard monitoring protocol for all lake components needs to be developed that pulls together existing knowledge and provides guidance to lake managers on what data to collect for a particular lake type, how to collect it and how to analyse it. The protocol should cover sampling frequency and optimisation of information extraction. Statistical analysis procedures need to be set out and related to the frequency of sampling. The sampling procedure should be based on the type of lake monitored.

5.1.1 Lake Types

Lakes vary in origin, depth, size and some are dominated by macrophytes and others by phytoplankton. Different parameters may need to be measured according to the type of lake. Some type of classification is useful to distinguish lake types so as to assist water managers to choose the most appropriate monitoring programmes.

New Zealand lakes have been classified for various purposes. Vant (1987) distinguishes six lake types as shown in Table 5.1.

Table 5.1: Major lake types often found in New Zealand (note that composite types area also found) (WN Vant in "Lake Managers Handbook", 1987)

a) Large, deep and clear. Phytoplankton and macrophytes sparse or restricted in distribution. Bottom waters well-oxygenated. Oligotrophic, eg Lakes Taupo, Wanaka and Coleridge.

b) Shallow and turbid. Phytoplankton either abundant (eg Lake Ngaroto), or restricted and masked by inorganic suspensoids (eg Lake Waahi). Macrophytes either sparse or absent. Wind-mixed and bottom waters well-oxygenated. Frequently eutrophic or hypertrophic.

c) Phytoplankton-dominated and turbid with bottom waters depleted of oxygen during summer. Macrophytes often present with distribution and abundance primarily dependent on bathymetry. Classic eutrophic lakes, eg Lakes Hayes, Rotorua and Tutira.

d) Macrophyte dominated. Lakes whose clarity and bathymetry are such that extensive areas are colonised by macrophytes, often the vigorous introduced species. Bottom waters may be oxygen-depleted, eg Lake Whangape. Catastrophic collapses of the macrophyte community are common (eg Lake Ellesmere, Omapere and Waahi).

e) Small lakes with brown-stained waters, frequently in peaty areas or undisturbed native forest. Phytoplankton and macrophytes may or may not be abundant, but are rarely of major management concern. Bottom waters may deoxygenate. Dystrophic, eg many lakes in Westland and the lower Waikato basin.

f) Reservoirs. Phytoplankton abundance and water clarity differ between reservoirs. Macrophytes frequently limited to a narrow littoral fringe by bathymetry. Bottom water oxygen depletion is uncommon in rapidly flushed reservoirs (eg Lake Karapiro), but its severity increases with increasing resident time (eg Auckland water supply reservoirs).

A simpler classification is suggested by N Burns (pers comm) where physical properties dominate the lake types:

a) Shallow lakes
- generally less than 17 m deep
- phytoplankton dominated
- macrophyte dominated
- peat (occasionally stratified)

b) Intermittently stratified lakes (polymictic)

c) Deeper stratified lakes
- moderate size (eg Lake Tarawera)
- generally deeper than 17 m

d) Stratified lakes (large, deep lakes) - phytoplankton & macrophytes sparse or restricted in distribution (eg Lake Taupo)

Representatives of different lake types need to be monitored in each region so that there is an understanding as to whether the ecosystem health of a lake is improving or deteriorating.

Lakes representative of each type need to be selected for monitoring that are as close as possible to their natural state to provide a baseline against which other lakes can be assessed. If there are no "pristine" lakes in a region, the best guess or best practical option should be chosen. A pristine lake is not necessarily oligotrophic; some lakes are naturally eutrophic so the "baseline" state needs to be chosen with this knowledge. The selection of lakes to be sampled needs care so that they are representative of lakes of that type in a region and changes in the monitored lake can be assumed to be reflected in other lakes of the same type in that region.

5.2 State Indicators for Lakes

As with rivers (Section 4.2), the individual components and indicators measured will depend on the type of lake and the DSS will guide the councils to measure the most appropriate indicators for that lake type. Trophic state is an index in its own right but it is still possible to aggregate all the components into one index as an aggregate of all the ecosystem components. These are shown in Figure 5.1.

The ecosystem components from which indicators can be selected, monitored and aggregated to a composite index include:

- Trophic state
- Littoral zone condition, species richness/diversity
- Riparian zone condition, species richness/diversity
- Invasion by exotic species
- Physico-chemical elements such as suspended sediment and nutrients
- Fish and birds

A decision support system will assist water managers to decide which are the appropriate types of indicators to be measured in a particular type of lake.

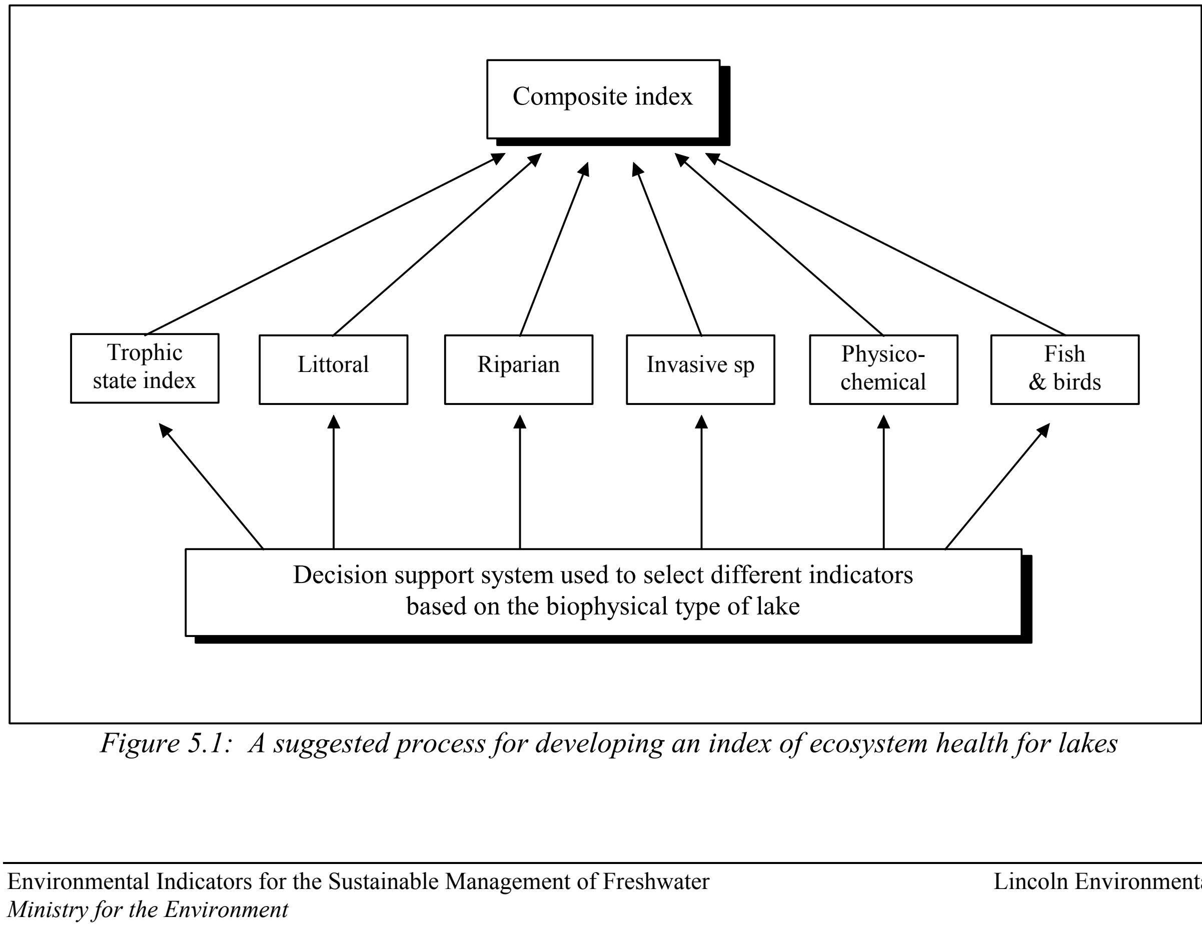

Figure 5.1: A suggested process for developing an index of ecosystem health for lakes

5.2.1 Index of Trophic State

The index of trophic state of a lake being developed at NIWA Hamilton uses the combined results of monitoring certain lake indicators (N Burns pers comm). At present five indicators (explained below) are used to describe the trophic state of a particular lake. These are:

- Chlorophyll-a
- Secchi disc
- Total phosphorus
- Total nitrogen
- Phytoplankton species

The measurements for each indicator can be combined to produce an index of trophic state of the lake and changes can be easily noted (Figure 5.2). The purpose is to help lake managers find out if the trophic state of a particular lake in their region is improving, degrading or showing no change. At present there is no easy way to assess small levels of change. The results should be available within two years.

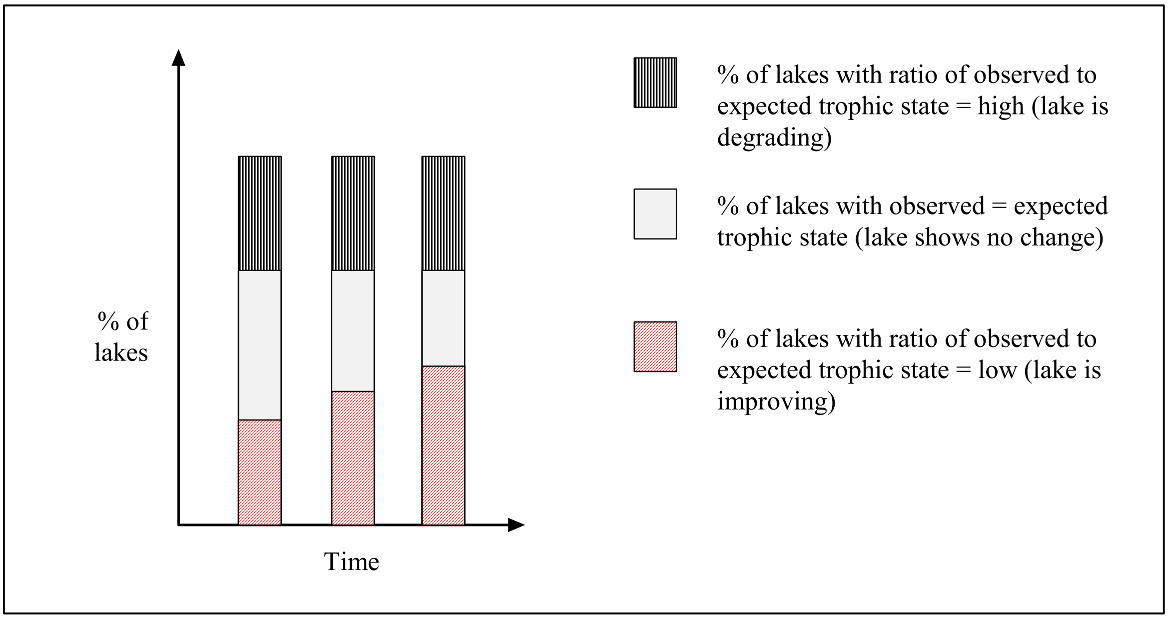

Figure 5.2: Graph to show change in trophic state over time of a number of lakes monitored in a region

A similar graph could show the observed/expected degree of naturalness.

A report on the condition of 24 New Zealand lakes and possible recent changes in their state will be completed by NIWA in 1997.

The occurrence and frequency of algal/phytoplankton blooms is important in some lakes when nutrient levels are high, the temperature is suitably warm and the weather calm. These algae can be toxic to stock, unpleasant for recreational use and aesthetically. When they die there may be a reduction in oxygen levels due to bacterial activity that can affect fish and invertebrates, and an unpleasant odour may be present if decomposing algae is washed ashore. The occurrence and frequency of algal blooms may need to be monitored in some eutrophic lakes.

For large deep stratified lakes, such as Lake Taupo or the large South Island lakes, a basic characterisation of the lake is needed using professional equipment and possibly professional help for initial intensive sampling. Then sampling can be restricted to trouble spots, such as high use areas. If risks are high, more sites may be required.

For intermediate size stratified lakes, such as Lake Hayes or Lake Tarawera, a basic monitoring programme would require an oxygen/temperature profile taken from the deepest part of the lake and an epilimnion (upper mixed layer) sample from this site. A second epilimnion sample should be taken at some distance from the first where the lake is still deep. Samples need to be taken about 8 times a year.

Shallow unstratified lakes need to sampled near the top and near the bottom.

Primary core indicators that will be aggregated to give an index of lake trophic state:

- *Oxygen depletion rate* - indicates how oxygen levels decrease with time. It is the first indicator to be measured: taken in the deepest part of the lake. Oxygen probes are suitable for measuring dissolved oxygen and temperature in lakes. However, in very deep lakes, specialised equipment is needed.
- *Temperature* - taken as a basic parameter for understanding lake processes
- *Water clarity* - is measured to assess light penetration for photosynthesis using a black and white 200 mm Secchi disk. A viewing box can be used to reduce variability due to differing conditions of the water surface and increase the reliability of the measurement.
- *Chlorophyll-a* - indicates the amount of phytoplankton present which is useful during algal blooms. It is measured by filtering a sample of lake water and analysing the residue on the filter paper for chlorophyll-a. Chlorophyll-a and nutrients should be sampled from the same epilimnetic layers. These samples should be drawn from all of the upper mixed layers, not just the surface. There should be at least four chlorophyll samples per sampling event.
- *Total nitrogen (TN) and total phosphorus (TP) concentrations* are measured to assess overall nutrient status of the lake. Total nutrients commonly measured include TKN and TP. Total N is often preferred over TKN because it is easier, cheaper and provides a more accurate analysis.

Second tier indicators of trophic state may need to be measured in some situations:

- *Dissolved nutrients* - (N & P) are measured to understand the nutrient status/productivity of the lake; plants can take up nutrients in dissolved form. Ammonia nitrogen (NH_4), nitrate nitrogen (NO_3), nitrite nitrogen (NO_2) and dissolved reactive phosphorus (DRP) are commonly measured. Bioassays to determine nutrient limitation may also be undertaken.
- *Phytoplankton species* - need to be measured from time to time so managers can become familiar with normal species composition so that changes in species distribution can be detected.. Some species are toxic; others affect taste and smell. Some species are indicative of eutrophication. Monthly samples can be pooled together, preserved with iodine and analysed once a year. It is possible monthly samples could be analysed to the genera level more easily. This issue is currently being investigated by lake scientists.

Trophic state indicators	- Oxygen depletion rate - Temperature - Water clarity - Chlorophyll-a - Total nitrogen and total phosphorus
Reason for monitoring	- Indicators measured using standard techniques to give understanding of tropic state
Status	- Ready to use
Research needs	- Development of index of trophic state

5.2.2 Littoral Zone Condition, Species Richness/Diversity

The littoral zone extends from the shore at the highest seasonal water level down to the limit of the submerged macrophytes (large aquatic plants).

Aquatic macrophytes can be important components of lake ecosystems because they:

- enhance the settlement of sediment,
- provide habitat for other biota such as algae, invertebrates and fish,
- are food sources for other animals including birds, and
- participate in nutrient re-cycling.

Plants can be submerged, free-floating and emergent. Emergent plants assist bank and margin stability and provide important habitat for birds. Research in Europe has shown that some macrophyte species are associated with organic enrichment. Other species cannot tolerate the algae that grow on them and subsequently die.

An over abundance of macrophytes can cause problems to other species and lake users (see invasion by exotic plants below). The depth to which plants can grow reflects the conditions in the littoral zone including light penetration, wave action and sediment type. Species richness/diversity of the littoral zone may be an important indicator because this area is most affected by un-natural fluctuations which can arise from hydro power requirements.

There is an aquatic macrophyte database at NIWA (Hamilton) for lakes that have been surveyed to date. At present it is being updated with the addition of data from the MAF aquatic macrophyte database. The combined databases will be accessible by regional councils when required.

Methods used to monitor aquatic macrophytes include taking photographic records, observing and collecting grab samples from a boat or the shore, and making underwater surveys using mask and snorkel or SCUBA. Annual monitoring will be required if problems are anticipated and possibly even 6-monthly monitoring in problem areas.

Certain aspects of aquatic plant monitoring could be undertaken by communities such as observational records of the presence/spread of introduced species.

Aquatic invertebrates and fish may depend on the aquatic macrophytes for protection, shelter and a source of food because algae and small invertebrates live on the plants. Sediment inflows to a lake may smother these organisms or prevent sufficient light to penetrate for photosynthesis.

Littoral zone indicators	- Depth of plant growth - Presence/absence of an expected species/community - % cover of zone by aquatic plants - Significant change in plant community composition
Reason for monitoring	- To assess species diversity and depths to which plants can grow as indicators of ecosystem health and natural character
Status	- Protocol needed to assess overall condition of the littoral zone

5.2.3 Riparian Zone Condition, Species Richness/Diversity

The condition of the riparian zone needs to be assessed for trampling by stock and causing bank erosion, sediment and nutrient runoff into the lake and deterioration of marginal vegetation and habitat (Figure 5.3). This condition can be assessed by aerial photography and ground truthing as described for rivers (Section 4.2). Land use in the catchment beyond the riparian zone may affect the zone and influence the health of the lake ecosystem.

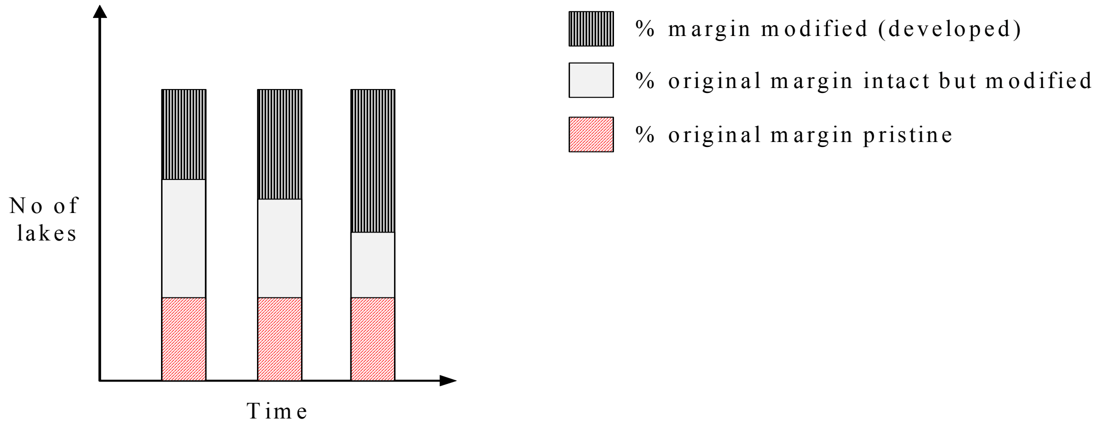

Figure 5.3: Percentage modified margin vs time

There is not a good protocol for the assessment of riparian condition of lakes but this should be fairly easy to develop considering the riparian guidelines for rivers (DoC/NIWA) and other current research.

Riparian zone indicators include	- % original lake margin remaining although modified - % original lake margin intact - % vegetative cover of lake margin
Reason for monitoring	- To assess the natural character and ecosystem health of the riparian zone
Status	- Good protocol needs to be developed but this should be straight forward

5.2.4 Invasion by Exotic Species

The invasion of shallow lakes and lake margins by introduced aquatic plants and fish has been an important issue in New Zealand. Introduced macrophyte species can cause smothering of native plant communities and therefore affect the whole ecosystem because the altered habitat may affect animals and birds. Luxuriant growths of some species block hydro-electric power intakes and may cause problems for swimming and boating. Introduced fish species such as koi carp can have a devastating effect on native aquatic ecosystems.

An example of a management problem has been the control of the exotic weed *Hydrilla verticillata* in the Hawkes Bay region. Grass carp were introduced to control this plant but long term trials at NIWA Hamilton indicate that grass carp cannot be used to completely eradicate *Hydrilla*, which can reproduce asexually. If a lake is to be restored with native species, the carp must first be removed and then *Hydrilla* will spread again. Long term use of grass carp may not be acceptable to management (Clayton and Hoffstra, 1996).

Water net (*Hydrodictyon reticulatum*) is another aquatic macrophyte introduced to New Zealand. It was first recorded at Tauranga in 1986 and has since spread to Lake Taupo, the Rotorua lakes, other sites in the Bay of Plenty and Lake Ariwhenua. It typically grows on the surface of large aquatic plants and at times masses of cells break off and float to the surface forming dense mats or scums that are washed ashore. Water net sticks to boats, ropes and swimmers so is easily transported to other sites. Decaying plants reduce oxygen levels and cause noxious odours. A special committee was established in 1991 to advise on its management and control.

From a national perspective, an understanding is needed on the spread of exotic species of macrophytes and fish, their distribution in the lake including depth range, and their rate of spread. A national map could be used to show distribution that is updated every five years. A macrophyte survey focused on problem areas, particularly boat ramps and access points, will signal the source of infestations. These data should be relatively easy to collect.

Invasion by exotic species indicators	
	- Presence/absence of exotic species - Extent of invasion within lake - Extent of invasion between lakes - Rate of spread of exotic species
Reason for monitoring	- To assess the degree of invasion or potential invasion by exotic species
Status	- Protocol for assessment of spread

5.2.5 Physico-Chemical Elements

Suspended sediment is measured in shallow lakes and the margins of deeper lakes because increased levels cause reduced light penetration and cause deterioration of habitat. It needs only to be sampled in shallow lakes to provide an indication of sediment re-suspension from wind or where there are high levels of sediment in the inflow waters. A simple American Public Health Association method exists for the analysis.

Nutrients are discussed above under trophic state.

5.2.6 Birds and Fish

Birds are indicators of suitability of lakes as bird habitat (availability of food, nesting sites, etc). Key species could be important indicators of the health and natural character of lakes.

The absence of certain expected native fish species in a lake could reflect the presence of barriers in the catchment (see river indicators) or unsuitable habitat. Therefore they could be important indicators in some situations.

5.3 Indicators of Environmental Pressure on Lakes

- ***Change in catchment/riparian land use*** may affect:
  - Change in water level;
  - Addition of sediment, nutrients, micro-organisms, pesticides, contaminants to lakes;
  - Stability of margins (stock trampling, removal of vegetation);
  - Plant communities;
  - Habitat for invertebrates, fish and birds.

Indicators	- % area of urban development in lake catchment - % area of agriculture/forestry in lake catchment - Proportion of lake margin accessible to stock

Status	- Ready to use

- ***Water level changes*** due to water level controls or abstractions from the lake may affect:
  - Plant and animal communities in the littoral zone;
  - Plant and animal communities on the lake margin;
  - Soil erosion on exposed margins.

Indicator	- Water level changes over time
Status	- Ready to use

- ***Introductions of exotic species***
  - Exotic plant and fish species introduced to a lake may affect the natural character and health of the lake ecosystem, eg by smothering or eating native plants.
  - The local community could assist in reporting the sighting of introduced plant and animal species.

Indicator	- Presence of unacceptable exotic species
Status	- Ready to use

- ***Point source discharge***
  - Affects water quality; may raise nutrient levels causing algal blooms, fish kills, etc.

Indicator	- Type and amount of discharge to lake
Status	- Ready to use

- ***Groundwater contribution to quickflow***
  - Groundwater can enter lakes through subsurface flow carrying with it nutrients into the lake.

5.4 Indicators of Management Response

These are the actions taken to address observed or predicted environmental changes or adverse effects.

- ***Land use controls in place***

Regional policy statements can encourage district councils to provide for public access in their district plans by creating esplanade reserves following subdivisions.

- ***Resource consent management and monitoring programme***

Resource consents are required for discharges to surface water to avoid adverse effects and thus to ensure minimum risk to water quality. Each consent is subject to conditions which need to be monitored. Monitoring water quality for a variety of land uses will provide overall trends in a region.

- ***Environmental education programme***

Advice to the community on management and use of river water can be provided in a variety of ways including freshwater plans and leaflets and informally through advice to landowners and community planting.

- ***Riparian zone management strategy***

Councils need a strategy to address management of riparian zones. This might involve protection and enhancement of riparian areas by planting.

- ***Consultation with iwi***

Iwi need to be involved at all stages of water management with input into policy statements and plans.

- ***Freshwater plans developed***

Regional freshwater plans are needed to address the effects of point and diffuse source discharges on water quality, use and diversion of water, and the discharge of contaminants. These plans can also address issues of maintenance and enhancement of public access to lakes.

- ***Ownership status***

Land ownership may influence the nature of the management response because land in private ownership may have no formal protection.

- ***Boat access restrictions*** where spread of exotic aquatic microphytes are a problem.

5.5 Data Presentation

Trend information rather than absolute numbers needs to be sent to Ministry for the Environment. Annual monitoring of indicators could be presented as a 5-yr update of trends.

For example, trends in key trophic indicators for each ecoregion, eg lowland Waikato lakes, could be represented on a national map so that increased, decreased, or unchanged trophic state can be clearly seen for that ecoregion.

Representative lakes must be chosen and fixed so the same lakes are monitored for trends.

Spread of exotic macrophytes could be presented using maps and GIS with 10 year update, unless there was a problem when more frequent reporting would be needed.

5.6 Summary

- All indicators must be relevant to policy and conform to the criteria set out in the Introduction (Section 1) as shown in Table 5.2.
- Indicators will be aggregated to form an index for a particular type of lake.
- A decision support system will be used to help councils select appropriate indicators for each type of lake.

The key components of lake ecosystems and suggested State indicators are:

- ***Change in trophic state***

Indicators - oxygen depletion rate
- water clarity
- chlorophyll-a
- total nitrogen and total phosphorus

- ***Littoral zone condition, species richness/diversity***

Indicators - depth of plant growth
- presence/absence of an expected species/community
- % cover of zone by aquatic plants
- significant change in plant community composition

- ***Riparian zone condition, species richness/diversity***

Indicators - % original lake margin remaining although modified
- % original lake margin intact
- % vegetative cover of lake margin

- ***Invasion by exotic species***

Indicators - presence/absence of exotic species
- extent of invasion within lake
- extent of invasion between lakes
- rate of spread of exotic species

- ***Physico-chemical elements***

Indicators - suspended solids
- nutrients

- ***Fish and birds***

A numerical index of the actual trophic state of lakes awaits development. Other indicators also need further work although the basis of their development is available. In particular, a protocol for when and how to measure a particular indicator is required.

Table 5.2: Comparison of State indicators of the health of lakes with the MfE criteria for indicators

Indicator	Criteria							
	Simple & robust[1]	**Policy relevant**[1]	**Scientifically valid**	**Responsive to change**	**Repeatable**	**Cost effective**	**Easily understood**	**Comments**
Trophic state O_2, clarity, chl-a, TN, TP	? index under development	✓ lsc, nc	✓ techniques needed	✓	✓	? unknown at this stage	?	index being developed
Littoral zone presence/absence sp. % veg cover community composition	✓ visual assessment	✓ lsc, nc important ecological function	✓ techniques available	✓ responds to changes over time	✓	✓ aq macrophyte database aids cost effective-ness	✓	needs good assessment protocol
Riparian zone % original margin % veg cover	✓ visual assessment	✓ lsc, nc important ecological function	✓ techniques needed	✓ responds to changes over time	✓	✓ simple to measure	✓	needs good assessment protocol
Exotic sp invasion presence/absence extent of invasion rate of spread	✓ visual assessment	✓ lsc, nc impacts on native ecosystems	✓ techniques available	✓ responds to changes over time	✓	✓ simple to measure	✓	needs protocol for assessment of spread
Physico-chemical suspended solids nutrients	✓ routinely measured	✓ lsc, nc (water quality)	✓ techniques available	✓	✓	✓ depends on indicators chosen	✓	needs good framework
Fish & bird sp. ?	?	✓ lsc, nc (top of the food chain)	?	?	?	?	?	more research needed

Note: 1 = for relevance to aesthetics, contact recreation, etc, see Section 8
lsc = life supporting capacity (RMA s5)
nc = natural character (RMA s6)

Considerable research is still needed to clarify the mode of measuring the indicators.

Indicators of environmental pressure on lakes

- % area of urban development in lake catchment
- % area of agriculture/forestry in lake catchment
- Proportion of lake margin accessible to stock
- Water level changes over time
- Presence of unacceptable exotic plant and fish species
- Type and amount of point source discharge to lake

Indicators of management response

- Land use controls in place
- Resource consent management and monitoring programme
- Environmental education programme
- Riparian zone management strategy
- Consultation with iwi
- Freshwater plans developed
- Ownership status
- Boat access restrictions

6 INDICATORS OF ECOSYSTEM HEALTH/NATURAL CHARACTER OF WETLANDS INCLUDING GEOTHERMAL WETLANDS

6.1 Background

Loss of wetlands through human development in New Zealand has resulted in only about 10 per cent of the original area remaining and the condition of these wetlands is not always without impact from surrounding land use. Wetlands have values for their functions in water quality, hydrology and ecology. They affect water quality through sedimentation, immobilisation of pollutants and limited uptake of pollutants and nutrients. Their organic substrate can act as a filter to immobilise substances that pass through them into groundwater. Hydrologically they can act as buffers against flooding by storing water during storm events and releasing it slowly. They can affect groundwater recharge and discharge depending on the local hydrology and climate. Ecologically, wetlands are important for supporting aquatic and terrestrial organisms. They can be highly productive and can support communities external to the wetland.

Wetlands are often found associated with the margins of rivers, lakes and estuaries and form a boundary zone between land and water. They may therefore be an integral part of the water body and its aquatic ecosystem. A narrow definition of wetlands is used in this section to include wet areas with emergent vegetation (pallustrine). Shallow lakes are covered in the lakes section.

It is recognised that a number of constructed wetlands exist that provide good bird habitat, but these are not included in the development of indicators although the same indicators may apply as in natural wetlands.

There is a need to develop indicators of ecosystem health for freshwater, saline and geothermal wetlands although there are no widely accepted indicators used for this purpose.

It is recognised that there will be overlap between indicators that are developed for wetlands and those that are to be developed for rivers, lakes, estuaries and biodiversity.

New Zealand has obligations under the international RAMSAR Convention on Wetlands (1971) to protect and monitor the (natural) ecological character of lakes, rivers, wetlands and estuaries.

Indicators need to be identified that are applicable to degraded and intensively managed wetlands as well as wetlands in their natural state and unmanaged ones. Some wetlands are restorable although not always the best ones biologically are selected by the community for restoration. The Montreaux Record established in 1992 allows for RAMSAR sites to be taken off the list if they are degraded beyond a certain level. Since limited resources are available for monitoring in New Zealand, perhaps this needs to be considered. Priorities need to be set for those areas which are (a) most representative of trends and (b) sensitive to management responses.

There are three reasons for monitoring wetland sites:

- To make sure the good wetlands (not subject to known pressures) are not degrading;
- To know how fast/or when to intervene in wetlands that are known to be degrading;
- To know the effectiveness of management of wetlands that are currently being managed.

Degraded wetlands of low natural values that are being managed may need to be monitored, but not at the expense of monitoring wetlands of value. There is a need to monitor sites that would give the most information for effort invested. There is a risk that monitored sites may get more management attention than unmonitored ones.

A decision support system for management may be needed to assist in site selection. Indicators must be sufficiently sensitive to show trends which can alert the need to review decisions yet generally relevant enough to be combined into composite indices which demonstrate overall policy performance.

Councils will need a manual to carry out wetland monitoring with a guide to site selection and monitoring for consistency between councils. Quality assurance, checking and auditing of council data may be needed.

There are many different types of wetlands but the types of indicators are common to most of them so some very simple indicators can produce some very useful information.

6.1.1 Wetland Types

There is a need to have an interim classification of wetland types each of which will need relevant indicators of ecosystem health. The classification needs to be functionally based and hierarchical. It also needs to be pragmatic and easily communicable. It needs to be remembered that individual wetland sites often include complexes or mosaics of several different vegetation types or classes.

Wetland classifications in New Zealand involve hierarchical subdivision into hydroclass, wetland types and community classes; each of the latter being easily recognised by the dominant vegetation. Two existing hierarchical classifications are considered to be suitable for the development of indicators of ecosystem health (Thompson, 1983; Richmond, 1994). Both classifications provide about 25 wetland community classes for freshwater, estuarine and geothermal New Zealand wetlands. Each community class requires relevant indicators of ecosystem health.

A manual containing criteria for assigning classes and defining boundaries is needed.

6.1.2 Benchmark Sites

The state of a wetland at any one time may exhibit natural variation that needs to be understood. In addition we need to know what the past state of the wetland was like, for example the state at 1840, to be able to assess the changes over time and perhaps the desired state if restoration is being considered. It is useful to have some benchmark sites that are as unimpacted or pristine as possible for baseline monitoring. In well developed catchments, the best available site in terms of naturalness may need to be used as the benchmark.

Criteria for the selection of wetlands to be monitored:

- Need to maintain a full range of community classes that are suitable for representative sampling sites.
- Need to maintain the full range of sizes.

In the Waikato, for example, large wetland mosaics such as Whangamarino or Kapuatai might be chosen along with a number of small isolated remnants that are impacted by agricultural activities , for example, to check on trends. Small wetland remnants are often very important, especially on non DoC land, with bird and invertebrate habitat. Site selection is where regional and district councils need most help.

The number of wetlands remaining in a region also needs to be monitored, along with the total area of wetlands remaining, so that small wetlands are not forgotten. An aerial assessment can be used for this purpose with ground truthing if required.

An rapid assessment protocol is needed. A baseline survey involving considerable time and plant and animal specialists could identify sites for on-going monitoring and further assessment by councils. All methods must be trailed before handing them over to councils. Certain benchmark sites are needed.

6.2 State Indicators for Wetlands

Two categories of indicators of wetland ecosystem health and/or natural character can be distinguished: region specific and site specific indicators.

Region specific indicators include the spatial extent of wetlands and their number. These indicators are easy to measure using aerial photographs and maps and, given the appropriate data, it may be possible to assess changes over time. It may also be possible to determine the general condition of a particular wetland in terms of whether it has been modified by surrounding land use and/or invaded by introduced plant species or whether it is essentially unmodified. The information could be presented as shown in Figure 6.1.

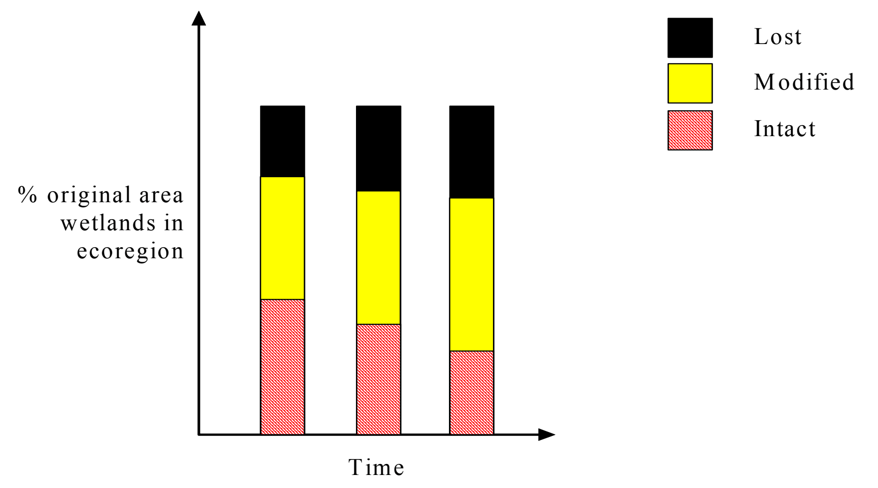

Figure 6.1: Change in area of wetlands over time

Region specific indicators using an 1840 baseline
- *number of wetlands*
- *% original area remaining although modified*
- *% original area intact and still viable*

Site specific indicators relate to particular wetlands and can be built around the ecological elements of the natural character of wetlands because they are policy relevant and robust. Since 1976 New Zealand has had an obligation under the RAMSAR Convention to monitor and report on changes in the (natural) ecological character of significant wetlands. Assigning a "degree of naturalness" assessment to a wetland element could be progressively refined as standard criteria become developed and sensitivity is enhanced. An initial 5 point ranking scale for hydrological naturalness (cf SSWI Botanical Ranking) could progress to a 10 point weighted criteria scale to a decimal per cent scale. This iterative non-parametric assessment should maintain comparability.

The natural character of wetlands can be assessed in terms of naturalness of various wetland components as suggested below. The per cent naturalness scores for a wetland could be aggregated up to give an index of the state of that wetland (Figure 6.2). Because a wetland is often composed of several different classes of plant communities, some indicators will be more important for certain classes than others. Therefore, in any particular wetland community class only some of the components and indicators within these components need to be measured. A decision support system will determine which are the important components and indicators to measure. It is suggested that a total of three indicators may be adequate to monitor each class of wetland.

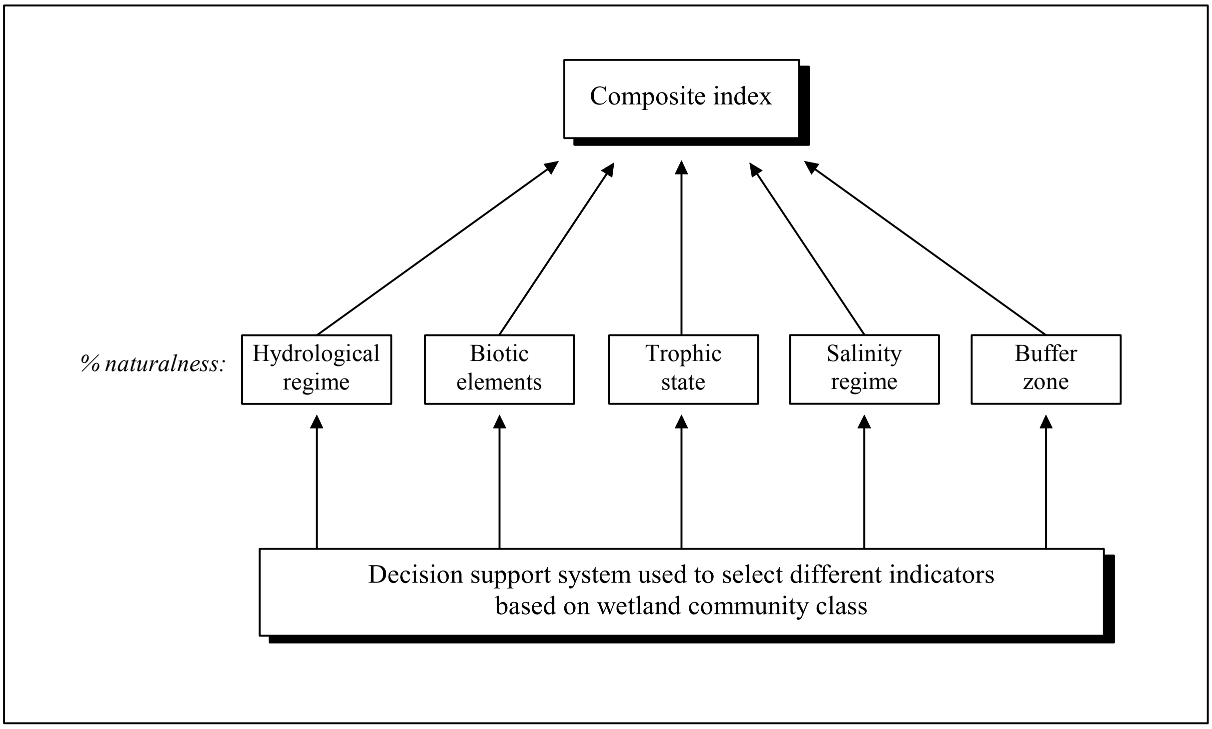

Figure 6.2: A suggested process for developing an index from the ecological elements of natural character of wetlands

The components of natural character of wetlands and suggested indicators are:

- ***Degree of naturalness of hydrological regime***

Some fluctuations of water level are normal for most types of wetlands and plant and animal communities can tolerate these. However, extreme fluctuations or change in mean water level or volume of flowing water can cause permanent change in vegetation types. Very long term changes in wetlands towards more terrestrial ecosystems are natural processes that need to be distinguished from short term change due to human interference.

- ***Degree of naturalness of biotic elements***
  (a) Fish populations/community especially with reference to migratory fish access (see Section 4.2.1)
  (b) Wildlife populations with species weighted for significance and sensitivity
  (c) Vegetation associations including weed induced changes
  (d) Invertebrates including benthos and zooplankton for different wetland types

Within the criteria, key species can be weighted in terms of endemicity and conservation as well as vulnerability in order to optimise for sensitivity and relevance (eg a high weighting could be assigned for the presence of rare and sensitive species like the dabchick).

- ***Degree of naturalness of trophic state*** *(*based on DSIR/NIWA formulae and new 5 point scales) A good indicator is the disappearance of oligotrophic species. Raupo and flax are good indicators of trophic level. Nitrate-nitrogen analysis can be used to sort out wetland types such as oligotrophic swamps from eutrophic wetlands. Qualitative and quantitative criteria can be combined in ranking scales.

- ***Degree of naturalness of salinity regime*** where tolerance of NZ is species known

- ***Character of buffer zone***

Width of buffer zone	- the wider the zone the more protection for the wetland from surrounding land use
Quality of buffer zone	- species in the riparian zone may affect the quality of the wetland

The top three indicators could be selected for each wetland community class for a minimum suite at each monitored site. Examples of these site specific indicators are shown below.

Examples of site specific State indicators of wetland community classes:

Kahikatea	- Degree of naturalness of hydrological regime eg magnitude and seasonality of level changes - Degree of naturalness of vegetation eg secondary changes in vegetation associations; impact of weeds
Restiad bog	- Degree of naturalness of hydrological regime - Degree of naturalness of vegetation
Mangroves	- % original area remaining intact/modified - Degree of naturalness of vegetation associations (% plant mortality; change in plant form)
Secondary indicators	- Sediment increasing/decreasing - Fish utilisation
Cushion bog	- Degree of naturalness of hydrological regime eg % change - Degree of naturalness of vegetation associations eg secondary changes

Status - To confirm and extend these to include other wetland community classes - small task

6.3 Indicators of Environmental Pressure on Wetlands

Changes to the spatial extent of wetlands at the regional level or dollars spent in wetland development can be used to give a national picture of environmental pressure on wetlands. Site specific pressure indicators need to be aggregated up to give a national trend and state of the overall wetland environments.

Site specific pressure indicators can include:

- ***Hydrological changes --*** water level variations are probably the most important stressors because wetland plants and animals can only tolerate a range of water levels for limited periods

Indicator	- Level and frequency of water level fluctuations
Status	- Ready to use

- ***Eutrophication/contamination***

Indicator	- To be developed

- ***Grazing, browsing, trampling --*** destroy plants and therefore wetland habitats

Indicators	- % wetland accessible to stock - % area grazed
Status	- Ready to use

- ***Fire --*** destroys wetlands

Indicator	- Extent and frequency of fire (% area)
Status	- Ready to use

- ***Barriers to access --*** fish may be prevented from reaching wetlands, which may be spawning habitat, by artificial barriers.

Indicators	- Type and height of barrier in relation to fish species - Distance from sea
Status	- Further work required

- ***Predators --*** may attack wetland species

Indicator	- Number and type of predator
Status	- Ready to use

- ***Weed invasions --*** smother native species

Indicators	- Type of weed - Extent of invasion - weeds assessed on a 1-5 scale (weed free - weed dominated/"stuffed")
Status	- Protocol needed for weed assessment

- ***Land drainage schemes***

Indicators	- % area affected by drainage - Land drainage expenditure
Status	- Ready to use

- ***Other changes in catchment land use/riparian condition --*** causing change in water level, addition of sediment, nutrients, micro-organisms, pesticides, contaminants to wetlands affecting stability of margins (stock trampling, removal of vegetation), plant communities, habitat for invertebrates, fish and birds.

Indicators	- % area of urban development in lake catchment - % area of agriculture/forestry in lake catchment - Proportion of wetland margin accessible to stock
Status	- Ready to use

6.4 Indicators of Management Response

These indicators are dependent on policy actions to be monitored such as Environment 2010, RMA section 6 matters of national importance, Wetlands Policy 1986:

- Proportion of each wetland type or class protected - in law
  - in practice
- Degree of public appreciation of wetlands - index of visits or key questions in surveys of public attitudes
- Degree of restoration funding provided by sources of pressure eg land drainage schemes
- % of each type of wetland restored/enhanced
- Number of wetland education programmes initiated including planting progammes in wetland margins
- Riparian/buffer zone management
- Consultation with iwi
- Land tenure/ownership status - may affect management possibilities

6.5 Data Presentation

Raw data needs to be sieved through the natural ecological criteria to form a non-parametric composite indicator. Each of these could initially be ranked on a 1-5 scale to give site-specific information. Some State indicator types may be able to be combined to give an overall index of natural ecological character.

Maps can be used for presentation of appropriate trend data, eg showing historical areas of wetland communities and present areas. These could be done using GIS.

Representative examples of each wetland community class could be surveyed every 2 to 5 years. For national consistency, a baseline survey is needed, which would be time consuming. Subsequently some changes could be recorded by remote sensing every few years. This would provide information about the boundaries but there would be a need to go back to the representative wetland community classes to assess the degree of modification.

Apart for the obligations of district and regional councils to monitor under the RMA, DoC has a responsibility under RAMSAR and New Zealand statutes to monitor protected areas, wildlife and freshwater fish; Fish and Game Councils have a responsibility to monitor their wetlands and those species assigned to them. It would be more efficient if all agencies were sharing the same databases with linkable GIS systems and working with each other.

6.6 Further Research

Further research on wetlands is needed in the following areas:

a) Databases need to be consistent and interchangeable so that regional and district councils, Fish and Game Councils and DoC can use them.

b) National guidelines are needed on the minimum number of examples of each wetland community classes to be monitored. Each site may contain more than one community class.

c) A framework is needed to decide what to monitor where. Some sites may be monitored primarily for pressure indicators; others for changes in state or condition; others for changes due to responsive management policy and action.

d) The ability to predict changes in wetlands needs to be refined as a result of both pressures and management responses (to assist decisions about the type and timing of intervention and the monitoring needed to assess changes).

e) There needs to be national consistency with regional councils and DoC working at different levels with different expertise. Need to get ecological principles down to a level where non-ecologists can understand them. Thinking needs to be more in terms of aquatic ecosystems and pressures than just water quality.

f) A rapid assessment protocol is needed as the basis of regular monitoring. A baseline survey involving considerable time and skill by animal and plant specialists could identify sites for on-going monitoring and further assessment by councils. All methods must be trailed before handing them over to councils. Certain permanent benchmark sites are needed as well as randomly selected sites.

g) Councils will need a manual to carry out wetland monitoring with criteria and a guide to site selection and monitoring for consistency between councils. Quality assurance, checking and auditing of council data may be needed.

6.7 Summary

All indicators must be relevant to policy and conform to the criteria set out in the Introduction (Section 1) as shown below in Table 6.1.

There is a need for an interim classification of wetland types each of which will have relevant indicators of ecosystem health. The classification needs to be pragmatic and easily communicable. Individual wetland sites often include complexes or mosaics of several different vegetation types or classes.

Region specific indicators include the spatial extent of wetlands and their number.

For site specific indicators, a composite index of wetland health needs to be developed using the ecosystem components listed below: A decision support system will be used to help councils select appropriate indicators to be aggregated for each type of wetland.

- Hydrological regime (degree of naturalness)
- Biotic elements (degree of naturalness)
- Trophic state (degree of naturalness)
- Salinity regime (degree of naturalness)
- Character of buffer zone

Examples of State indicators include:

- Number of wetlands
- % original area remaining although modified
- % original area intact and still viable
- Magnitude and seasonality of water level changes
- Secondary changes in vegetation associations
- Presence of rare and sensitive bird species
- Change in trophic state
- Width and quality of buffer zone

Examples of Pressure indicators include:

- Level and frequency of water level fluctuations
- % wetland accessible to stock
- % area grazed
- Extent and frequency of fire (% area)
- Type and height of barrier in relation to fish species
- Distance from sea
- Number and type of predator
- Type of weed
- Extent of weed invasion
- % area of urban development in lake catchment
- % area of agriculture/forestry in lake catchment
- Proportion of wetland margin accessible to stock

Table 6.1: Comparison of State indicators of the natural character of wetlands with the MfE criteria for indicators

Indicator	Criteria							
	Simple & Robust[1]	Policy relevant[1]	Scientifically valid	Responsive to change	Repeatable	Cost effective	Easily understood	Comments
Spatial extent % original area	✓ aerial photos	✓ lsc, nc	✓ techniques being developed	✓	✓	✓ aerial photos	✓ area is easy concept to grasp	needs guidelines for use
Hydrological regime water level changes	✓ visual assessment once set up	✓ lsc, nc	✓ techniques available	✓	✓	✓ once set up	✓	needs guidelines for use
Biotic elements Change in veg. assoc. Rare/sensitive bird sp	✓ visual assessment	✓ lsc, nc	✓ techniques available	✓ responds to changes over time	✓	✓ simple to assess	✓	needs guidelines for use
Trophic state change in state	?	✓ lsc, nc	✓ techniques available	✓	✓	?	?	needs assessment protocol
Salinity regime	✓ easily assessed	✓ lsc, nc	✓ techniques available	✓	✓	✓ simple to measure	✓ simple to measure	needs good framework
Buffer zone Width, quality	?	✓ lsc, nc	? more data needed	✓ responds to changes over time	✓	?	?	needs guidelines for use

Note: 1 = for relevance to aesthetics, contact recreation, etc, see Section 8
lsc = life supporting capacity (RMA s5)
nc = natural character (RMA s6)

Indicators of management response

- Proportion of each wetland type or class protected - in law
  - in practice
- Degree of public appreciation of wetlands - index of visits or key questions in surveys of public attitudes
- Degree of restoration funding provided by sources of pressure eg land drainage schemes
- % of each type of wetland restored/enhanced
- Number of wetland education programmes initiated including planting progammes in wetland margins
- Riparian/buffer zone management
- Consultation with iwi
- Land tenure/ownership status - may affect management possibilities

7 INDICATORS OF ECOSYSTEM HEALTH OF GROUNDWATER

- While there are potentially specialised biota in groundwater, these are not related to national indicators of ecosystem health so they will be discussed under indicators of biodiversity. For example, the Karst system in Nelson provides an interesting groundwater ecosystem.

- Groundwater frequently flows into surface water so ecosystem health is covered in the surface water flows.

- Known uses and values of groundwater are covered in Section 8.

Refer to drinking water standards, indicators of biodiversity, and indicators of pollution.

8 CORE FRESHWATER INDICATORS OF HUMAN USES AND VALUES

National indicators to measure the suitability of water resources for human uses and values are often measured by regional councils or health authorities as part of their state of the environment or regulatory monitoring. They include indicators for drinking water, contact recreation, water based recreation and agriculture. State indicators for these different water uses vary between uses but some are consistent with the indicators suggested for ecosystem health of water bodies. Indicators of environmental pressure and management response are similar for all human uses and values and are similar to those suggested for ecosystem health.

8.1 Drinking Water

Guidelines for drinking water standards are available from the New Zealand Ministry of Health. The Ministry can provide data on the percent of population where water supplies are adequate, inadequate or where there is insufficient information.

Most municipal drinking water is obtained from well-managed surface reservoirs, but groundwater is also an important source of drinking water in New Zealand.

Groundwater is stored in aquifers which are large, underground reservoirs that are connected with lakes, rivers and wetlands. The flow in aquifers is predominantly driven by rainfall, either by direct recharge (rainfall that drains through the topsoil) or by indirect recharge via rivers, lakes, etc. Groundwater systems can cover large spatial areas and, depending on the flow rates, can store water for very long periods of time. Contamination or over-abstraction of the groundwater can therefore have widespread effects that can last a long time.

The composition of water in an aquifer is directly dependent on the geology of the site and the origin of the water. The vulnerability of an aquifer to contamination or over-abstraction will depend on flow rates, and the depth of aquifer. Groundwater is most vulnerable to contamination in areas where the aquifer is unconfined (eg there is no impermeable sediment overlying the water-bearing zone). However, contaminated water can leak from these unconfined aquifers into deeper, confined aquifers.

Both the quality and quantity of groundwater resources will depend on activities on the surface. Management of groundwater quality is frequently achieved by identifying the major sources or areas of recharge and managing activities within these zones. Industrial areas and land-based effluent disposal within these zones are an obvious concern but forestry and agriculture can also have a significant influence on the quantity and quality of water that drains to groundwater.

A review of international standards indicated that there are no routinely used indicators of groundwater quality or contamination. Countries have water quality standards that depend on the intended use of the water. Standards exist for drinking water, water used for industrial purposes, irrigation water or water for livestock. Similar classifications are used as water quality classes in Schedule 3 of the RMA. However, because groundwater is such an important source of drinking water that is often sensitive to long-term and widespread contamination, groundwater is usually required to meet health-based drinking water standards (Ward *et al*, 1996).

- ***State indicators for use of groundwater***

  – **Groundwater quality**

The National Groundwater Monitoring Network was set up by the Institute of Geological and Nuclear Sciences (GNS) in 1990 and now covers the North Island and the heaviest groundwater use areas of the South Island. Wells are sampled by regional councils every 3 months and data is analysed by GNS for pH, alkalinity, conductivity, sulphate, chloride, nitrate, ammonium, phosphate, sodium, potassium, calcium, magnesium, iron, manganese and monomeric silica and occasionally for other elements such as fluoride and bromide (Rosen, 1996).

Point source contamination to groundwater may occur through consented discharges such as from the petroleum industry in Taranaki. These need to be carefully monitored.

Iron, nitrates and pesticides levels are often monitored in groundwater to ensure they do not exceed levels of nuisance (iron) or health safety (nitrate, pesticide). In regions where groundwater is used for drinking water, areas with nitrate and pesticide problems could be mapped to show the relationship to health and land use trends in time over the region.

Radon in water has become a big issue recently in the US and Australia (M Matthews pers comm). The NZ drinking water standards have adopted a maximum acceptable value of 100 becquerels per litre. (The bequerel, Bq, is the unit of radioactivity where 1 Bq = 1 nuclear transformation per second.) Radon is an inert gas produced by radioactive decay of radium in rocks. Groundwater passing through these rocks picks up radon and releases it at atmospheric pressure when the water is piped to ground level. There is some low health risk associated with inhaling radon or drinking water containing it (Matthews, 1996). Radon levels can be reduced by storage (radon has a radioactive half life of 3.8 days), aeration or heating.

Groundwater quality needs to be referenced to some benchmark so that water that is naturally unsuitable for drinking or irrigation can be located. The state of groundwater in both confined and unconfined aquifers needs to be mapped.

- ***Routine indicators measured for drinking water quality*** include:

  – pH for assessment of corrosiveness or scale formation in pipes
  – Conductivity/Total dissolved solids for hardness and taste
  – Nitrate-nitrogen in relation to health effects
  – Boron for testicular atrophy and plant toxicity
  – Lead, copper, antimony, nickel for corrosion and toxicity
  – Disinfection by-products as carcinogens
  – Iron for staining and possible promotion of bacteria growth in pipes
  – Manganese for staining and possible health effects
  – Sulphate for taste and corrosion
  – Chloride for taste and corrosion

- ***Second tier indicators*** may be required to reflect land-use activities where contamination is suspected. These include:

  - Faecal coliforms from effluent spraying, animals and birds in the catchment, or human recreational use
  - Phosphorus from fertiliser application
  - Chemicals from pesticide application
  - Colour, taste, odour and turbidity in some circumstances

Drinking water indicators

Indicators for use of groundwater
- quality - iron. nitrates, pesticides, radon
- resilience - flow, dissolved oxygen, redox potential, microbial populations

Indicators for drinking water quality:
- pH
- conductivity/total dissolved solids
- nitrate-nitrogen
- boron
- lead, copper, antimony, nickel
- disinfection by-products
- iron
- manganese
- sulphate
- chloride

8.2 Contact Recreation State Indicators

It has been estimated that up to 50,000 people swim in New Zealand lakes and rivers on a typical fine weekend summer day. The development of contact recreation indicators involves monitoring where people swim and undertake water sports during the appropriate season, particularly when low flows occur at this time. Do people select sites for bathing based on rigorous criteria such as the needs for shade, suitable access to water, adequate access to the site, amenities present, aesthetic water quality or faecal coliform levels? There has been no rigorous assessment of these criteria although E2010 states the need for suitable quality of freshwater for swimming. The RMA s6(d) lists the maintenance and enhancement of public access to and along the coastal marine area, lakes and rivers as matters of national importance, and s7(c) points to having particular regard to the maintenance and enhancement of amenity values.

An assessment protocol is needed to develop these indicators with involvement of regional councils. Key areas to be assessed for the development of indicators for contact recreation include:

- Water quality (clarity, colour, odour, floating debris, litter, periphyton, macrophytes)
- Safety and health issues (faecal coliforms, stock access to water)
- Public access
- Amenities (public toilets, picnic tables)

An index of suitability for a particular use could be developed from values for coliforms, water clarity and periphyton or macrophytes.

Microbiological organisms are used to indicate water contamination especially from sources such as sewage, agricultural and industrial wastes. Faecal coliforms, *Escherichia coli* (*E. coli*) and enterococci are used as indicators of public health safety, not because they are, themselves, a significant risk to health but because their presence indicates the possible presence of pathogenic organisms from faecal material, eg polio virus and hepatitis virus. The risk of contamination of these viruses increases with greater faecal contamination as indicated by high *E. coli* numbers. Water with an *E. coli* count of 0/100 mls has been assumed to contain no pathogens (Shaw, 1996).

It has been suggested that *E. coli* and enterococci may not be the most appropriate microbial indicators of risk of disease. This is because of different responses of *E. coli* to environmental factors such as uV light and temperature compared with the organisms of greatest concern. Enterococci have also been found on plants and in association with insects (Sinton *et al.*, 1993). Therefore, alternative microbial indicators are being sought that better reflect the potential risk to the New Zealand environment and people.

These indicators could be used for all surface and ground water systems. They apply to indicators of human uses as well as indicators of ecosystem health.

Suggested indicator for core set until more information is available:

Numbers *E. coli*/100 mls water

Water clarity - affects people's perception of water suitable for contact recreation

Periphyton/macrophytes

- These affect people's perception of water, ability to see the bottom, entanglement and slipperiness of rocks.
- More than 40% periphyton cover as a seasonal maximum is considered unacceptable for contact recreation (MfE Guidelines, 1992).

Contact recreation indicators	
	- Number of *E. coli*/100 mls water
	- Water clarity
	- Periphyton/macrophytes
Status	- Need detailed protocol of when to monitor

8.2.1 Data Presentation

Aggregate values of these three indicators may indicate suitable/marginally suitable/not suitable for that particular use. A decision support system could be developed to help local authorities decide on the selection of bathing sites to be monitored and when this needs to be undertaken.

Data could also be presented as number of sites with values for coliforms, water clarity and periphyton being unacceptable.

8.3 Water-Based Recreation State indicators

Water based recreation includes boating, fishing, walking, picnicking and bird watching.

Natural character is a key component of water based recreation and has both ecological and landscape components (Urlich and Ward, 1996). Research is needed into indicators of natural character of freshwater so that the instream and riparian environments of the river, lake or wetland meet the needs of a variety of users.

Trend indicators may be developed by regional councils for river reaches that are used by recreationists. One reach may meet the needs of some types of recreational use while another may not and this may vary over time.

Components to develop State indicators of water based recreation might include:

- Access -- Public access to and along rivers and lakes is recognised in the RMA section 6(d) as a matter of national importance. Access allows the use and enjoyment of rivers and lakes by a variety of user groups and for cultural and spiritual values. More work is needed on how to monitor the adequacy of access.

- Natural character of river and lakes -- The preservation of natural character of lakes, rivers and their margins and protection of them from inappropriate subdivision, use and development are also recognised as matters of national importance in the RMA section 6(a). Further work is required to tease out key indicators of natural character, but they might include water clarity, stream flow, shaded waterway and banks, vegetative cover of bed of river or lake, bank stability and vegetation for non-gravel bed rivers, and aspects of instream flora and fauna.

- Aesthetic quality of water – This can be important for certain types of recreation. It could include odour, clarity and odour of water, the presence of floating debris or litter, and excessive macrophytes and periphyton (see Section 4.2).

- Condition of fish stocks – Fish and Game Councils carry out some fish population monitoring related to their particular objectives, but this could be tied in with water quality monitoring carried out by regional councils. Monitoring includes:

  - Estimate of trout and salmon populations by fish counts or spawning counts in tributaries of rivers or lakes and where artificial barriers have been put in place and stopped spawning fish from migrating upstream;
  - Recruitment of juvenile fish to population in tributaries of some rivers;
  - Drift diving for numbers of adult salmonids (over about 30 cm) on some rivers where visibility exceeds 3 m;
  - Electrofishing for native and introduced fish species in upland streams to give an estimate of the health of the ecosystem; and
  - Biomass measurement of fish stocks providing comparable reaches can be used.

Research is currently underway on the effects of water quality on fish growth at Cawthron Institute.

- Amenity values -- These may be important to certain types of water based recreation such as the provision of toilets or picnic tables. They are listed in the RMA S7(c): having regard to the maintenance and enhancement of amenity values.

Perceptions of water quality also need to be considered in terms of landscape values and pollution.

Components for the development of indicators of water based recreation	
	- Access - Natural character of river and lakes - Aesthetic quality of water - Condition of fish stocks - Amenity values
Status	- Need detailed protocol of when to monitor particular indicators, how to measure access, how to assess natural character, how to incorporate Fish and Game Councils data on fish populations. Almost ready to use.

8.4 Agriculture

The availability of water and the quality of that water are important for agriculture. Indicators to show if water is unsuitable for a particular agricultural use, eg irrigation, stockwater, are suggested below.

Indicators may need to be measured to reflect land-use activities where contamination is suspected	
	- Faecal coliforms from effluent spraying - Phosphorus from fertiliser application - Chemicals from pesticide application
Status	- Need detailed protocol of when to monitor

8.5 Indicators of Environmental Pressure on Human Uses and Values

- Microbiological loadings
- Sediment/nutrient/organic matter loading

- Restricted access for recreationists due to subdivision, use and development of lake and river margins

- Water abstraction
  – % of allocable water allocated (groundwater/surface water)
  – Drop in groundwater level below acceptable value

Need more policy work on abstraction consents for regional councils

- Groundwater contamination
  – Nitrate contamination exceeds a safe health level
  – Management of groundwater quality is frequently achieved by identifying the major sources or areas of recharge and managing activities within these zones. Industrial areas and land-based effluent disposal within these zones are an obvious concern but forestry and agriculture can also have a significant influence on the quantity and quality of water that drains to groundwater.

- Condition of riparian zone
  - % vegetation cover
  - % shade
  - % invasion by weed species

- Pesticides and hazardous wastes affecting water quality and fish habitat
  - A suite of residues in water need to be monitored for bioaccumulation problems and for fish health advisors
  - The Ministry for the Environment has a research programme on monitoring organochlorines in the environment. This will provide a baseline and the results will be assessed for relevance to the indicator programme when the programme is completed in mid 1997.

- Fish access blocked (see discussion of native fish barriers in rivers section)
- Saltwater intrusion

8.6 Indicators of Management Response for Human Uses and Values

These are the actions taken to address observed or predicted environmental change or adverse effects:

- Land use controls
- Water treatment
- Use of water resources
- Resource consent management and monitoring programme
- Environmental education and change in human behaviour to remedy a situation
- Riparian/buffer zone management
- Consultation with iwi
- Review of contaminant residues in fish
- Fish passes installed
- Freshwater plans developed
- Regional groundwater monitoring programme

8.7 Summary

State freshwater indicators of suitability for human uses and values:

- Drinking water indicators
  - pH
  - Conductivity/Total dissolved solids
  - Nitrate-nitrogen
  - Boron
  - Iron
  - Manganese
  - Sulphate
  - Chloride

- Contact recreation indicators
  - Number of *E. coli*/100 mls water
  - water clarity
  - periphyton/macrophytes

- Water-based recreation indicators
  - access
  - natural character of waterbody
  - water clarity
  - macrophytes/periphyton
  - condition of fish stocks

- Indicators of water suitable for agriculture
  - supply of water available
  - faecal coliforms
  - phosphorus above acceptable levels
  - pesticide residues above acceptable levels

8.7.1 Indicators of Environmental Pressure

- Microbiological loadings
- Sediment/nutrient/organic matter loading
- Restricted access
- Water abstraction
  - % of allocable water allocated (groundwater/surface water)
  - Drop in groundwater level below acceptable value
- Groundwater contamination
  - Nitrate contamination exceeds a safe health level
- Condition of riparian zone
  - % vegetation cover
  - % shade
  - % invasion by weed species
- Pesticides and hazardous wastes
  - A suite of residues in water
- Fish access blocked
- Saltwater intrusion

8.7.2 Indicators of Management Response

Actions taken to address adverse environmental change:

- Land use controls
- Water treatment
- Use of water resources
- Resource consent management and monitoring programme
- Environmental education and change in human behaviour to remedy a situation
- Riparian/buffer zone management
- Consultation with iwi
- Review of contaminant residues in fish
- Fish passes installed
- Freshwater plans developed
- Regional groundwater monitoring programme

9 CONCLUSIONS/RECOMMENDATIONS

The development of indicators for sustainable management of freshwater is based on two objectives that arise from the RMA and the Government's Environment 2010 Strategy:

- Indicators to measure life supporting capacity/ecosystem health; and
- Indicators to measure suitability for human uses and values.

Indicators to measure suitability for human uses and values include indicators already measured by most regional councils.

A holistic perspective of monitoring freshwater ecosystem health is presented, but an effort is made to build on to the existing monitoring efforts of regional councils so that historical data sets can be used and extra expense is minimised.

All indicators must conform to the criteria set out by the Ministry for the Environment and are based on a pressure-state-response framework (MfE, 1996). The Ministry is interested in trends over time and data needs to be presented by regions to shown these trends.

Benchmark sites are needed against which to measure change from a pristine or desired state such as the best available land management practice. Observed values relative to expected values can then be plotted to obtain change over time towards or away from an expected state.

Indicators of ecosystem health have been divided into rivers, lakes and wetlands. The aim is to develop an integrated index for a particular waterbody or wetland from a selection of indicators that are chosen through a decision support system. The indicators are grouped into ecosystem components to provide an holistic approach to ecosystem health.

A decision support system, to guide councils as to the most appropriate indicators to monitor, needs to be developed along with protocols and regularly updated. Since NWSCA was abolished there has been very little development work of new tools for water managers.

9.1 State Indicators

The key components for the development of State indicators for freshwater are listed below. There are common components for rivers, lakes and human uses and values which would make the use of the same indicators much more straight forward for councils.

9.1.1 Primary Core State Indicators for Rivers

- Physical/chemical indicators
  - Amount of time the pH varies from the expected value for that river
  - Per cent of time that the sample exceeds a certain clarity value expected for that river

- Periphyton indicators
  - Presence/absence/% cover of heterotrophic slimes (sewage fungus)
  - Presence/absence/% cover of benthic algae (blanket weed, dark brown slimes, green filamentous growths in rivers)

- Aquatic macrophytes indicators
  - Floating plants: % cover; % cover of introduced/native sp.
  - Submerged plants: % cover; species, height/biomass with water depth; % cover introduced sp.
  - Emergent plants: % cover, biodiversity, % cover introduced/native sp.

- Macroinvertebrate indicator
  - Invertebrate community index scores observed/expected for that river type exceeds 0.75

- Fish indicators
  - Presence/absence of native species that are widespread, abundant and sensitive to environmental change: eg giant kokopu, banded kokopu, koaro, redfinned bully

- Birds indicator
  - Presence/absence of expected bird species

- Instream habitat indicators
  - Bottom substrate and available cover
  - Embeddedness
  - Velocity and/or flow
  - Pool/riffle or run/bend ratios

- Primary indicators of the riparian zone at the reach scale
  - % cover of riparian zone with vegetation along the length of the reach
  - % shade of waterway
  - % reach with eroded or collapsed banks in non-gravel bed rivers

Techniques are readily available and easy to use to measure most of these indicators.

9.1.2 Primary Core State Indicators for Lakes

- Change in trophic state indicators
  - Oxygen depletion rate
  - Water clarity
  - Chlorophyll-a
  - Total nitrogen and total phosphorus

- Littoral zone condition, species richness/diversity indicators
  - Depth of plant growth
  - Presence/absence of an expected species/community
  - % cover of zone by aquatic plants
  - Significant change in plant community composition

- Riparian zone condition, species richness/diversity indicators
  - % original lake margin remaining although modified
  - % original lake margin intact
  - % vegetative cover of lake margin

- Invasion by exotic species indicators
  - Presence/absence of exotic species
  - Extent of invasion within lake
  - Extent of invasion between lakes
  - Rate of spread of exotic species

- Physico-chemical elements indicators
  - Suspended solids
  - Nutrients

- Fish and birds

The trophic state of lakes has been traditionally monitored but techniques need to be improved so that small levels of change in state can be easily recognised by managers. There is also a need to move to a broader understanding of ecosystem health of a lake so that aspects other than those traditionally monitored are included. These are covered in the last five key components listed above. Indicators and protocols for measuring some of these components still need to be developed.

9.1.3 Primary Core State Indicators for Wetlands

- Number of wetlands
- % original area remaining although modified
- % original area intact and still viable
- Magnitude and seasonality of water level changes
- Secondary changes in vegetation associations
- Presence of rare and sensitive bird species
- Change in trophic state
- Width and quality of buffer zone

Only three indicators need to be selected for any particular type of wetland. More work is needed to define some of these indicators and the baseline condition of each type needs to be identified.

9.1.4 State Indicators of Human Uses and Values

- Drinking water
  - Data readily available from Ministry of Health
  - Suitability of groundwater for use includes groundwater level, quality and resilience

- Contact recreation
  - Microbiological organisms
  - Water clarity
  - Macrophytes/periphyton

Some more work is needed on micro-organisms, macrophytes and periphyton as indicators.

- Water-based recreation
  - Access (public access to and along rivers and lakes)
  - Natural character of river and lakes (key indicators could include water clarity, stream flow, shade, vegetative cover, bank stability)
  - Aesthetic quality of water (important for some types of recreation)
  - Condition of fish stocks (Fish and Game Councils monitoring data could be useful for health of fish populations)

- Agriculture
  - Water availability
  - Faecal coliforms from effluent spraying
  - Phosphorus from fertiliser application
  - Chemicals from pesticide application

These indicators could affect water used for irrigation or stockwater.

9.2 Indicators of Environmental Pressure

These are similar for all aquatic ecosystems:

- Change in catchment/riparian land use (may affect change in water level, addition of sediment, nutrients etc, stability of margins, plant communities and habitat for invertebrates, fish and birds)
- Point source discharges (may affect water quality)
- Barriers restricting fish access (affects inland migration of fish)
- Water level changes (affect plant and animal communities on the margin and may cause soil erosion)
- Introductions of exotic species (alter the natural character of the system, eg introduced plants smothering native plants)
- Eutrophication/contamination (high levels of nutrients, pesticides etc affect the natural ecosystem)
- Grazing, browsing, trampling (destroys plants and therefore habitats)
- Fire (destroys wetlands)
- Restricted access (to people wanting to use water for recreation)

Indicators of pressure on human uses and values include:

- Microbiological loadings
- Sediment/nutrient/organic matter loading
- Restricted access
- Water abstraction
  - % of allocable water allocated (groundwater/surface water)
  - Drop in groundwater level below acceptable value
- Groundwater contamination
  - Nitrate contamination exceeds a safe health level
- Condition of riparian zone
  - % vegetation cover
  - % shade
  - % invasion by weed species
- Pesticides and hazardous wastes
  - A suite of residues in water
- Fish access blocked
- Saltwater intrusion

9.3 Indicators of Management Response

These are similar for all aquatic ecosystems and human uses:

- Land use controls in place (regional policy statements can encourage councils to provide for public access)
- Water treatment
- Resource consent management and monitoring programme (resource consents are required for discharges to surface water to avoid adverse effects and thus to ensure minimum risk to water quality)
- Environmental education programme (advice to the community on management and use of water through freshwater plans, leaflets, talks, etc)
- Riparian zone management strategy (would help councils address management of riparian zones)
- Consultation with iwi (need to be involved at all stages of water management)
- Freshwater plans developed (to address effects of point and diffuse source discharges)
- Ownership status (may influence nature of management response)
- Boat access restrictions (where spread of exotic macrophytes are a problem)
- Proportion of each wetland type or class protected, in law and in practice
- Degree of public appreciation of wetlands (index of visits or key questions in surveys of public attitudes)
- Degree of restoration funding provided by sources of pressure, eg land drainage schemes
- % of each type of wetland restored/enhanced
- Review of contaminant residues in fish in response to results of bioaccumulation of pesticides

All indicators discussed in the report need supporting documentation so that they can be easily applied by local authorities.

9.4 General Recommendations

- Regional councils need to:
  - Adopt an ecosystem approach to monitoring under the RMA and E2010.
  - Be able to distinguish the ecotypes of rivers, lakes and wetlands in their region.
- A decision support system for rivers, lakes and wetlands is required to help councils to select the most appropriate indicators to monitor in a particular type of ecosystem in order to minimise costs and make use of current monitoring procedures.
- National consistency is needed with regional councils and DoC working at different levels with different expertise. Ecological principles must be expressed in terms that are understandable by non-ecologists. Council thinking should be more focused on aquatic ecosystems and pressures than on just water quality.
- There is a need for current up-to-date tools. Since NWASCA was abolished, there has been no further evaluation of tools.

- The system relies on good quality data, so good quality databases and handling protocols are required. In the past specific investigations have provided scientists with the data they need to develop an understanding of aquatic ecosystems. Increasingly this data is being collected by water managers, and data storage systems need to be accessible by both scientists and water managers. A current impediment overseas is the lack of consistency of data. For a small country the size of New Zealand, it is absurd to have many different data collection systems and protocols.
- Databases need to be consistent and interchangeable so that regional and district councils, Fish and Game Councils, DoC, iwi and community groups can use them.
- Further development of indicators and water science needs to build on existing data collected by regional councils wherever possible.

9.5 Requirements for Specific Freshwater Systems

- Standardised protocols are needed for aerial photography and ground truthing for riparian areas of rivers, lakes and types of wetland.
- A regional council technical working group is required to further develop methods for assessment of riparian systems.
- A numerical index of the trophic state of a lake needs to be developed.
- An intensive investigation of distribution and abundance of native fish in pristine freshwater habitats is required to provide a baseline against which to measure change in habitat and fish fauna, especially at low elevations.
- The life histories of poorly known fish species need to be studied.
- Research is required on the reproductive ecology of all large whitebait galaxiids.
- Quantification of habitat preferences for nearly all native fish species is wanted.
- The interactions between native and introduced fish species needs more research.
- An understanding is needed of the role of riparian and catchment vegetation as it affects stream fish species.
- National guidelines are required on the minimum number of examples of each wetland community classes to be monitored. Each site may contain more than one community class.
- Councils will need a manual to carry out wetland monitoring with criteria and a guide to site selection and monitoring for consistency between councils. Quality assurance, checking and auditing of council data may be required.

9.6 The Way Forward

Considerable development is needed to provide better protocols to bring monitoring in New Zealand up to the standards required in the RMA and Environment 2010. This will be achieved through the Ministry for the Environment's Standards and Guidelines Programme, the National Agenda for Sustainable Water Management, and through the Environmental Indicators Programme. Overlap between these programmes is envisaged. For example, a guideline on macroinvertebrates could cover indicators, consenting and policy development. The core is a good understanding of macroinvertebrates.

Regional councils as primary water managers need to work together. This can only be done in a collaborative manner involving regional councils, unitary authorities, central government, Crown Research Institutes, Fish and Game Councils and Department of Conservation.

Certain aspects of monitoring, such as collecting surface water samples and subjective assessment of plant and algal associations can be undertaken by communities. For this purpose, a community monitoring manual and training programme would need to be developed.

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APPENDIX I:

Overseas Freshwater Indicators

APPENDIX II:

Environmental Monitoring Performed by Regional & Unitary Authorities in New Zealand

(As at 30/9/96. Currently being updated.)

APPENDIX I: Overseas Freshwater Indicators

United States Environmental Protection Agency (USEPA)

The USEPA is developing a national set of indicators of water quality based on the Pressure, State, Response system (USEPA 1996). They have 13 freshwater indicators with targets set for the year 2005. Ten indicators are State indicators, two are Pressure indicators and one is a Response indicator.

The ***State*** indicators are:

1. Drinking water systems violating health standards.
2. Unfiltered community water systems at risk from microbiological pollution.
3. Drinking water systems exceeding lead action levels.
4. Fish consumption advisories to alert anglers of risks associated with eating contaminated fish.
5. Biological integrity (based on health of aquatic communities).
6. Species at risk that depend on aquatic or wetland habitats.
7. Wetland acreage.
8. (a) Drinking water supply designated use (% surveyed water bodies that meet standards)
   (b) Fish and shellfish consumption designated use.
   (c) Recreation designated use.
   (d) Aquatic life designated use.
9. Groundwater pollutants: nitrate levels above 10 mg/l.
10. Surface water pollutants: dissolved oxygen, dissolved solids, nitrate, total phosphorus, faecal coliform, suspended sediment.

The ***Pressure*** indicators are:

1. (a) Point source loadings to surface water: BOD, lead
   (b) Point source loadings to groundwater: untreated and commercial wastewater through septic systems (Response = number of shallow industrial waste disposal wells closed).
2. Non-point source sediment loadings from cropland: annual rate of sediment erosion to surface water.

The ***Response*** indicator is:

1. Source water protection: no. drinking water systems with source water protection.

Canada

Canada is also developing a national set of indicators for freshwater quality (Environment Canada, 1991[1]). In 1991, these were presented as:

1. Population served by treated water supply.
2. Municipal discharges to freshwater: BOD, total suspended solids, phosphorus.
3. Pulp and paper mill discharges to freshwater.
4. Discharges of regulated substances by petroleum refineries to water: TSS, oil and grease, ammonia nitrogen, phenols, sulphide.
5. Concentrations of phosphorus (total P, dissolved P) and nitrogen (nitrate + nitrite) in water.
6. Maximum observed concentrations of pesticides in water: 2,4-D, atrazine, lindane.

Indicators of ecosystem health are also being developed in Canada. Managers use ecosystem objectives when selecting indicators to determine whether changes in structure and function are acceptable (Canadian Council of Ministers of the Environment, 1994[2]). Ecosystem objectives therefore become critical elements to the indicator selection process. The Canadian Water Quality Guidelines Task Group suggests a participatory multi-stakeholder process to establish ecosystem goals and objectives which describe the desired state of ecosystem health in broad terms. Indicators are selected or developed that will measure the progress towards the attainment of each ecosystem objective. Any data gaps can then be targeted towards research and monitoring to meet decision makers' needs.

Suggested indicators of ecosystem health for Lake Ontario (Ecosystem Objectives Work Group, 1992[3]) include:

Aquatic communities:	fish level harvest size spectra of top predators benthic community structure physical measurements (eg: pH, temperature)
Wildlife:	presence/absence of Northern Pike deformities in Green Frog contaminants in Black Tern eggs hunting success of Belted Kingfisher
Human Health:	toxic contaminants body burden public perception of risk
Habitat:	area of wetland length of tributary channels area ratios (eg: urban/industrial)
Stewardship:	water consumption population density environmental volunteers land use

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1 Environment Canada (1991): A report on Canada's progress towards a national set of environmental indicators. *SOE* Report No 91-1.

2 Canadian Council of Ministers of the Environment (1994): *A framework for developing goals, objectives and indicators of ecosystem health: Tools for ecosystem-based management.* Water Quality Guidelines Task Group.

3 Ecosystems Objectives Work Group (1992): Interim report of the Ecosystems Objectives Work Group on ecosystem objectives and their environmental indicators. Draft report. August 1992.

APPENDIX II: Environmental Monitoring Performed by Regional and Unitary Authorities in NZ

	Rivers/Streams			***Lakes***			***Groundwater/Other***		
	Physical	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***
Wellington RC	•pH •Turbidity •Temperature •Levels •Flows	•DO •BOD •DRP •NO_3-N •DIN •Ammonia	•FC •Macroinvertebrate Communities				•Rainfall		•Macroinvertebrates •Periphyton cover
Otago RC	•Site description •Velocities							Yes	Yes MCI species diversity
Northland RC	•Flow •Description (depth, velocity, width)						•Common physico-chemical parameters •Groundwater depth		•Microbiological data
Taranaki RC	•Flow •Physico-chemical parameters	•Nutrients	•MCI •Algal cover			•Fish passage register	•Common physico-chemical water quality parameters •Pesticides •Ions •Wetlands - condition of (improved/deteriorated)		•Faecal indicator organisms •Invertebrate/algae

	Rivers/Streams			Lakes			Groundwater/Other			Coastal/Esturaine		
	Physical	*Chemical*	*Biological*	*Physical*	*Chemical*	*Biological*	*Physical*	*Chemical*	*Biological*	*Physical*	*Chemical*	*Biological*
Environment Waikato	•Habitat •Cross-sections - Bed levels etc •Flow •Levels •Turbidity* •SS* •pH* •Conductivity*	•Temperature* •DO* •%DO* •BOD* •TOC, DOC* •Alkalinity* •Nutrients and metals*	•Macro-invertebrates •Periphyton •Macrophytes •Chlorophyll a* •FC* •Enterococci* * Waikato River only	•Water level •Temperature •Depth •Turbidity •SS •pH •Conductivity •Absorbance	•DO •% DO •BOD •Nitrate •Ammonium •NO_3-NO_2 •TKN •DRP •TP	•Chlorophyll a •Phyaeophytin •Phytoplankton •FC •E. coli •Enterococci	•Rainfall •Common physico-chemical water quality parameters		•Faecal indicators, •phytoplank-ton	•Turbidity •SS •Salinity •Temperature •pH •Conductivity •Absorbance	•DO, % DO •BOD •NO_3^-, NH_4, TKN •NO_3-NO_2 •DRP, TP •SO_4^{2-}	•FC •TC •F Strep •E. coli •Enterococci •Heterotrophic plate counts
Southland RC							•Standard Physical - chemical parameters		•Aquatic Macro-invertebrate •FC			
Canterbury RC	•Temperature •pH •Conductivity •SS	•DO •NNN •NH_3 •TKN •SRDP •TP •Pesticides	•Invertebrates •FC •Chlorophyll a •Phaeophyton	•Temperature •Conductivity •Seechi •Turbidity	•NNN •TKN •NH_3 •TP •SRDP	•Chlorophyll a •FC	•pH •Conductivity •Saltwater intrusion	•Ca •Mg •Na •K •SO4 •Cl •HCO3 •Fe •Mn •NO3-N •Ions •Pesticides •Hydrocarbons	•FC •TC			
Auckland RC	•Fish Habitat Characteristics		•Fish Species •Invertebrate Species •Intertidal sandflat communities									
Nelson CC	No regular baseline monitoring undertaken - one survey per year on particular area of concern. Consent monitoring undertaken. Monitoring strategy underway at the present time.											

	Rivers/Streams			*Lakes*			*Groundwater/Other*			*Coastal/Esturaine*		
	Physical	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***
Marlborough DC	•Recently established programme - basic physico-chemical parameters (nutrients, DO, BOD etc)		Coliforms Invertebrates, algae for specifically targeted rivers) IFIM, fish survey occasionally on some rivers				Physical-chemical parameters. Pesticides biannually.					
Gisborne DC	•Temp •SS	•DO, BOD, pH •BOD_5 conductivity •SO_4^{2-} •DRP •NH_3, Na^+, K^+, Cl^- •Total hardness	•FC •TC •Enterococci				•Temp	•pH •Conductivity •Salinity •Total hardness •Alkalinity •HCO_3 •CO_2 •Fe, Na^+, K^+, Al^{3+}, Mn^{2+}, Cl^- •SO_4^{2--} •DRP •NH_3, NO_3^- •BOD, COD •Pesticides	•TC •FC •Enterococci	•Temp •SS •Floatable grease •Total grease	•pH •Conductivity	•TC •FC •Enterococci
Environment BOP	•Flow •Levels •Black disc •Absorbance •Temperature	•DO, BOD, SS, pH •Conductivity •Turbidity •TKN, TP, DRP, NO_3-N, NH_4-N,	•MCI (based on stream invertebrates) •Enterococci •FC, E.coli	•Levels •Temp •Secchi disc/ •Black disc •Light extinction coeff.	•DO, TN, TP, DRP, NO_3-N, NH_4-N	•Phytoplank-ton •Chlorophyll a	•Levels •Rainfall	•SO_4 •NO_3-N •NH_4-N •Fe, Al, Ni •Zn, B, Cu •Cr, Pb, Cd •Mn, As,Se •SiO_2, TP				•Macrofauna •SPS •TOC •Algae

	Rivers/Streams			***Lakes***			***Groundwater/Other***			***Coastal/Esturaine***		
	Physical	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***	***Physical***	***Chemical***	***Biological***
Hawkes Bay RC	•Temperature •Conductivity •SS •Turbidity	•DO, pH, BOD_5 •Cl^-, SO_4^{2-} •Mg, Ca, Na, K •TP, DRP, soluble P •NO_3, NH_4, TN •TOC •Alkalinity •flouride •Bicarbonate, carbonate •Mg, Ni, Zn, Cd, Pb, Cr, Cu, AS, H, g* •Herbicides, pesticides & SVOC, VOC, PAH* *Selected sites	•TC •Enterococci •Macro-invertebrates** •Periphyton** •MCI •Presence/ absence of fish **One-off survey									
Manawatu-Wanganui RC	•Conductivity, DO, pH, SS, PAR •Turbidity •Visibility •Temperature	•NH4 •DRP •NO2 •NO3 •BOD5	•Algal growth •Enterococci									
Tasman DC	•Levels •Ground levels		•Vegetation changes									
West Coast RC	No baseline or regular monitoring undertaken - only with respect to compliance with resource consents, eg oxidation ponds sampled biannually. Specifically, no sampling undertaken in lakes, and only limited turbidity and SS in some rivers re resource consents. Plan to undertake a monitoring programme later in 1996.											