NSW State
Rivers and Estuaries Policy

State of the Rivers and Estuaries

Environmental Indicators
A Literature Review

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Water Resources

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INTRODUCTION

Environmental indicators provide a feedback loop in the management system. A prerequisite of sustainable resource management is a sound knowledge of the condition of the resources, the existing and emerging problems and the trends toward either further deterioration or improvement. There is now general agreement that rivers must be managed on a whole-catchment basis, therefore indicators used to assess the state of the rivers may also be useful to assess the broader state of the catchment. Appropriate and accessible information about the 'health' of stream ecosystems also assists in choosing management actions and evaluating the success or otherwise of past management strategies.

This review discusses environmental indicators to assist in identifying a preferred set of indicators with which to assess the condition of our rivers and estuaries over time. Following this review a preliminary set of indicators will be identified and used in the New South Wales Rivers and Estuaries Policy pilot study of the Orara River on the north coast of NSW. This initial pilot study will report on the adequacy of existing environmental data and make recommendations for the future in relation to State of the Rivers and Estuaries reporting and the use of river and estuarine indicators. State of the environment reporting such as this may be defined as a systematic analysis, description and presentation of credible, scientifically-based information on environmental conditions and trends, and their significance to human relationships with the biosphere (Ministry for the Environment New Zealand 1991).

Many river systems are seriously degraded and their long term ecological sustainability is in jeopardy (Hart 1992). Appropriate indicators of a river and catchments ecological condition should satisfy four conditions if they are to be used to help reverse the trend of river deterioration (after Hart 1992; Mitchell 1990; and Keogh and Quinn 1991): First, the indicator must provide a sensitive reflection of changes in the river or stream. Commonly used physicochemical indicators alone are not sufficiently sensitive to environmental changes (Commissioner for the Environment 1988). Second, the indicator should be measured relatively easily. Third, for the indicator to be useful in providing information on the trend in quality over a period of time, adequate long term data bases must be available. Fourth, key indicators should be chosen for their pivotal position in the system so that changes to the indicator are likely to be of importance to the entire system. Indicator variables should also be causally linked to human impacts where negative impacts need to be determined.

A problem with catchment assessment in Australia has been the failure to set clear and specific objectives for the quite expensive monitoring programs undertaken by State agencies (Cullen 1990). This has meant there is no basis on which to decide on appropriate indicators and sampling regimes. Additionally, high natural variability in climatic conditions, flow regimes, water quality and in the abundance of biota in Australian streams and wetlands, makes it difficult to establish trends in ecosystem functioning. The inherent variability in these processes requires a special sensitivity to issues of seasonality in data gathering and statistical analysis aimed at determining trends, and a relatively long period of monitoring (Bennison et al 1989; Commissioner for the Environment 1989).

In assessing river and estuarine indicators, this review considers the methods of using the indicator, what the indicator says about the river estuary or catchment, the possible causal links to human impacts and the appropriateness and applicability of the indicator.

2.0 WATER QUALITY INDICATORS

The best developed indicators of those reviewed are physicochemical indicators of water quality. These are well suited to monitoring objectives related to control of input of contaminants, but are not as well suited to monitoring ecological integrity (Constable 1991). Physicochemical water quality indicators directly monitor environmental quality objectives. These include most of the utilitarian objectives such as the provision of a safe drinking water supply, recreational uses and water for agriculture and industrial uses.

Monitoring has generally provided a broad assessment of changes in levels of individual inputs, but has not been sufficiently sensitive to environmental concerns to permit an association of, or differentiation between, natural and human impacts (Commissioner for the Environment 1989).

To validate comparisons of water quality, the degree of uncertainty (precision) must be estimated and environmental variability must be accounted for in sampling (Norris and Georges 1986; Maher and Norris 1990). Australian fluvial systems are characterised by low discharges and highly variable flows and have unique ecosystems in their catchments and lotic environments (Hart and Campbell 1991). A broad range of species have adapted to relatively major natural stresses. These species and environmental processes, however, cannot tolerate certain changes in water quality or composition which occurs through the introduction of contaminants or as a result of significant systemic changes (Commissioner for the Environment 1989).

The difficulty in establishing trends caused by the large natural variability in Australian streams has been highlighted in several case studies (CEE 1990).

In studying the effects of phosphorus removal from discharges to Jacksons Creek in Victoria, it was found that the change in flow patterns from year to year overshadowed the effect of large alterations in phosphorus input. Thus, even with a large change in nutrient input, a long period of monitoring is essential to establish the effects. Concurrent monitoring of streamflow and multi-variate analysis may be useful in establishing trends.

In examining water quality data for the Ovens River and Cann River basins, it was found that the 1982-83 drought 'masked' many of the trends which may otherwise have been apparent. Thus, even with almost a decade of monthly data, a significant drought within an eight year period of monitoring made it difficult to establish statistically significant trends at many stations and for many parameters.

In studying the sediment flux into Westernport Bay, it was found that the bulk of the sediment (more than 80%) was transported in a few large floods. Thus it was not possible to make year to year comparisons of sediment transport, and only feasible to make decade to decade comparisons on the basis of a sophisticated flow/ flux analysis.

Monitoring on an event by event basis may be required for various water quality parameters particularly associated with non-point source pollution.

Computer pollutant mapping and the use of geographic information systems (GIS) has potential to be a powerful management tool in relation to environmental indicators. Pollutant and 'hotspot' mapping have an essential role in our fight for chemical awareness and a cleaner environment (Grinter and Wickens 1991). In 1990 the research group of the North Coast Environment Council was awarded funding by the Federal Department of Environment to compile pollutant computer maps for the Coffs Harbour Region, NSW. A regions chemical or pollutant load may be better understood by linking identified landuse to an information system about the chemicals used and identified as residues. The computers analytical power may be used to determine where these potential pollutants could end up and what their effects would be on the regions environment (Grinter and Wickens 1991).

GIS can also include all potential point source pollution such as rubbish tips, cattle tick dip sites, industries and sewerage outlets. Other essential data is the geographic location of fish kills, water, soil and fauna residues and algal blooms and human health concerns (Grinter and Wickens 1991).

2.1 TURBIDITY

The *turbidity* of water is connected with the presence of suspended and colloidal substances of various origins. These substances contain particles of suspended silt including a complex mixture of solid organic and mineral substances, coagulating organic colloids of iron and aluminium hydroxides, microorganisms, phytoplankton and zooplankton (Water Board 1992; UNESCO and WHO 1978).

Turbidity is measured as the light scattering caused by the water sample. The instrument generally used to measure this light scattering is called a nephelometer and the units are nephelometric turbidity units (NTU) (Mackay et al 1988; Water Board 1992).

Appearance is associated with turbidity and is a subjective indicator which represents the extent to which the river waters appear to be polluted by foam, scum, obvious algal blooms, discoloration, oil slicks or rubbish (CEE 1990). These visual and aesthetic indicators may be more important to, and better recognised by the community, than other less tangible indicators of river quality. The community may respond more strongly and have a better perception of visual as well as odour problems with a river section.

Colour is generally not a useful indicator of other forms of pollution although it may indicate elevated levels of organic material.

By reducing the light available for photosynthesis, *turbidity* can have a profound effect on phytoplankton, attached algae and submerged macrophytes in the river. This impact on primary production can be one environmental factor determining the nature of zooplankton, benthic invertebrates, fish and waterbird populations (Mackay et al 1988; Water Board 1992). Since 1974, 90% of samples taken at Burtundy (Darling River) had a turbidity in excess of 27 NTU (Bek and Robinson 1991). Turbidities in this order are expected to significantly reduce light available for growth and hence represent a measure of inhibition against plant growth. Lloyd (1985, cited in Blue-green Algae Task Force 1992) concluded that an increase in turbidity of 25 NTU in clear shallow streams may reduce stream plant growth by 13-50% or more.

Poor farming practices, stream bank erosion, the presence of dispersive clay soils and extreme variability of climate may have led to increases in *turbidity* in the Murray-Darling Basin. European carp have also been cited as the cause of an increase in river turbidity (Mackay et al 1988). For the river Murray in South Australia there are reliable turbidity records spanning four decades. These records clearly show the natural variability in river *turbidity*, however, because of this variability, it is not possible to establish a meaningful trend in turbidity levels (Mackay et al 1988).

Satellite remote sensing (e.g. Landsat Multispectral Scanner) with computer techniques to analyse spectral data offers the potential to monitor large areas efficiently using measured changes in spectral reflectances from landscapes and waterbodies to show where environmental changes have occurred (Ritchie and Cooper 1991). If changes in spectral reflectance measured from waterbodies by satellite sensors can be quantified and related to surface suspended sediment concentrations, monitoring programs using such reflectance data could be developed to locate water quality problems caused by surface suspended sediments. Studies have shown good relationships between changes in surface suspended sediments and spectral data (Ritchie and Cooper 1991 and references therein).

2.2 TEMPERATURE

Water *temperature* is an important characteristics which determines, to a considerable extent, the trends and tendencies of changes in water quality. *Temperature* measurement is also necessary for conductivity measurements and is important in the interpretation of biological data (UNESCO and WHO 1978).

A reduction in water *temperature* may severely limit the growth rates of fish and production rates within the stream, particularly during known fish migration and spawning. The feeding activity and metabolic rate of fish also depends on water temperature (Jackson 1986).

Temperature affects the solubility of dissolved gases in the water (particularly dissolved oxygen) which affects phytoplankton growth. Calm conditions and high temperatures may result in thermal stratification of the water body. This may have profound effects on all phytoplankton (Blue-Green

Algae Task Force 1992). *Temperature* stratification is a common phenomenon occurring in deep lakes and reservoirs and for short periods in river weir pools in summer.

Impoundments are a major cause of change to water temperature in streams. Most headwater impoundments release water from valves at the bottom of the structure which is significantly cooler than the water flowing into the impoundment (Lawrence 1991). There is a corresponding lag in the seasonal changes in downstream water temperature and these effects are apparent for some distance downstream.

In some cases, *temperature* is the direct index of the influence of human impacts on the quality of water (Thermal pollution) (UNESCO and WHO 1978). Water temperature therefore may best be assessed downstream of impacts, such as power plants and impoundments.

2.3 pH

pH is governed partly by the mineral content of the water and hence by the geology and soil processes of the catchment. *pH* is also affected by bioactivity in the water via photosynthesis (UNESCO and WHO 1978). *pH* may increase as a result of photosynthetic uptake of carbon dioxide by algal blooms during the course of the day (Water Board 1992).

Changes to *pH* may indicate changes to water quality which will directly affect the condition of the environment, or point to the presence of other harmful pollutants, such as those from industrial discharges (Water Board 1992). *pH*, like temperature, has a diurnal cycle which may affect its measurement depending on the time of sampling.

2.4 CONDUCTIVITY

Conductivity (salinity) is a measure of the concentration of salts or major ions in solution. The significant salts are chlorides, sulphates and bicarbonates of sodium, potassium, calcium and magnesium. *Salinity* is a key indicator due to its importance to water users and the possible impacts on aquatic and riparian vegetation and macroinvertebrate fauna.

The long records of *salinity* available for a number of locations along the Murray have been examined for trend using a variety of statistical techniques, from simple regression analysis to more complex methods involving transformation of the data and removal of seasonal and irregular components (Cunningham and Moreton 1983 and 1985; EWS 1983, cited in Mackay et al 1988).

Each of these studies showed a statistically significant trend of increasing *salinity* in the lower reaches of the river. As emphasised by the authors of these studies, the *salinity* of the River is highly variable and there are wide confidence limits on the trend estimates.

As the variation in *salinity* can largely be explained by variation in flow (salinity increases under low flow via the regional watertable) it might be assumed that the trend of increasing salinity in a river is a consequence of decreased flow as more water is diverted for irrigation upstream (Mackay et al 1988). For the Murray River the unavoidable conclusion is that a real increase in river *salinity* is occurring as a result of ongoing changes (natural and human-induced) in surface and groundwater hydrology (Mackay et al 1988).

One of the fundamental determinants of the character of estuaries is the *salinity* regime at various depths and distances upstream. Change to this regime is often a precursor to more observable change in the estuarine and foreshore flora and fauna (Victorian Institute of Marine Science 1991). Monitoring of the *salinity* (and temperature) profile over the depth of the estuary is all that is required to detect such change and is recommended for estuaries subject to human induced change (Victorian Institute of Marine Science 1991). Numerical models may offer some assistance in this assessment.

2.5 NUTRIENTS

Nutrient data provide a composite picture of the nutrient environment, as such they describe the potential of the system as an algal or macrophyte habitat. The realisation of that potential depends on a number of other characteristics both biological and physicochemical (Mackay et al 1988). Turbidity and temperature are the parameters most likely to alter algal ability to utilise the nutrient environment.

The plant nutrients phosphorus, nitrogen and silica are necessary for the ecological viability of the river. However, in excess, they are potentially serious pollutants encouraging nuisance growths of algae, blue-green algae and aquatic plants and, in the case of nitrate-nitrogen, posing a direct threat to human health.

Research is needed to determine the intermediate and ultimate fate of nutrients and to determine direct methods for identifying sources of nutrients.

2.5.1 Phosphorus

Phosphorus is rare in the geology and soils of NSW. Its introduction to waterways as a residue of fertilisation and other farming practices, and in effluents from urban and industrial areas, increase its concentrations well above natural background levels (Bek and Robinson 1991). Most of the NSW rivers, especially those in the west, have *phosphorus* levels far higher than what may be called natural (Bek and Robinson 1991).

Phosphorus is considered to be a conservative element. After it enters a river system it will remain, recycling through components of that system until it reaches the sea, is permanently lost to the sediment or leaves as part of the food chain (UNESCO and WHO 1978).

Under aerobic conditions, *phosphorus* is bound to iron or manganese which precipitates into the river bed sediment surface. In this way the *phosphorus* becomes immobilised and thus unavailable to phytoplankton. Under these conditions the external loading (e.g. sewage effluent) is the major source of bioavailable phosphorus. However due to the breakdown of organic matter by microorganisms, the sediment interphase may become anoxic resulting in the dissolution of the metal ions, releasing soluble phosphorus into the water column. This concept applies equally well to flowing water bodies where longitudinal displacement of the cycle due to flow creates a spiralling of nutrients (Blue-green Algae Task Force 1992).

Phosphorus is a key indicator due to its driving influence in the blue-green algae problem and, with nitrogen, is a major macronutrient for plant growth. For sufficient *phosphorus* to support the recent Barwon-Darling algal bloom, there may have been phosphorus release from the river bed sediment under an anaerobic conditions (Blue-green Algae Task Force 1992).

Aquatic plants can choke river channels, and algal blooms and scums are unsightly and foul smelling (eutrophication). Blue green algae can be toxic to animals and humans through body contact and ingestion. When plants and algae die their decomposition consumes oxygen dissolved in water, creating stagnant conditions and a hostile environment for fish, crustacea and other aquatic animals (Bek and Robinson 1991).

Total-phosphorus (generally milligrams phosphorus/litre in the water sample) includes that *phosphorus* bound to particulate matter and also colloidal and soluble orthophosphate. Total-phosphorus data for the River Murray water quality study (Mackay et al 1988) reveals a steady increase in concentration along the Murray. The increase from the upper Murray to its lower reaches in South Australia is approximately five-fold. Concentrations appear to be higher in tributary streams than in the Murray at each point of confluence. This is particularly true of tributaries with intensive agriculture in their catchments and those small streams which carry irrigation drainage water.

Filterable reactive phosphorus (FRP) or soluble phosphorus is a component of total-phosphorus and represents an estimate of the concentration of phosphorus immediately available for plant uptake and growth (CCREM 1987).

2.5.2 Nitrogen

Nitrogen is an important macronutrient for plant growth and is specifically useful for monitoring treatment plant effluent (CEE 1990). *Nitrogen*: phosphorus ratios are also useful to indicate the potential for a blue-green algal bloom (Blue-green algae task force 1992).

Nitrates are the end product of the biochemical oxidation of ammonia which is formed chiefly as a result of the breaking up of protein substances. Increased concentrations of *nitrates* may indicate faecal pollution of the body of water in the preceding period (UNESCO and WHO 1978).

Nitrites appear in the water mainly as a result of biochemical oxidation of ammonia or the reduction of nitrates. The reduction of *nitrates* with the formation of *nitrites* takes place under conditions where there is a deficit of oxygen in natural layers of the water and in bottom deposits. Together with other ingredients, the concentration of *nitrates* and its dynamics and distribution serve as an important index of the above mentioned process (UNESCO and WHO 1978).

Ammonia is toxic to fish and some invertebrates, is a standard water quality parameter for effluent and river water and provides a measure of possible toxicity (CEE 1990). Existing monitoring may collect all the *ammonia* data required.

Total organic nitrogen generally measured as **Kjeldahl-N** differs in form and ecological significance from soluble inorganic nitrogen ions (NO_x). *Kjeldahl-N* represents all organic forms of nitrogen including dissolved ammonia, suspended organic material and complex proteins in the bodies of microscopic organisms. Thus it represents that part of the nitrogen resources of the system currently in the organic 'pool' (Mackay et al 1988).

2.5.3 Total nutrients

CEE (1990) recommends *total nutrients* as an indicator that takes into account the ratio of nitrogen to phosphorus in aquatic algae which is typically 10:1, and hence is calculated as:

Total nutrients = Total N + 10 x Total P.

Total nutrients provides a direct measure of the potential for algal blooms.

2.5.4 Chlorophyll-a

Chlorophyll-a is the green photosynthetic pigment of plants. It is widely used to estimate the phytoplankton standing crop (Water Board 1992). A common approach is to classify waterways in terms of their trophic status; however this measure is not suited to measuring the trophic conditions in upper catchment sites. There is a good relationship between nutrient concentration and *chlorophyll-a* concentration (McComb and Lukatelich 1990). *Chlorophyll-a* is generally measured in micrograms of chlorophyll per litre.

2.5.5 Soluble organic carbon

Soluble organic carbon (SOC) is derived from living and dead vegetation and animals in the catchment. The measured *SOC* includes a portion from the cellular material of algae ruptured during the filtration process carried out prior to analysis. *SOC* completes the picture of the nutrient status of a water body and is a more valuable parameter to measure than chemical oxygen demand (COD) because the latter includes other non-carbonaceous compounds which exert demand for oxygen under the conditions of the determination.

Soluble Organic Carbon is a relatively newly measured parameter and periods of record are too short to allow any substantial interpretation of data. For the Murray river where *SOC* has been monitored since 1984, data suggest a positive correlation with flow, and an increase in concentration with distance downstream (Hine and Bursill 1987 cited in Mackay et al 1988).

2.5.6 Silica

Dissolved silicon (in filtered samples) is used as a measure of *silica* available for diatom nutrition (Mackay et al 1988). Dissolved *silica* enters surface water mainly from geologic sources and is measured in milligrams of silicon dioxide per litre. Depletion of dissolved *silica* from the water column may limit the development of diatom populations (Water Board 1992). The value of silica as an indicator is therefore limited to use in relation to diatom assessment.

2.6 DISSOLVED OXYGEN

Dissolved oxygen concentrations (DO) influence the biotic structure of a water body. *DO* determines the form in which a chemical will dominate and therefore effects phytoplankton. It may also determine species dominance in the food chain (Blue-green algae task force 1992).

The oxygen content of water can be an important indicator of pollution of a water body, indicating its biological state, the predominant processes, the destruction of organic substances and the intensity of self purification (UNESCO and WHO 1978).

Stress on aquatic organisms is mostly related to the lowest concentrations of *DO* each day. Variations in *DO* indicate the trophic status of a river and the likely stress on aquatic organisms due to algal blooms and biological decomposition (CEE 1990).

2.7 BIOCHEMICAL OXYGEN DEMAND

Biochemical Oxygen Demand (BOD) has been a major indicator of organic pollution in the water industry. The problems associated with the *BOD* test can be eliminated, thereby retaining confidence in its use (Tyres and Shaws 1989). Commissioner for the environment (1989) recommends *BOD* as one of its key chemical indicators for state of the environment reporting in Victoria.

The National Rivers Authority (1991b), U.K., selected dissolved oxygen, *BOD* and ammonia as their three major parameters for their survey on the nation's rivers. This limited range and the variability of these measures may give a quite different assessment of U.K. rivers if other and equally valid parameters are used. This was illustrated for this survey where the Guardian newspaper in Britain, studied the nation's rivers using different parameters and revealed a quite different assessment of the rivers. This emphasises the importance of selecting a range of indicators which will provide a clear and realistic picture of the state of the rivers and be useful for management.

2.8 FAECAL COLIFORMS AND *ESCHERICHIA COLI*

These parameters are useful in identifying changes in the microbiological quality of effluent as well as river water at recreational sites (CEE 1990). The presence of *E.coli* is an indicator of recent faecal contamination of water by warm blooded animals. It is generally assumed that high counts of these bacteria may be associated with heavy rainfall and runoff. It is likely that in the Murray the primary source of contamination comes from the faeces of stock grazing along the river (Mackay et al 1988).

Other coliform bacteria are free living in the soil and on vegetation, so that *total coliform* count is not, in itself, an indicator of faecal contamination (Mackay et al 1988).

A problem with coliform bacteria analysis is the time taken to determine the results. A simple rapid method for determining *total coliforms* and *E.coli* in drinking water was evaluated by Argent et al (1991), using defined substrate technology.

2.9 TOXIC SUBSTANCES

Toxic substances such as heavy metals, petroleum derivatives, polychlorinated biphenyls (PCBs), Lyanids, and pesticides are generally associated with industry (e.g. manufacturing, refining), sewage treatment works and mining wastes. They inhibit important biological processes, cause physical distress in wildlife, have cumulative effects in the food chain and may be mutagenic or carcinogenic, e.g. PCBs (Department of Water Resources, Victoria 1989).

2.9.1 Chemicals

A toxicant creating a polluted environment will affect biota by stressing or eliminating sensitive individuals or populations of organisms. The chemical will exert a selection pressure on the organism, and their fitness or reproductive ability may be affected (Blank et al 1989).

In aquatic environments subject to pollution stresses, increased tolerance has been found in populations of bacteria, algae and aquatic animals such as chironomids, polychaetes, gastropods and fish (various references cited in Blank et al 1989).

In relation to pesticides and other toxic substances, rather than monitor the water it would be more effective to investigate the *levels of pesticides in bottom sediments and biota* (where pesticides are known to accumulate) from localities of known pesticide use (Mackay et al 1988).

The Victorian Advisory Group on environmental indicators proposed chlorinated and brominated hydrocarbons in sediments as key indicators for Victorian state of the environment reporting.

2.9.2 Heavy metals

The geochemistry of heavy metals in aquatic ecosystems is dominated by solution, complexion, oxidising and reducing reactions, precipitation and remobilisation processes. Their ecotoxical properties, especially their bioavailability, changes markedly in accordance with their chemical status (Schirmer 1990).

When heavy metals reach the tidal and/or brackish water region they are subjected to pronounced changes in hydrographic and chemical conditions. The accumulation of suspended solids, an increase in fined grained and organic material in the sediments, and growing salinity are the predominant factors affecting their geochemical status in estuaries. Often heavy metal monitoring practices do not adequately recognise these dynamics (Schirmer 1990).

The concentration of *heavy metals in sediments and indicator organisms* can provide a direct measure of the extent of accumulation of these contaminants over time (CEE 1990). However, determinations on organisms tissue may be expensive, may show great variation with the age of the organism (and within age groups) and could be difficult to interpret (Mackay et al 1988). The choice of organisms to use as indicators in this regard must satisfy very specific criteria (discussed by Mahar and Norris 1991).

Elevated metal loads may also occur naturally. It is assumed that whenever molluscs, for example, are found with heavy metal loads which exceed the legal limits imposed on mollusc products for human consumption, there is a source of pollution involved. Legal limits are arbitrary standards set to protect human health and may not indicate the condition of the ecosystem or the health of the molluscs.

The Victorian Advisory group on environmental indicators recommends the use of metal concentrations in sediments (finer sediments, such as those in estuaries and backwaters), as key indicators for state of the environment reporting, including Pb, Zn, Hg, Cu, Cr.

2.10 WATER QUALITY INDICES

Water quality indices assist in the dissemination of water quality information. Monitoring for an indicator must meet minimum requirements for sampling frequency and period. Once this is achieved, data may be assessed against an index of quality derived for that indicator, including scientific criteria for water quality (Christoff unpubl.).

To provide an overview of developments in the use of physicochemical criteria overseas, House (1989) outlines the theoretical basis underlying the development of a new series of water quality indices, used by United Kingdom water authorities and River Purification Boards.

The use of a water quality index (WQI) in the operational management of river water quality has the potential to bridge the gap between monitoring and reporting and allow changes in river quality to be highlighted and the effectiveness of management to be evaluated (House 1989).

Four water quality indices are applied for different uses. The first is a general water quality index based on routinely monitored determinands and relates water quality to a range of potential uses. The remaining three indices are use-specific. The potable water supply index (PWSI) reflects water quality in terms of its suitability for us in potable water supply. The aquatic toxicity index (ATI) and the potable sapidity index (PSI) are indices based on less frequently monitored heavy metals, pesticides and hydrocarbons. The ATI indicates the ability of a river to support healthy fish and wildlife populations.

The National Rivers Authority (NRA 1991a) conducted a major survey to assess the quality of rivers, canals and estuaries in England and Wales. The class for particular stretches of freshwater was determined mainly by data on concentrations of dissolved oxygen, biochemical oxygen demand (BOD) and ammonia as well as a 'biological override' (based on the extent to which a macroinvertebrate community of the watercourse falls short of what would be expected in a 'clean', or unpolluted system).

Computerised models have recently become available which enable predictions to be made about the nature and composition of biological communities based on certain natural physical and chemical properties at a given river site. These approaches show potential for the development of a nationally-applicable criteria, because they take into account the natural properties of catchments which determine the nature of biological communities. Using this system it is therefore possible to separate the influence of the natural factors from those which are pollution-related (NRA 1991a). One such model, called 'RIVPACS' (River Invertebrate Prediction and Classification System) developed by the Institute of Freshwater Ecology (U.K.), allows the ratio of the observed to predicted status of invertebrate communities to be expressed as an Ecological Quality Index (EQI) (NRA 1991a).

For estuaries, the system combines an assessment of the biological and aesthetic state of the water with the measurements of minimum levels of dissolved oxygen (NRA 1991a). Components include, dissolved oxygen, ammonia and nutrients in the water; aesthetic criteria based on sewage derived material; the concentration of persistent substances in sediments; and a measure of ecological quality based on benthic invertebrates.

A report prepared by Mitchell (1990) "The Environmental Condition of Victorian Streams", rates the environmental condition of 868 sections and reaches and places them into one of five rating categories; excellent, good, moderate, poor and very poor. The environmental rating for each site was obtained by looking at ten environmental factors considered likely to be important to aquatic organisms. The criteria used to rate sites were based on an estimate of how that factor would contribute to the biological diversity and productivity at that site (Mitchell 1990). This study adopted qualitative assessments on approximately 200 variables describing catchment land use, stream bed and banks, stream verges, channel characteristics and aquatic habitats. A number of photographs were taken at each site. Opinions of local water management officers closely agree with the results of this rating system.

Indices of biological and community integrity (Karr 1991; Plafkin et al 1987 both cited in Hart and Campbell 1991) attempt to incorporate some indicators of community function by including metrics on relative numbers of fish from various trophic levels or invertebrates from functional feeding groups.

Indices of biological and community integrity use a range of metrics incorporating indicator taxa, indicators of ecosystem function (trophic or functional groups) and condition of individual organisms (frequency of deformities) in the final index value. The value of each individual metric may be graded by comparison with values from an unimpacted site in the same region.

3.0 ECOLOGICAL INDICATORS

The present focus on ecological sustainability (Commonwealth of Australia 1990; IUCN et al 1991) will require new methods for assessing the ecological conditions of catchments. It will be recommended that the biological communities are known, that the range of their variations in response to natural fluctuations in these systems are also known and that the factors (natural and anthropogenic) causing both short and long term changes are known (Hart 1992; Keogh and Quinn 1990; Bennison et al 1989).

The lack of biological indicators to assess the ecological and biological condition of a water resource is a serious limitation with present water quality guidelines (Hart and Campbell 1991; Hart 1992). Despite the desirability that indicators of biological and ecological condition be introduced, there is still insufficient information on the most appropriate indicators for particular ecosystem types (Cullen 1990).

3.1 RIPARIAN ZONE

The riparian (or river bank and vegetation) zone is a vital component of river health. The maintenance or revegetation of riparian vegetation is an accepted principle of total catchment management. There is an obvious need to protect riparian vegetation and revegetate degraded sections of watercourses to a width and quality which ensures riverbank stability, the sustainability of the riparian buffer, water quality and aquatic/terrestrial ecosystem functions. Native vegetation is a crucial factor which should be managed for diversity and structure (ground covers, understorey and overstorey); width (recognising that width suitable to protect water quality may not be sufficient to sustain habitat); and longitudinal extent (ideally continuous for the drainage system) (Riding and Carter 1992). Considering these factors, the *longitudinal extent on both banks, condition and width of riparian vegetation* are key indicators of river quality.

The riparian zone provides a buffer strip between land use and watercourses, removing sediments and other pollutants from diffuse runoff (Odum 1990; Riding and Carter 1992). Understorey vegetation and groundcovers are necessary for buffering effectiveness. The importance of the riparian vegetation in controlling erosion and siltation, providing habitat and a food source for both instream and terrestrial fauna and protecting water quality is undoubted.

To draw a broad picture of the change that has taken place in the riparian zone, information may include:-

- current riparian extent;
- history of vegetation cover from aerial photographs;
- vegetation cover prior to European settlement;
- vegetation community composition;
- details of under- and overstorey vegetation;
- condition of the vegetation;
- extent of unhealthy vegetation;
- presence or absence of exotic species;
- adjacent land use;
- the presence/ absence of stock-proof fencing; and
- the type of any stream management works.

Detailed classification of riparian vegetation should enable assessment in relation to its values. Information regarding *species, foliage structure, density, width and longitudinal extent* of such vegetation is probably a minimum requirement (Department of Water Resources, Victoria 1989; Riding and Carter 1992).

In estuarine systems, mangrove ecosystems play a similar role to inland stream riparian vegetation (Saenger et al 1977). Saenger et al (1990), for example, studied a site near Wynnum tip, Brisbane where a mangrove forest forms an effective barrier against the movement of any metallic tip leachates to the waters of Moreton Bay.

Spot satellite imagery as well as aerial photographs allow mapping to establish riparian extent, trends in those areas over time and may indicate the health of those areas. The description, assessment and mapping of groundcover and understorey density of riparian vegetation may be beyond present remote sensing capabilities. Representative field sampling may be the best way of obtaining detailed information, however this is probably too costly for State-wide application.

For the river Murray floodplain, structural vegetation was mapped from aerial photographs and floristic details were documented from field survey plots. A versatile GIS called ARC/INFO was used to store and manipulate the data and present it in mapped form (Margules and partners 1989).

A further indicator of riparian zone/aquatic ecosystem health, may be the *proportion of aquatic systems in conservation reserves* managed for their aquatic conservation values (Australian Environment Council 1987).

3.2 CATCHMENT VEGETATION

It is well recognised that catchment clearing produces hydrological changes which cause changes to stream ecosystems, channel form and river processes (Macmillan and Kunert 1990). The *area of vegetation* in the catchment and on the floodplain is a broader indicator, which may provide a wider view of catchment changes over a reporting period. Broader catchment indicators may suggest changes to the river or estuarine environments.

The *size and botanical significance* of catchment vegetation stands (including floodplain vegetation) may be used to indicate river and catchment condition. Earl and Bennett (1986) surveyed the flora and fauna in four catchments of the Gellibrand river basin, Victoria. The criteria selected for assessment of conservation potential are as follows.

1. Floristic diversity - indicated by the number of native species and sub-communities.
2. Rarity - indicated by the presence of rare, endangered species and sub-communities.
3. Naturalness - measured in terms of the absence of introduced species, the absence of utilisation in the form of timber harvesting and/or grazing, within native vegetation communities, and the amount of land supporting non-native vegetation.

Vegetation in the catchment may be assessed by criteria such as the presence of public reserves supporting native vegetation, and degree of threat by uncontrolled human intervention, measured by the amount of land in private tenure where there are virtually no limitations on land use practices (Earl and Bennett 1986).

Information on vegetation cover is exceptionally diverse. It ranges from detailed species lists to broad classifications based on community structure. It may be available in mapped form, aerial photographs and digital Landsat data, as well as scientific papers, books and Government reports (Department of Water Resources, Victoria 1989). The most up to date and best geographic coverage of vegetation and land use is available from aerial photographs and Satellite imagery. This method is very reliable however the accuracy of the interpretation can only be assessed by field verification. (Department of Water Resources, Victoria 1989).

Changes in land cover over time have had significant effects on catchment hydrology, therefore data sources useful in establishing the extent and type of pre-European native vegetation would be useful.

The Australian Environment Council (1987) has recommended as indicators: 1) area of native vegetation cleared by vegetation type and 2) area of reforested land. These are related to the sub-objective of retaining native vegetation stands, promoting reforestation and avoiding clearing native forests for plantations.

Other indicators related to the protection of sites of high conservation potential include: proportion of identified sites being managed for their conservation value and percentage of native plant community types in conservation reserves (Australian Environment Council 1987). The latter indicator may be restricted to regions of states where listing of areas of high conservation value has been made.

A quick and cost effective way to monitoring an objective of arresting and reversing the decline of native vegetation in rural Australia, the Australian Environment Council (1987) recommends the indicator: native plant cover per hectare for different alliances.

3.3 BIOLOGICAL INDICATORS

The end product of pollution and other environmental stresses is on the biological components of a system (Cullen 1990). This requires a measurement of the biota in order to evaluate, manage and predict human impacts. Even if chemical and physical data are a valid indicator of how a biological system behaves, most data sets are unreliable due to both sampling and analytical errors, and there has been inadequate understanding of the basic variability of these indirect indicators of ecosystem condition (Cullen 1990). This emphasises the importance of developing relationships between biological, physical and chemical relationships for monitoring river condition.

Due to biomonitoring being in its early stages of development and the lack of information on methodological issues such as site selection and sample collection, these programs have been considered to be more expensive. Cullen (1990) considers that biological monitoring of aquatic ecosystems has not been shown to be more expensive than traditional chemical/physical monitoring if the same standards of variability are required. The biological communities are often a sensitive, integrative measure of water quality and the integration of such results can be simpler and cheaper, since variability is likely to be less and the biological communities of interest can now be measured directly.

Biomonitoring requires clear goals, planning, statistical considerations of sampling and cost effectiveness. It is apparent that a considerable amount of background research data is needed for the design of a satisfactory program, such that variability, statistic, taxonomic and funding problems are considered (McComb and Maher 1990). This also probably demonstrates why the acceptance of bioindicators in monitoring programs has been so slow. To change the perception of the usefulness of bioindicators examples are needed where biomonitoring has been instrumental in detecting and reversing environmental degradation. Adequate funding only comes if it is clear to others that the work is significant and relevant to management (McComb and Maher 1990). The positive and negative aspects of biomonitoring have been addressed by Cullen (1990).

There are many approaches to biomonitoring of the environment, and no widespread agreement about the most appropriate tools and when to apply those tools. The main established tools include: changes in species or community composition and diversity, presence or absence of key species, biomass of various components, biochemical indicators of stress and analysis of pollutants (Cullen 1990). The important areas requiring further work include taxonomy, autecology, toxicity and bioassay and environmental description. These areas are discussed further by Williams (1980).

The following groups may be useful as biomonitors: gastropod and bivalve molluscs, oligochaetes, amphipods, isopods, atyid and palaemonid prawns, stoneflies, mayflies, dragon and damselflies, caddis flies, certain bug families (Hemiptera), most dipteran families, some beetle families (coleoptera), fish and certain algal groups (Williams 1980).

Four animals have been identified in Williams (1980) that appear to meet the criteria (reviewed by Cullen 1990) that should be met by taxa useful in this context. They are *Paratya australiensis* (an atyid prawn); *Austrochiltonia australis* (or sub *tenuis*, an amphipod); *Velesunio ambiguus* (a bivalve mollusc); and *Galaxias maculatus* (a fish). Unfortunately *V.ambiguus* has been shown to have serious shortcoming as a bioindicator (Walker 1981; Millington and Walker 1983 both cited in Maher and Norris 1991).

Although some value has been attached to the use of bioaccumulation of toxicants in indicator organisms to assess water quality (Bayley and Lake 1979, cited in Maher and Norris 1990), their Australian potential is yet to be realised and extensive work needs to be done before acceptance of the approach (Norris and Georges 1986).

Communities, which are often used to assess levels of impact, have the capacity to assimilate pollutants and they will function under pollutant stress. Thus managers need to make value judgements about when a community structure or function has shifted from acceptable to adverse. Therefore in areas such as bioassay it is difficult to set meaningful levels that are not to be exceeded, for use by managers (Maher and Norris 1990).

Measurement of community structure using diversity indices is considered inappropriate for use in Australia. Diversity indices may be affected by many factors other than pollution (Bayley and Lake 1979 cited in Maher and Norris 1990) and give unreliable results (Faith et al 1991).

Ecological monitoring programs measure progress toward restoring and maintaining ecosystem integrity. This statement implies that the baseline state to which the ecosystem should be restored is known. Instead, biological communities display unpredictable temporal variability at various spatial scales and, in addition, communities are spatially heterogeneous (Jones 1990 and references therein). Consequently, baseline descriptions should seek to encompass ranges of natural variation in both space and time (Jones 1990). Therefore an important consideration is the quantification of the extent of natural successional change, i.e. baseline variation (Jones 1990).

Probably the most pervasive ecological concept influencing the choice of what to measure in environmental monitoring was the intermediate disturbance hypothesis, whereby disturbances (including anthropogenic ones) actually maintain local diversity, by disrupting successional sequences (Keough and Quinn 1990).

The phenomenon of synergistic effects, that is two or more toxicants or impacts having a combined effect on organisms greater than the sum of their effects alone, need also to be considered. Such effects can not be detected by physicochemical monitoring alone (Campbell 1982).

3.3.1 Macroinvertebrates

Macroinvertebrates, and in particular benthic macroinvertebrates have been assessed in many studies for their value as indicators of water quality, habitat value and productivity. Community structure of benthic invertebrates at a site in a stream is the result of the inter-play of numerous factors including flow, substratum, temperature, water chemistry, aquatic and riparian vegetation, food sources and biotic interactions (Armitage 1984 cited in Storey et al 1991).

Human activities within catchments or within the stream itself can significantly alter the characteristics of invertebrate communities and therefore affect animals higher in the food chain. Changes in sediment load and stream flow, clearance of riparian vegetation, modification of stream form and increases in nutrients and toxic chemical input may all affect community structure (Department of Water Resources, Victoria 1989). A summary of impacts on macroinvertebrate communities is provided by Department of Water Resources, Victoria (1989).

Cranston (1990) reviewed invertebrate taxonomy in relation to biomonitoring. Three prevalent methods have been used to alleviate the need for universal species-level identification: selection of indicator taxa, taxonomic reduction, and allocation to functional groups.

Selection of key taxa is generally based on ease of sampling and identification, availability of taxonomic expertise, and on species richness and ecological diversity. Indicator species should be exposed by their ecology to the environmental parameters being monitored, be functionally important in stream or estuarine ecosystems, and be responsive to environmental purturbations at a convienient and detectable scale (Cranston 1990).

Data collected to the family level, from different sites within a basin, give a broad indication of variations in invertebrate communities. Comparisons between sites and a knowledge of the area may indicate likely causes of variations in those communities. For a more confident and detailed assessment of water quality it is necessary to use data at the genera or species level. Within families, for example, there may be genera or species which are intolerant of poor water quality (Department of Water Resources Victoria 1989; Cranston 1990). A further developmental problem with the use of invertebrates is the Statewide variation in river environments and invertebrate communities. Species to be used for water quality and ecosystem monitoring may have to be selected for each river system.

Bennison et al (1989) report on the aquatic macroinvertebrates of the River Murray and the lower reaches of its major tributaries between 1980 and 1985. The primary aim of the project was to record the distribution, diversity and abundance of the species in order to provide baseline data from which future comparisons could be made in relation to the effects of river development and changes in water quality.

Grouping the animals into functional feeding groups revealed a gradual change along the length of the river, consistent with the general principles on which the 'river continuum' concept is based. Community changes were observed to occur with increasing distance downstream as the source of food changed from being generated mainly within the catchment (allochthonous) to within the river (autochthonous) (Bennison et al 1989). Very little is known of the relative importance of autochthonous verses allochthonous organic matter in stream ecosystems. It is generally stated that with increasing distance downstream invertebrate abundance is increasingly reliant upon autochthonous rather than allochthonous production (Boulton and Suter 1986; Bunn 1986). It should also be considered that photosynthesis decreases with increasing turbidities downstream.

Temporal changes at each site over the course of the river were also examined. The factors which most affected species diversity and abundance were the drought in 1982 and the high flows experienced in 1983. The changes were complex, such as temporary increases in diversity in South Australian sites after high flows, as animals were washed downstream.

Larval chironomid (midge) populations sampled at Euston (Murray River) and Burtundy (Darling River) exhibited a high incidence of mouthpart deformities of the type which have been linked to environmental stress (including pesticide pollution) in overseas studies.

Having established an inventory of aquatic macroinvertebrate fauna and obtained preliminary information on the effects of drought and floods on the invertebrate populations of the river, it is now proposed to monitor changes in invertebrate community and population structure as an indicator of specific changes in water quality resulting from point source discharges of salt, industrial effluent, treated sewage effluent and turbidity (Bennison et al 1989).

Faith (1990) studied the use of benthic macroinvertebrates in biological surveillance using Monte Carlo significance tests on functional groups' responses to environmental gradients. This approach reflects that more direct information about community processes and functions is regarded as necessary for a better understanding of basic freshwater ecology, and ultimately for effective management of these ecosystems (Mathews et al 1982, cited in Faith 1990).

There is empirical evidence that functional feeding groups are useful in distinguishing among stream habitats, and that these groups respond in an orderly way to important environmental gradients in streams (Minshall et al 1983, cited in Faith 1990). Again the spatial and temporal heterogeneity of streams in Australia limits the general applicability of these deterministic patterns (Faith 1990).

A challenge in assessing functional groups responses to environmental gradients is to avoid unwarrented assumptions about the nature of the relationship between functional groups and the environment. Tests of functional groups response patterns have in the past used measures of correlation with environmental variables that assume only a linear relationship (Faith 1990). Any apparent functional group response pattern must be viewed cautiously and evaluated relative to the pattern that could be obtained for purely random assemblages of taxa.

Pettigrove (1990) stressed the importance of site selection in monitoring the macroinvertebrate communities of the Yarra River, Victoria. From this study it was suggested that, in general, nutrients and riparian vegetation had greatest impact on the riffle communities, and turbidities had greatest impact on the pool communities. Full consideration should therefore be given to the type of stream habitat sampled when attempting to determine which water quality parameters have significant long-term effects on the condition of the fauna.

Aquatic macroinvertebrates are fundamental to the floodplain ecosystem, for example they can mediate litter processing and provide and important food resource for fish and waterfowl (various references in Boulton and Lloyd 1991). Information on macroinvertebrate assemblages (preferably from relatively pristine floodplain habitats) is essential for successfully predicting the influence of river regulation and alteration of the flooding regime upon the biota of aquatic habitats on the floodplain and for developing appropriate management strategies (Walker et al 1992 cited in Boulton and Lloyd 1991).

Boulton and Lloyd (1991) researched macroinvertebrate assemblages in floodplain habitats of the lower River Murray, South Australia. They concluded that surveys of floodplain rivers for management purposes must include samples from aquatic habitats adjacent to the main channel because the fauna of the floodplain is potentially most threatened by regulation and alteration of the flooding regime.

Jones (1990) studied zoobenthic species variability associated with a flood and drought in the Hawkesbury estuary. Fixed-factor sampling designs used in this study, which are widely used, may be unrepresentative of other areas due to differing ranges of natural variation. Unfortunately the alternative approach of stratified random sampling will probably be both prohibitively expensive and difficult to implement in the complex estuarine benthic habitat. Further, short term studies will probably be grossly unrepresentative of natural temporal variation.

Attempts to reduce expenses by using only one or two abundant species as characterising communities or as indicators of physicochemical conditions may be unreliable because of variation in both space and time in dominant species and the lack of pollution/response knowledge for local species (Jones 1990).

Little is known about the effect of drought in estuaries. This is unfortunate because such knowledge is important for management purposes. For example, the increased impoundment of river mimics droughts by reducing freshwater input to estuaries with a variety of possible consequences (Armstrong 1982; Harris 1984 both cited in Jones 1990). Factors potentially causing ecological changes include salinity, erosion, and/or deposition of sediment, dissolved oxygen, flushing and availability of colonists (Jones 1990).

Diversity indices using macroinvertebrates have serious deficiencies for assessing water quality especially in Australia and their use should be avoided (Faith et al 1991). *Similarity indices*, however, make few assumptions about the data and they may be of most use as a basis for classification programs. Classification programs based on species distribution patterns, followed by multiple discriminant analysis, has been shown to be useful for water quality assessment (Norris and Georges 1986).

Faith et al (1991) in studying statistical power in biomonitoring using measures of *community dissimilarity* based on benthic macroinvertebrates in Rock-hole Mine Creek, Northern Territory, concluded that all measures adopted in this study will perform poorly for some data sets and that the Bray-Curtis measure will be the most robust for a range of disturbance patterns. The only reason why a poor performance has not been observed for the Bray-Curtis measure may be that only two years data have been examined.

The rationale for dissimilarity models depends on the existence of an environmental difference between control and impact sites as well as the community-based, multivariate dissimilarities that can be calculated between the two sites.

3.3.2 Fish and fish kills

Fish are a biological indicator of great significance to the public. The *presence of a healthy natural fish population* is a good indication of a healthy river. There is, however, a substantial development phase to be completed before *community structure of fish populations* can be properly assessed and interpreted for many catchments (Commissioner for the Environment 1990). Historic, commercial and recreational fisheries information as well as on-going data collection may be useful to assess the status of fish communities and their habitats.

Reduced fish numbers may be due to a variety of causes other than pollution such as changes in river flow, decreased habitat availability and quality due to river regulation, desnagging, erosion, riparian vegetation removal, overfishing and introduced fish species (Burchmore 1991). Fish are a relatively long lived species near the top of the food chain and thus tend to respond to all factors affecting the various life stages of fish and the food chain which supports them (Commissioner for the Environment 1990).

Small fish populations, or the complete *absence of a particular species* from a stream or parts of a stream, may indicate the presence of one or more disturbing factors. Conversely, the *presence of known rare, endangered, vulnerable or restricted species* may indicate a reasonably undisturbed, or natural system, as could the *absence of introduced species* (Department of Water Resources, Victoria 1989). In this case the stream should be protected from further disturbance.

Since original diversity and abundance of fish is generally unknown in most impacted catchments, it is difficult to use fish as indicators of environmental quality or naturalness of streams (Department of Water Resources, Victoria 1989). The paucity of freshwater fish species in Australia is another disadvantage of using fish as indicators. Fish community composition is likely to be a poor water quality indicator in inland waters in south-eastern Australia, where species diversity is relatively low. (Hart and Campbell 1991).

In an example of using fish as an indicator, water releases from Hume Weir on the Murray River have been monitored over several years and show that dissolved oxygen concentrations are depressed for 100 kilometres and seasonal temperature changes are delayed by one month for 200 km below the dam (Walker et al 1979, cited in Australian Environment Council 1987). It would be tempting to conclude that reductions in the population of golden perch are due to these physicochemical changes and could be reversed by altering the discharge level from Lake Hume. In fact, the reduction in fish population is probably due to reduced frequency of overbank flows leading to a reduction in food source. If so, altering the discharge level may have no effect on reversing the decline in numbers. Accordingly, it would be better to monitor the number of golden perch than temperature or dissolved oxygen (Australian Environment Council 1987). Provided research confirms a correlation between reduced frequency of overbank flows and the decline in fish numbers, the responsible authorities can then implement management changes to increase the frequency of overbank flows, rather than alter the discharge level.

Individual species or indicator species may be used such as *Galaxias olidus*. There has been a fragmentation of populations of *G. olidus* due to the introduced *Salmo trutta* (Fletcher 1986 cited in Macmillan and Kunert 1990). Fletcher's research has shown that introduction of *S. trutta* to *G. olidus* habitat can alter the abundance and composition of dominant invertebrate taxa.

Biological indicators may signal changes in freshwater quality but offer less information on the long-term trends in ecosystem succession. As an improvement over biological indicators in river management, Copp et. al. (1991) propose the use of 'functional describers', abiotic and biotic elements that reflect alterations in ecosystem function and succession through changes in their concentration or abundance, including the appearance and/or extinction of organisms or groups or organisms.

Juvenile fish have been found to be useful functional describers in many fluvial situations encountered in Europe. Using the regulated Rhone River as an example, the *absence or presence of juveniles* is shown to provide a direct reflection of a biotypes potential as a spawning area, particularly if recent hydrological conditions have not facilitated juvenile fish displacement and the lone presence of a predator species has not suggested the elimination of other fish species (Copp et al 1991).

When time, labour and/or funding is limited, the functions and succession of numerous biotypes within a catchment or large fluvial system can be monitored cost effectively by analysing the juvenile fish assemblages via the functional describer approach (Copp et al 1991). Potential functional describers identified in floodplain research include macroinvertebrates, nitrogen/carbon ratios and macrophytes (various references cited in Copp et al 1991).

The accuracy of fish-based indices, such as the Index of Biotic Integrity (Karr, 1981; Karr et al 1986) could be improved by marrying the functionally descriptive aspects of juvenile fish with the information gathered on older, larger size classes. This would provide fisheries and resource managers with a more accurate index for assessing the current and potential long-term effects that impacts (pollution) or resource management schemes (regulation, channelisation) can have on a fluvial system (Copp et al 1991).

3.3.3 Algae

The *biomass* and the *species composition of algae and algal blooms* may have potential for use as an indicator of nutrient inputs to a stream. Depending on depth, velocity, turbulence and turbidity, additional nutrient inputs may cause an increase in phytoplankton biomass as well as changes in macrophyte communities (CEE 1990). Cullen (1986) has recently reviewed research which suggests that light is not the only limiting factor for reduced plant growth due to turbidity, rather that the high levels of particulate phosphorus in turbid water may not be available for algal growth.

The *algal species composition* is a response to the environmental conditions and the *dominant species* of algae determines the type of impact of an algal bloom (proportions of green/blue-green/diatom).

The stimulation of algae in the rivers and estuaries of urban Sydney has been observed and documented, and research into predicting the response of algae to various concentrations of nutrients (as well as various stream flows and turbulence levels) is being pursued (CEE 1990).

The use of algae as an ecological indicator of chemical pollutants and industrial wastes has been examined in the publication: "Algae as Ecological Indicators" (Shubert 1984 ed.). Utilisation of *algal culture and bioassay* may include effects of nutrients, effects of complex effluents, effects of chemicals and effects of heavy metals.

McComb and Lukatelich (1990) studied the inter-relations between biological and physicochemical factors in a database for a shallow estuarine system. The paper examines data obtained since 1976 in Peel Inlet and the Harvey Estuary, a shallow estuarine system in Western Australia which has nuisance growths of macroalgae and seasonal blooms of the blue-green algae *Nodularia spumigena*. The information has been used to relate the magnitude of summer blue-green blooms to the winter loading of phosphorus from the surrounding catchment, and the magnitude of macroalgal biomass to light penetration through the water column (McComb and Lukatelich 1990).

The indicators used to determine these relationships were phytoplankton (chlorophyll-a), water nutrients (N and P), salinity, temperature and light penetration collected at the same sites at weekly or fortnightly intervals since 1976. The program is of more general interest because it explores the use of long-term data bases for understanding behaviour in highly variable systems (McComb and Lukatelich 1990). This study also highlights the value of other indicators for estuaries such as tidal flushing and estuarine geomorphology. A conclusion from this study was that while it seemed that extreme year to year differences might lead to difficulties in data interpretation, the reverse has been the case, the large year to year variance has enhanced the ability to interpret biological events.

The NSW Blue-green Algae Task Force (1992) has mapped the weekly occurrence of algal blooms in NSW from November 1991 to 1992. This occurrence reporting approach and mapping may be useful for State of the environment reporting (see appendix 1 for map example). Regular monitoring is at the main Department of Water Resources (DWR) storages, with other information supplied by the Water Boards and by regional offices of the DWR for rivers. There is some additional monitoring, usually on an 'ad-hoc' basis, carried out by individual shires, Public Works Department and some regional offices of the Department of Health.

Bloom assessment and algal identification have been carried out at the regional level. Confirmation of *algal identification and cell counts*, as well as *analysis for nutrients*, have been carried out in laboratories operated by the DWR, Water Boards, and to a lesser extent by the CSIRO (Blue-green Algae Task Force 1992).

3.3.4 Aquatic macrophytes

Aquatic macrophytes (aquatic plants other than microscopic algae) have many useful roles in aquatic systems. They are nutrient sinks and sources; they act as physical filters; they stabilise sediments; they activate sediments (i.e. provide oxygen) and they provide habitats for fish and other aquatic organisms (Burchmore 1991).

Fringing, floating and submerged aquatic plants provide shelter and food for some freshwater fish, particularly juveniles. They may also be critical factors in recruitment success of some species of fish such as the Australian bass (Burchmore 1991).

Aquatic plants have become a major problem in NSW due to excessive growths that block flows, structures and pumps. These excessive growths usually indicate nutrient rich waters and sediments, and cause poor water quality, stagnation and nutrient release when they decompose (Bek and Robinson 1991).

Trends in *area of aquatic macrophyte* coverage could not be assessed on a Statewide basis and trends may be difficult to determine. Changing area/coverage of macrophytes may best be assessed at key sites in conjunction with a multiple data gathering exercise. The *presence and extent of exotic macrophytes* could be used as an appropiate parameter for evaluation of river condition (Macmillan and Kunert 1990).

3.3.5 Waterbirds

Waterbird breeding for many species is stimulated by periodic inundation of wetlands. Breeding habitat is provided for many species including ibises, egrets, herons, spoonbills and a variety of water fowl (Magrath et al, 1991).

The success of a breeding event and survival of the fledglings depends upon the slow recession of a flood or the occurrence of follow-up floods to maintain water under rookery nests. Adequate aquatic food supplies (invertebrates) need also to be maintained by slowly receding flood waters until the fledglings can survive independently (Magrath et al, 1991).

Bird breeding events may fail naturally due to insufficient flood waters. However, river regulation, and water extraction for irrigation cause the loss of some inundation events, a more rapid recession of flood waters and the loss of follow-up events.

If the rate of flow into wetlands is significantly diminished and the water beneath the nesting birds falls sharply then adults desert their young, which are still reliant on parental care. This situation occurred in the Lachlan Valley, Booligal Wetlands where modification of the natural flood regime is likely to have contributed to the failure of the colony in 1984 (Magrath et al, 1991).

Monitoring and reporting on *waterbird breeding and desertion events* would be necessary for their management. A negative trend in the occurrences of these events may indicate the need for better habitat and water management of wetlands associated with major waterbird colonies. If it is established that river regulation and extraction for irrigation can result in failed bird breeding events, contingent environmental flows could be provided, or changes to the policies governing abstraction of high or off-allocation flows could be implemented to allow such events to be completed.

3.4 HABITAT DIVERSITY

Maintenance of *habitat diversity* is a useful guiding principle for river management. Aquatic habitat diversity is greatest in rivers and streams which are structurally complex. Watercourse features such as bends, changes in width and gradient, and the presence of rocks, logs, plant roots and plant stems cause a variety of flow speeds and flow directions. These factors lead to complex sedimentation and erosion patterns, a range of water depths, a patchy distribution of organic detritus, and micro-scale variations in water temperature, dissolved oxygen levels and nutrient concentrations (Olsen and Skitmore 1991).

Environmental changes such as loss of riparian vegetation, or increased temperature, salinity, nutrient or pesticide levels reduce diversity by eliminating those members of a river's flora and fauna which fail to cope with the change (Olsen and Skitmore 1991).

The assessment of *habitat diversity* may best be achieved at established key sites for monitoring, where a quantitative and qualitative description and ranking of sites by field officers and photographs may be utilised. Macroscale habitat diversity may be indicated by aerial photography and satellite imagery of the river and floodplain, showing features such as areas of aquatic macrophytes, billabongs, anabranches and backwaters.

Cover for fish and other instream biota is provided by features such as snags, boulders, undercut banks, aquatic macrophytes riparian vegetation and deep pools (Burchmore 1991). The importance of snags and floodplain vegetation to native fish in the Murray-Darling river system is reviewed by Walker (1991, cited in Boulton and Lloyd 1991) who discusses the ecological threats to the river posed by desnagging.

The survey by Mitchell (1990) recorded the *percentage cover of channel obstructions*, including logs, and the *presence or absence of boulders in the bed.* This information along with photographs for each site were used to rate the amount of cover for fish.

The detrimental effects of desnagging and channelisation on the fish population were clearly evident from a study of channelised and non-channelised sections of the Bunyip River carried out by Hortle and Lake (1983, cited in Department of Water Resources Victoria 1989). Fewer species and lower numbers occurred in the disturbed sites, apparently related to the absence of suitable habitat.

Substrate type can be an important factor in fish breeding, as some species, such as the Macquarie Perch lay eggs which lodge in the spaces between small cobbles and pebbles in the stream bed (Mitchell 1990).

Up-stream sites with coarse bed material (boulders, cobbles and shingle) may indicate better stream condition (as well as a variety of habitat types, e.g. pools and riffles) than those with a bed of fine materials. Differing bed material may, however, simply indicate different river characteristics where there may be naturally lower diversity in the more uniform sites. When rating bed composition, stream size and distance downstream should be accounted for, since average bed material or particle size decreases down the length of a river. Similarly, catchment geology and stream gradient are the prime determinants of bed material size. Streams with fine bed materials tend to be relatively deep and narrow (i.e. low width: depth ratio) with a well defined pool/riffle sequence. Coarse sediment streams tend to be relatively wide and shallow (i.e. high width: depth ratio) with a longer spaced pool/riffle sequence.

A useful indicator of catchment and river ecosystem condition reflected by Boulton and Lloyds' (1991) study is the *diversity of floodplain habitats.* In this study macroinvertebrates were sampled in seven microhabitats. These are:-

- submerged woody debris;
- reeds;
- sedges;
- inundated grass;
- floating aquatic vegetation;
- lignum; and
- unvegetated littoral.

These microhabitats were incorporated into a variety of macrohabitats including:-

- single temporary and permanent ox-bow lakes (billabongs) and channel billabongs;
- fast and slow flowing anabranches;
- backwaters; and
- the main channel.

The dynamics of every floodplain river ecosystem rely upon the interactions between the river and its floodplain habitats. During floods, these links are reinforced when the aquatic habitats are replenished with water, allowing exchange of nutrients and biota (various references in Boulton and Lloyd 1991).

3.5 WETLANDS

Wetlands, as well as having their own ecological and aesthetic values, play a crucial role in nutrient transfers and cycling, maintaining water quality and utilising nutrients, trapping sediments, flood mitigation and shoreline protection, providing habitat and enhancing groundwater recharge (Williams 1990).

The *extent of wetlands, their number, type and* *condition* would provide important information for the management of these significant areas and to assess their relationships with the main watercourse.

Wetlands and other sites of environmental significance may be identified and trends in their area and possibly condition may be determined using satellite imagery or aerial photography. Remotely sensed data on *area and duration of inundation* should be collected where ever possible.

Wetlands vary considerably because of meteorologic and climatic fluctuations and have inherent indeterminate boundaries, therefore the use of *digital geographic overlay procedures* is a logical approach to estimating wetland loss (Kuzila et al 1991). The use of an automated GIS may be based on digitised data such as wetland maps, wetland soil maps, and area of inundation from specific meteoroloical conditions. Changing boundaries and net losses or gains in area may be determined by subtracting mapped data of one period from a previous period.

Establishing trends in the condition of these areas and the biophysical processes of wetlands would require specific studies of different wetland types. In this respect *water balance models* would be useful, for example, the amount of water needed to inundate a wetland and keep it flooded for a preferred time period, as well as *inflow hydrographs* and *internal distribution and storage*. As the area of wetlands within a floodplain changes there are corresponding changes to their established functions and values.

In relation to estuaries, mapped areas of coastal wetlands, in the north coast region for example, have been reproduced from Department of Planning maps associated with State Environmental Planning Policy 14 (coastal wetlands). These maps only cover the coastal local government areas of the region and only indicate wetlands that are of state significance.

3.6 OTHER FAUNA

The *presence or absence of natural fauna* in a catchment would be an important community concern, particularly species such as the platypus, water rat, waterbirds and other birds associated with the riparian zone and wetlands.

An example of using the occurrence of other fauna as an indicator of improved river and catchment condition comes from Rainbow Creek, a branch of the Thompson River, Victoria. The creek has undergone an active streamside revegetation program and subsequently there has been a return of the platypus and the white faced chat (Taylor 1986).

It may be impractical to quantify the occurrence of river associated fauna for assessment on a State-wide basis, however community information on fauna presence/absence or changes to this status would be beneficial. Platypus surveys and sighting records are being established for the Clarence and Richmond river catchments. These continued records may provide an indication of areas of river improvement or impacted areas as a result of human activities (David Rohweder pers. comm.).

4.0 GEOMORPHIC INDICATORS

4.1 EROSION

A major feature of the river channel and verge is its spatial and temporal instability. The natural dynamics of features of the river and floodplain are dependant on the variability of catchment geomorphology and dominant soil types, as well as long term climate patterns (secular increases in rainfall). Unnatural or accelerated change, however, can result from human activities leading to lowering of the river bed, excessive bank erosion and a reduction in channel values (Warner 1983). For example, on the Mitta Mitta river in the upper Murray Basin many stream management works have beeen required due to accelerated erosion. This was largely due to human disturbances such as irrigation releases from the Dartmouth dam (Department of Water Resources, Victoria 1989).

Cumulative loss of riparian vegetation, riverbed lowering and increased frequency of localised disturbances can lead to severe bank erosion. Three factors summarise the causes of major bank erosion (Paula Douglas pers. comm.).

1. Increased discharge (either due to increased run off or rainfall, or due to river regulation).
2. Increased water velocity (due to increased discharge, decreased roughness, decreased vegetation cover or changed bedslope due to bed lowering or channel straightening).

3. Increased streampower (due to decreased availability of coarse sediment as a result of dams/weir traps or gravel extraction).

Widespread bank erosion leads to shallowing and widening of the river and loss of habitat diversity such as infilling of deeper pool areas (i.e. changes to the width: depth ratio). Loss of habitat diversity and increase in turbidity as a result of unnatural erosion can have a number of direct and indirect impacts on aquatic fauna. For example, there can be smothering of benthic invertebrates, reduced light penetration for photosynthesis and smothering of eggs laid between cobbles and pebbles by fish such as the Macquarie perch (Mitchell 1990).

The links between disturbances to the river or stream and the 'health' of river ecosystems are poorly known. One reason for this is that river and floodplain ecosystems' flora and fauna are adapted to the high variability in these systems. It is well known that erosion of stream banks and to a lesser degree within the catchment will generally increase the levels of suspended solids and turbidity downstream, however, our capacity to predict the actual increases in turbidity for a particular system is limited, as is our ability to predict in any quantitative manner, the effects these increases will have on the stream biota (Hart 1992).

Department of Water Resources, Victoria (1989) commissioned the Land Protection Division to produce a map of Victoria's water erosion hazards. The map produced was based on regional staff knowledge coupled with field investigations and economic considerations. Firstly, land types were broadly defined as lands with similar attributes experiencing similar erosion problems. Secondly, assessment of the extent of areas that required reclamation works and the cost per hectare of those management works were made to determine the severity of erosion. The resultant map shows potential erosion in relation to associated land uses, but does not indicate actual erosion as this can change in a relatively short period of time.

Mitchell (1990) assessed the composition of the stream bed, bank stability and the amount of aggradation and degradation at each site, as well as the use of photographs to determine a rating for the level of sedimentation or erosion.

The Australian Environment Council (1987) selected indicators related to agricultural land as: 1) suspended sediment loads in streams draining (predominantly) agricultural land, and 2) the percentage of seriously degraded land which has been restored. The area restored can generally be estimated by district soil conservation officers who advise landholders on the techniques for restoration. A potential problem with this indicator is how to treat restoration that has failed.

While it is difficult to monitor and interpret river stability statewide it is important to measure its effects on the aquatic ecology such as:-

- downstream siltation;
- destruction of aquatic habitat;
- burial of macrophytes;
- release of colloidal particles with attached pollutants; and
- destruction of riparian vegetation habitat;

but also on its effect on the socioeconomic environment including:-

- loss of prime agricultural land;
- threats to bridges, roads and other infrastructure;
- siltation of navigation channels;
- potential for stream diversion with its associated threats to ecological, geomorphic, social and economic environments; and
- reduction in the quality of instream recreation sites.

4.2 GULLYING

Gullying is a broader catchment indicator that relates to soil removal by water flow forming channels deeper than 30 cm, down which sediment and suspended materials flow. Erosion of this type causes the removal of surface and subsurface soil, nutrients and organic matter as suspended sediment as well as additional sedimentation in rivers (NSW Landcare Working Group 1992).

More than 35 percent of New South Wales is affected by some form of sheet, rill or gully erosion (NSW Landcare Working Group 1992). The primary cause is insufficient groundcover that exposes bare soil, this occurs in recently cultivated areas or disturbed soils during site preparation, after overclearing or overgrazing and during the concentration of runoff into inappropriate drains (NSW Landcare Working Group 1992).

An increase in the number and size of gullies is an indication of an increase in the sediment yeild of the catchment over a peroid of time. Similarly a decrease in the number of gullies may show a catchment in recovery.

A repeatable system for identifying and measuring gullies may be difficult to develop and not feasilble for statewide assessment. Changes to gullying patterns may also be attributed to seasonal variations.

4.3 FLOODPLAIN SCOUR AND SILTATION

Floodplain degradation is generally associated with erosion of land forming the alluvial river flats that are periodically inundated by floodwater. The causes of floodplain degradation include artificial concentration of floodflows, inappropriate development of the floodplain, vegetation clearing and inappropriate location, size and type of structures (NSW Landcare Working Group 1992).

Assessments may be made in problem areas with remotely sensed data possibly in conjunction with other river and estuary features such as riparian extent and area of wetlands. More detailed or quantitative assessments of floodplain scour and siltation would not be practical for the whole of the state. Assessment of streamside and floodplain vegetation (e.g. the presence of flood buffer vegetation strips across the floodplain, perpendicular to the watercourse) may provide a more feasible indication of floodplain condition.

4.4 TOTAL STREAM LENGTH

Total stream length is generally not a useful indicator for state of the environment surveys unless major short- term changes in river length are occurring in a particular catchment. To determine changes in stream length, air photographs and/or Landsat interpretation would be required. Where there are large numbers of minor streams in parts of a basin, stream length may be determined by estimating the drainage density (length of stream per unit area) in each part and multiplying this by the area (Goudi 1981 cited in Mitchell 1990).

For general uses of this indicator, such as calculating the proportion of stream length in poor or good condition or the proportion of stream length with continuous riparian buffers, stream lengths may be measured from topographic maps at 1:25 000 scale using a map wheel (Mitchell 1990).

4.5 POOL: RIFFLE SEQUENCE

Rivers and streams with a diversity of habitats (mixture of pools and riffles) is a useful indicator of a stream in good condition. *Riffles* are likely to have a more diverse invertebrate fauna than pools, whilst *pools* are important in providing deeper areas for fish (Mitchell 1990). Consideration should be given to stream size on the assumption that pools are likely to be more common as stream size increases.

The important issue is *changes in pool/ riffle sequence* (similarly width: depth ratio) *over time* at each site. Trends may best be assessed at key sites or at guaging stations by field officers. Changes may be recorded by a series of photographs and on field observation sheets.

4.6 WIDTH: DEPTH RATIO

Width: depth ratio refers to the variation in channel form and cross-sectional shape resulting from variations in stream discharge, type of bed material and land types. The physical characteristics of channels contribute to the control of deoxygenation, bacterial death rates, benthal decomposition and reaeration. Streams with fine bed materials tend to be relatively deep and narrow (i.e. low width: depth ratio) with a well defined pool/ riffle sequence. Coarse sediment streams tend to be relatively wide and shallow (i.e. high width: depth ratio) with a longer spaced pool/ riffle sequence.

In conjunction with pool and riffle sequence measurements, trends in *width: depth ratios* may be recorded at key sites and guaging stations. Changes may be assessed by width and depth measurement cross-sections or by observations and photographs.

4.7 SINUOSITY

The *sinuosity* of a stream refers to the ratio of channel length to down-valley distance and is therefore a critera for the degree of meandering. Channel shortening causes decreased *sinuosity* or meandering while increased *sinuosity* or meandering causes channel lengthening. It is useful to measure the long-term stability of a river, however, similar to the drainage network, sinuosity reacts to changes comparatively slowly.

Sinuosity incurs monitoring problems similar to total stream length in that a long period of manual measurement of aerial photographs would be required. This problem could be reduced by targeting critical reaches, but any monitoring program would be a long term project with limited worth (River Corridor Unit, Department of Water Resources).

4.8 ESTUARINE SILTATION

Estuaries are highly dynamic zones of transition. Comprehensive scientific data bases are needed so that balanced and controlled coastal zone protection and management strategies may be enacted to restore and maintain the biological, physical and chemical integrity of estuarine zones in the wake of human induced modifications (Eyre 1990). Fundamental to this program is an understanding of estuarine hydrodynamics and a holistic approach to estuarine studies.

Sediment characteristics and circulation and salinity patterns result in estuaries acting as sediment and nutrient traps or sinks, causing essential elements to be recycled over and over. This sediment and nutrient sink effect is caused by several factors as follows.

1. Estuaries naturally tend to fill up over time due to inputs of terrestrial sediments from rivers and marine sediments reworked shorewards since the last marine transgression.

2. The nature of estuarine sediments, with their high percentage of clay minerals, having a great adsorptive capacity which produces sediments containing large quantities of adsorbed nutrients, trace elements and other materials.

3. The process of biodeposition, whereby filter feeders remove enourmous quantities of suspended matter which are compacted and extruded as feces or pseudofeces, to be incorporated in the sediments.

4. There is a tendancy for nutrients to become trapped through a combination of horizontal ebb and flow of water masses of different salinities.

Sedimentary processes in estuaries are determined by the dissipation of energy from river inflow, density gradients, the tide, waves and meteorological forces. As energy is dissipated, sediments are transported, mixed, exchanged or accumulated and the bottom geometry is modified (Kennish 1986).

A number of techniques are available for the determination of sedimentation rates (see Eyre 1990). Sediment-water fluxes are important for at least three reasons (various references in Eyre 1990).

1. They are important in controlling the water column concentrations and speciation of elements.

2. They are a measure of the depth integrated reactions occurring below the sediment-water interphase.

3. They have a substantial contribution to the maintenance of high rates of biological productivity or alternatively sediment fluxes may act as a sink for nutrients.

Modifications to estuarine morphology would be a major concern for management agencies and the community. The quantities of dredge spoil removed through maintenance dredging or capital works may provide a useful indicator, particularly in the lower reaches.

Such assessments may be achieved by aerial photographic analysis and monitoring of volumes of spoil removed (Victorian Institute of Marine Science 1991). In estuaries known to have been affected by human activities, the frequency for monitoring has been suggested to be over a period of ten years (Victorian Institute of Marine Science 1991).

4.9 SEDIMENT ANALYSIS

Sediment analysis in estuaries (as in rivers) would provide valuable management information.

Measures may include the percent values of sediments in each *standard grainsize class, percentage fines, total organic carbon, total Kjeldahl nitrogen and total phosphorus.* Bed sediments may be sampled at geographically fixed positions on a fixed grid to uniformly sample each depositional environment.

5.0 HYDROLOGIC INDICATORS

5.1 FLOW CHARACTERISTICS AND FLOODS

Changes in streamflow can have a major impact on the character of both river and estuaries. Reductions in streamflow can decrease the dilution of pollutants and the flushing of pools with a subsequent reduction in water quality. A decrease in the frequency and duration of peak flows can reduce the wetting of wetlands, riparian and foodplain communities with a subsequent reduction in plant and invertebrate productivity, and in the reproductive and recruitment opportunities of vertebrate species. A change in the seasonal characteristics of the follows can affect the growth of plants and the lifecycles of the biota. A reduction in the reliability or size of lowflows can affect the condition or availability of habitats and increase species competition over reduced food supplies.

Data on *flow frequency and magnitude* as well as *flood extent, duration and recession rate* can provide an overall picture of stream condition. In conjunction with other indicators, trends in long-term flow characteristics and flooding regimes may be determined. These changes may be due to natural fators such as long term climatic variation or due to human induced factors such as major dam construction, water extraction, or catchment clearing.

A wide range of hydrological indicators can be used to describe the changes in flow characteristics. The relationship between streamflow or disharge, and the condition of dependent ecosystems, habitats or water quality is not linear and in fact is highly complex being determined by parameters such as depth of flow, wetted area and flow velocity. These parameters are not only influenced by disharge but by the geomorphology and vegetative condition of the stream channel, riparian zone or wetland.

These parameters may therefore provide more meaningful hydrological indicators than streamflow itself. For Example, data on *area and duration of inundation in wetlands* should be collected where ever possible (from areal photography or satellite imagery). Similarly, the *proportion of wetted area (wetted perimeter) within the stream channel* would be a better indicator of habitat and food availability (could be estimated from cross sectional data).

Unfortunately such information is more difficult to collect and has not been generally available to date. Correlations between streamflow or stage and wetted area (inchannel, wetland or floodplain) could be developed where possible to allow these indicators to be derived from streamflow records.

Often streamflow itself is used as the indicator despite the problem of nonlinearity between it and ecological condition. Streamflow can be described in many different ways to help analyse trends. Common and useful techniques include flow duration curves and double mass curves.

Flow duration curves illustrate the percentage of time different flows are equalled or exceeded. Differences between actual and predicted or control curves (see below)can be compared over time to indicate changed conditions. Changes in the seasonal characteristics of flows can be shown by using monthly or seasonal curves.

The *double mass curve* technique provides a direct means of estimating the human impact on flow. *Double mass curves* enable the cumulative actual streamflows to be compared with cumulative predicted/control flows. The deviation over time would provide an indication of the change in total flow but cannot indicate whether the impact has been predominantly on lowflows or on peakflows etc. Tributary inflows are adjusted to 'natural' conditions with allowance made for evaporation losses (Mackay et al 1989).

Differences in the frequency of peakflows between actual and predicted/control records can be determined. Similarly correlations between peakflow and the recession slope constant (k) can be derived and used to identify changes in flood recession characteristics over time.

The *double mass curve* method has been applied to estimating the changes in flow to South Australia in the Murray River, since 1902 by Mackay et al (1989) (see appendix 2). The estimated natural flow is shown against actual flow with two points of inflection. The slope of the curve is constant from 1901 to 1932. Hume reservoir commenced filling in 1929 and was first filled in 1934 indicated by the first change in slope. From 1965 onward a new constant slope is apparent due to diversions by upstream states growing rapidly in the mid 1950's. This change in slope indicates a reduction in flow to South Australia of 43% (Mackay et al 1989).

In the above examples the usefulness of the streamflow indicators depends upon two requirements.

1. The length of the actual streamflow record. Many streamflow gauging stations on smaller streams only go back 20years or so and are often discontinuous.

2. The availability of a predicted or control record over the same time period as the actual streamflow record. Without this the human induced changes in streamflow could not be distinguished from the effects of climatic variability. Because of the typically heterogeneous and changing character of most catchments the opportunity to use a "control" catchment is very limited. In most cases it will be necessary to generate a simulated streamflow record using a runoff/rainfall or streamflow model calibrated to a short period of the actual record. There are some major practical problems in doing this, and the reliability of the estimates are very dependent on the quality of the rainfall and streamflow records as well as the models themselves. The reliability of the estimates must be considered when drawing conclusions about the trends in streamflow as the errors of the estimates may be greater than the degree of change.

The land inundated by a flood of a set probability reflects the effects of a wide range of processes within the catchment. Floodplain land use, bridges levees and vegetation as well as streamflow changes will all affect the extent of flooding. Flood flow duration curves and flood recession curve analysis (which can be derived from the flow duration curve) may be useful in determining trends in flood regimes and recession rates.

The Victorian Rural Water Commission mapped approximate areas inundated during floods at a scale of 1: 200 000. The maps were based on major flood mitigation studies and utilised staff knowledge. The extent of flooding is usually ascertained by aerial photographs taken at the height of the flood. Large inacuracies occur when using these techniques. On a statewide basis the practicality of *area of inundation* as an indicator is low. Even locally, the extent of flooding is more importantly due to variability in rainfall rather than environmental factors or human activities within the catchment.

5.2 WATERTABLE AND WATERLOGGING

Regional *watertable* levels are an important indicator for agricultural land, particularly related to areas of land affected by salinity and waterlogging. Soil salinity and waterlogging control is required to achieve a sustainable level of rural productivity, improve environmental quality and reduce saline groundwater entering streams.

Shallow watertables occur in irrigated areas due to a number of factors (after MDBMC 1988) including:-

1. clearing of vegetation which reduces the amount of water taken up for plant usage;

2. high moisture levels maintained in the soils by irrigation which reduce their capacity to absorb rainfall, resulting in water movement to greater depths;

3. an excess of irrigation water over the plant requirements being applied to provide a net downward flow and hence prevent the accumulation of salt in the root zone, (this 'leaching fraction' adds to the groundwater);

4. applying excess irrigation water which percolates to the watertable; and

5. irrigation works interfering with the natural drainage pattern, causing ponding of water and hence greater depth of percolation.

Saturation of the soil root zone, can have a marked affect on crops due to lack of oxygen at the plant roots. Saturation also alters the physical characteristics of the soil (MDBMC 1988).

Unless deep drainage conditions permit these additional accessions to the groundwater to dissipate, in time watertables will approach the surface. Capillary action may then become significant, transferring moisture to the surface for removal by evaporation (MDBMC 1988).

Soil salinisation can occur when the upward capillary movement carries salt, contained in the groundwater or soil, closer to the surface where it accumulates through evaporation unless leached down again by the movement of water (MDBMC 1988).

Thus shallow watertables may cause the following problems (from MDBMC 1988):-

1. by reduced yields due to salinisation in the root zone;
2. by reduced yields due to a greater propensity to waterlogging;
3. by creating greater difficulties in cultivation and harvesting;
4. possibly higher salinity levels in surface streams and lakes;
5. continued decline of trees, wherever groundwater reaches the root zone (vegetation may change to species which are more tolerant of waterlogging and/or salinity); and
6. a reduction in biodiversity and habitat changes.

The main indication that there is a pending salinity problem is the existence of *saline groundwater which is rising at a fast enough rate to reach about one meter below the ground surface within a relatively short period of time* (Australian Environment Council 1987).

One method for determining watertable levels requires a series of bores into the major aquifers with monthly samples of water measured for salt concentration and depth. Monthly samples are required to account for seasonal variation (Australian Environment Council 1987).

The extent of land already affected by salinity and waterlogging is difficult to establish quantitatively on a state-wide basis. Due to the impracticalities of a state-wide assessment, known problem areas may be assessed.

Areas of shallow watertables and visibly salinised areas have been established for the Riverine plains zone in regions of the Murray-Darling Basin (MDBMC 1990). The report tabulates the extent of shallow watertables and land salinisation for the Riverine plains in 1985. It also indicates the area likely to have shallow watertables by the year 2040.

5.3 ESTUARINE TIDAL LIMIT

The limit of tidal influence refers to the furthest upstream extent of salinity as a result of tidal currents. The *tidal limit* is a zone of transition which moves up- and downstream in response to changes in discharge from the catchment, changing tidal cycles and physical change to the estuary such as sedimentation or the extensive removal of bed and bank material in the locality of the tidal limit zone. The different density between saline and freshwater also creates features such as saline wedges, depending on the geomorphology and hydrodynamics of the tidal/ freshwater transition.

Longterm trends may highlight catchment changes however is not as important for state of the rivers and estuaries reporting

5.4 TIDAL FLUSHING

Tidal flushing is important for the distribution and transfer of materials including pollutants. Decreases in the effectiveness of flushing (e.g. due to sedimentation) may create decreased water quality conditions such as excessive nutrient concentrations leading to problem algal blooms.

An evaluation of an estuary should consider the hydrodynamic and hydrological characteristics which control the circulation and mixing of water, particulate and dissolved materials within a system (Eyre 1990). In assessing tidal flushing, longitudinal, transverse and depth distributions of properties need attention which are dependant on water flow and circulation patterns (hydrodynamics).

In any hydrodynamic assessment the following is considered important (Eyre 1990):

1. Establishment of the hydrodynamic regime of the system by defining the advective and diffusive processes resulting from river flow, density current flow and tidal currents.
2. The temporal and spatial variability of these

processes, with particular reference to seasonal variations of catchment hydrology and tidal effects.

These assessments are achieved in the simplest form using estuarine cross-sections. These cross-sections also allow definition of material fluxes between estuarine compartments. The temporal and spatial sampling rates will vary from estuary to estuary.

6.0 HUMAN INDICATORS

6.1 LAND USE

Comparison of the *land type/ use* combinations with known water quality problems may help to identify areas where improvements in land use and management should be sought and identify areas where monitoring should occur or continue with regard to other environmental indicators.

Assessment of land use can directly highlight sources of impacts. Urban areas, for example, impact river systems by modifying runoff patterns brought about by the increase in impervious surfaces and the velocity of water in urban channel systems; increasing sediment yields particularly from exposed construction sites; and deteriorating water quality through point sources of industrial and dommestic wastes and non point sources such as nutrients, sediments, trace metals and pesticides (Macmillan and Kunert 1990 and references therein).

Planning information that generally exists for catchments relates to land capability to support various land uses. With this understanding and a knowledge of proposed land uses, activities that pose specific risks to the water resources can be directed to those parts of the catchment where they will do the least damage.

In the Maribyrnong Basin, Victoria, the Department of Water Resources (1989) have overlain land systems on land use patterns to give a broad impression of the character of the basin. The information on water quality alone is not detailed enough to define problem areas, but can be combined with land type/ use information to highlight specific problems in the basin. Water sampling at one site downstream of grazing and cropping indicated high salt, nutrient and turbidity levels and low levels of dissolved oxygen. The turbidity and nutrient problems are consistent with both the soils and land uses in the catchment, while the elevated salt levels are consistent with the dominant soil type.

Geographic information systems (GIS) can provide a conceptual relationship between land use changes and water quality changes in a catchment. GIS may include information on all preferred indicators and allow immediate environmental inputs into land use planning and water quality decisions.

6.2 RIVER REGULATION

The negative impacts of *river regulation* and extraction of water on the biophysical function of stream ecosystems is well documented (Irvine and Jowett 1987; Lawerence 1991; Pigram 1986; Petts 1988; Stanford and Ward 1980; Walker 1985). These impacts include altered flow volumes; altered seasonality of flow; increased rate of fall of river levels; altered water quality; creating barriers to fauna movement; changes to nutrient cycling, changes to invertebtate production and macrophyte production; and creating conditions more favourable to exotic species.

Information that is accessable from the NSW Department of Water Resources, on major storages, dams, weirs and water management procedures could be used in conjunction with other indicators to determine trends in river regulation and river quality. Impacts on fish movement may be assessed for example, by a decreasing trend in the number of weirs leading to an increase in the range and abundance of native fish species. Conversely, additional weirs may lead to a decrease in fish passage unless specifically provided for in the design criteria. Natural barriers such as waterfalls should also be identified, this would require inspection of 1 : 100 000 scale maps.

The OECD (1991) in their report on broad scale environmental indicators for national and international purposes, focus on the presures on freshwater resources due to water withdrawal. They propose an indicator founded on water resource accounting: water withdrawal (demand) as a percentage of gross annual availability of water (supply). Trend analysis shows that most OECD countries have increased their water withdrawal over the past two decades by more than 20%.

6.3 RIVER MANAGEMENT WORKS

River management works (RMWs) can be grouped for convenience into two broad categories. These are bed and bank stabilisation works, and river clearing.

Bed and bank stabilisation measures are designed to reduce stream erosion by measures such as structural bank protection works, revegetation of banks, drop structures, grade control structures and rock chutes.

River clearing works involve the removal of obstructions, including gravel deposits, where carrying capacity has been reduced or erosion is causing problems. These works include desnagging and sediment dredging (Department of Water Resources, Victoria 1989).

The amount and type of *RMWs* may be influenced by a number of factors including differences in landform, soils, climate, landuse and land values. When assessing RMWs as an indicator these factors need to be considered. The amount and type of RMWs may indicate the erosive potential of rivers in each basin due to these rivers possibly having steeper slopes, more frequent bankful flows (e.g. due to irrigation releases) and floods of a greater magnitude. River management works involving desnagging, channelisation and sediment dredging may also indicate a stream environment that has poor ecosystem potential (Department of Water Resources, Victoria 1989).

The level of disturbance to any given area may not be able to be assessed with existing data. Problems may include inconsistencies in location descriptions; lack of specific details, such as type of works; and omissions of data, such as unrecorded illegal works. As a result, data on the number and type of stream works do not necessarily indicate those areas most affected by flooding and erosion (Department of Water Resources, Victoria 1989).

At present, in New South Wales, costly RMWs are only undertaken on regulated streams. Funding for such works has been very limited. The growth of Landcare groups may influence funding allocated to RMWs for private landholders on unregulated streams in the future.

6.4 EXTRACTIVE INDUSTRIES

The *location, number, type and size of extractive industries* are indicators that must be measured due to their well documented impact on river system functions and values (Erskine et al 1988; State Pollution Control Commission 1984). Department of Water Resources NSW (1992) provides a summary of environmental impacts of sand and gravel extraction in non-tidal rivers and reflect the important issues in relation to extractive industries.

Data on extractive industries are kept by the Department of Water Resources as part of their management. The River Corridor Unit is currently compiling a data base on all known extractive activities for management purposes. Management plans will also be undertaken where their is a high demand for sand and gravel. These will incorporate *monitoring of cross sections* throughout the stream.

6.5 REVEGETATION PROGRAMS AND RIPARIAN FENCING

Trends in community involvement in floodplain and river bank *re-vegetation programs* and the extent of protective *riparian fencing* may provide useful supporting information for the riparian zone indicator (section 3.1).

Various factors influence community involvement in re-vegetation programs, therefore the use of this indicator can only be qualitative and assessed tentatively.

The extent of riparian fencing may be useful in state of the rivers reports due to the effectiveness of this measure in rehabilitating and protecting the important riparian buffer. The high costs to landholders of effective stock proof fencing and their willingness to support this management option may hinder the rate of fencing.

6.6 HUMAN INDICATORS FOR ESTUARIES

These indicators provide supporting information for the key components of the estuarine system. The Victorian Institute of Marine Sciences (1991) recommend the following process/activity indicators for estuaries.

1. Extent of capital dredging works monitored

every five years utilising surveys of the records of port authorities, coastal management agencies, and regulatory authorities combined with analyses of aerial photography.

2. Occupancy rates of marinas and swing moorings monitored every five years summarising annual averages. This would involve analyses of records of marina operators, yacht clubs and minor ports.
3. Annual number of boats registered involving summaries of boat registration figures and yacht club craft numbers.
4. Quantity of antifouling paint applied to small craft. Annual averages should be summarised every five years via an audit of manufacture and sales of anti fouling paint.

For indicators two to four it would be useful to separate prodominantly estuarine from offshore craft.

6.7 WATER RELATED HEALTH PROBLEMS

In State of the Rivers and Estuaries reports it would be useful to describe trends in the incedence of health problems or epidemics as a result of poor water quality.

The major concerns are the deterioration of the quality of water (both surface and subsurface) for human use, and for recreation, from factors such as increased nutrient load, faecal contamination and diseases (e.g. chollera) from sewage effluents.

Changes in environmental amenity which can also affect health, for example, may be the increasing quantities of refuse such as metal or broken glass leading to wounds and lacerations becoming infected due to poor water quality.

6.8 COMMUNITY ATTITUDES AND SURVEYS

Public attitudes can affect the quality of river systems in a number of ways. Individuals and communities can mobilise support for particular issues and exert political pressure that causes changes in public environmental policies. Public attitudes can also affect the way in which individual members of society act in relation to river environments, for example, reducing litter and dumping around river banks or into the river.

River corridor management should include some form of appraisal to identify the types of river corridor features which the public prefer and the way in which the public would like to see the river managed. Community surveys and other methods of obtaining information from the public and landholders may also assist in filling gaps in the information for a catchment.

Although the public may not posess a formal knowledge of the best environmental options available for river-works or management, they have strong preferences for certain environmental features (House and Sangster 1991).

In the U.K., House and Sangster researched the public's perception of water and river-corridor quality to assess the importance of these aspects to the public's selection of sites for use in recreation. The results suggest that there is a close relationship between the type of riverscape preferred by the public in their use of rivers for recreation and amenity and that desired by conservationists.

Information obtained from local authorities and landholders can highlight local catchment issues. These indicators can provide logistically simple and cost effective assessments and often provide essential information in relation to other indicators.

Eyre (1990) for example, notes that discussions with, and surveys of, local authorities and landholders may give a quantitative determination of total nutrient input to a catchment or estuary system. The questionnaire may include:-

1. the number of people and number and type of farm animals on the land area;
2. the methods of waste water, solid waste and sewerage water disposal for both the people and animals;
3. types of crops, crop production and amount and type of fertilisers used, and temporal application of these fertilisers; and
4. type and amount of commercial and industrial wastes released into the catchment area.

Various problems need to be considered in relation to community surveys and their results. These include the development of effective survey questions and structure, statistical analysis, identifying target groups and determining catchment boundaries.

Publicly contributed environmental information such as biological databases may offer a high profile and cost effective way of collecting scientifically credible information that is of direct use to management (Fleming 1991; Blyth 1983). Fleming's (1991) study demonstrates that observational data collected voluntarily by skilled non-professionals adequately sampled the bird populations that are present in the Northern Territory Gulf Region.

6.9 POPULATION

Population is a major determinant of environmental conditions and performance. Firstly, population density means human activity density and is correlated with pollution and with resource use (OECD 1991).

In the Hawkesbury-Nepean River system, for example, proposals are under way for new housing projects which will bring a million people into the river valley in the next 30 years (Water Board 1992).

At current population levels the river system is showing considerable signs of environmental stress. Downstream from the dams, the river environment is deteriorating rapidly (Water Board 1992).

At present the system supplies 97 % of Sydney's drinking water and is a receiving water for increasing levels of urban runoff and treated effluent. The community also depends on the river for a wide range of social, agricultural, industrial and recreational activities. One of the major environmental limitations to the growth in this region is protecting the quality of the river (Water Board 1992).

Analysis of population figures will show general trends and allow projections to be made on future population figures. Estimating the impacts of increasing populations on environmental condition would be difficult to quantify. It is clear, however, that with continued growth it is difficult to have sustainable water resource use in terms of quality and quantity.

One problem with reporting population trends on a catchment basis is that census distict boundaries do not correspond with catchment boundaries.

7.0 SUMMARY OF INDICATORS

Environmental indicators are measures which can be used to show significant trends in the state of the environment. If the preferred indicators developed after this review are to highlight these significant trends then they should meet the following criteria (from Australian Environment Council 1987). They should:-

1. be applicable to the whole of a defined segment of the environment, i.e. an indicator of river quality should be conceptually applicable to all Australian rivers;
2. where practicable, be based on existing data collection, storage, retrieval and interpretation programs;
3. relate directly to stated environmental quality objectives (where such exist) and to the ecosystem being measured;
4. enable spatial and temporal trends in environmental quality to be assessed; and
5. should facilitate broad community environmental quality assessment and awareness.

Various groups of indicators also came out of the literature, these cover:-

1. broad catchment changes (e.g.'s shifts in land use, agricultural practices, areas forested/ cleared, population increases);
2. broad floodplain changes (e.g.'s area/ quality of floodplain vegetation, floodplain scour, floodplain habitat diversity);
3. whole river system trends (e.g.'s riparian vegetation extent, phosphorus levels, river continuum trends);
4. indicators of specific river site problems and point source impacts (e.g.'s 'severe' erosion sites, sewage discharges indicators);
5. indicators related to the occurrence or increasing/decreasing rates of occurrence of specific incidences such as algal blooms, fish

kills, oil/chemical spills, waterbird breeding events and water related health problems/ epidemics;

6. indicators which measure actions to reduce impacts or management response indicators (e.g.'s re-vegetation programs, activities of Landcare groups, riparian fencing);and
7. community attitudes and awareness indicators (e.g.'s perceptions of river quality, community surveys, changes in perceptions of river management, communities mobilising support for issues and exerting political pressure, positive trends in the way people act in relation to the environment.

With regard to whole river system trends it is practical to select a small number of indicators which are most likely to provide meaningful management information in the long-term. For other important indicators for whole river systems, it may be more cost effective to monitor them at key sites which have been established and are used regularly; for example, river gauge inspectors could also gather information on habitat diversity and condition for that river section.

There are also complexities in the applicability of different indicators for the different types of regions and ecosystems. Due to the heterogeneity of catchment ecosystems, different indicators could be used to reflect differences between region/ catchment type; upstream/ downstream reaches; coastal/ inland streams; and tidal/ non-tidal areas. Due to the the variability between regions and the high variability in water quality and ecosystem processes in Australia is is important to select a range of indicators to supplement and support the key indicators for whole river system trends on a Statewide basis.

A range of indicators may be used for measuring water quality downstream of point or site specfic sources of pollution. The selection of indicators to be used at each site will depend on the nature of the point source (e.g. temperature downstream of a power plant, cattle dip sites).

Section 12 tabulates the preliminary river and estuary indicators which were developed from consultation with State and local government agencies; academics; the local community within the Orara river pilot area; and this review on environmental indicators. Units of measurement and standard methods for monitoring and reporting state of the rivers and estuaries condition will need to be established for many of the indicators. Where available, units and general methods have been noted in the tables.

8.0 CONCLUSION

Aquatic ecosystems are dynamic, living organisations that are exceedingly complex. Scientific understanding of factors that regulate ecological composition and structure is far from complete. Influences act with varying intensities and often on different time scales (Bird and Rapport 1986).

Our knowledge about river ecosystems as functioning entities has to be increased. Fundamental deficiencies in the available data set and the problems of determining adequate baselines for monitoring, emphasise the scientific importance of those few remaining environmentally intact catchments, as reference areas for comparative analysis, and for the determination of baselines which are closer to 'natural' conditions (Commissioner for the Environment 1989). There is a tendency to prefer doing research in polluted waters. However, since many of the valued properties have already been lost, a disturbed ecosystem can hardly be expected to reveal these properties (Ringelberg 1982).

Recent efforts to develop measures of aquatic ecosystem condition have focussed on the biological integrity of ecosystems (Karr 1991). Biological integrity in this context has been defined as "the ability to support and maintain a balanced integrative, adaptive community of organisms having species composition, diversity and functional organisation comparable to that of the natural habitat of the region (Karr and Dudley 1981).

These approaches rely on 'ecoregions'. Ecoregions are regional reference sites, selected to represent healthy ecological communities typical of the region. Such an approach has clear applications to Australia, both at the national and state levels.

Natural water quality conditions vary across the spectrum of inland and coastal waters. Within each state there is a broad range of aquatic habitats which must be considered separately for water quality management (Hart and Campbell 1991). The unique features of Australian lotic systems make it imperative that we obtain our own understanding of their ecology.

A major problem at present is the translation of objectives into the most useable and practical indicators. We need to know what evaluation techniques are available as there has been little work done in New South Wales stream reporting in relation to:

1. the development of specific and measurable objectives;
2. moving from objectives to assessment;
3. developing baselines of data against which subsequent information on trends is to be assessed;
4. the frequency with which samples must be taken;
5. the minimum period over which data must be gathered;
6. units for monitoring and reporting;
7. siting criteria and sampling methods, (interagency consultation and further investigations will be required to standardise units and methods for SRE reporting);
8. applying the evaluation to the use of objectives;
9. integration of information (available data are often held in a manner which renders them inaccessible for integrated assessments of current conditions and trends, this is despite the availability of technologies for such integration Examples of these include GIS and a Statewide or nationally applicable stream and catchment reference/numbering system such as the system used by Victoria, see Wilson and Nason 1990); and
10. communication of information about current conditions, changes in management and community requirements (Christoff unpubl.).

Future studies must be integrated and catchment-wide, and should include studies of the ecology in collaboration with the hydrology, geomorphology and water quality, the linkages between the river and its catchment, the riparian zone and floodplain. The precise manner in which human activities impact on the system need to be clarified in these studies (Hart and Campbell 1991).

Although the broad links between many catchment activities and the river are recognised, the more detailed quantitative relationships needed, if management prescriptions are to be formulated, remain unrecognised in most cases (Hart 1992).

Hart (1992) summarises the use of environmental indicators where he concludes that there should be the use of existing water quality information coupled with a rapid assessment of the stream biota (based on the macroinvertebrate community) and an assessment of the physical condition of the river, its riparian zone and catchment.

The required information must be supported by a sustained and focused long-term ecological research program.

One unifying feature of most documents examined in this review was the theme of managing the environment and its resources for sustainablity. This acknowledges the close relationships between economic, social, scientific and political factors which should result in clearly stated and quantified objectives and indicators for the assessment of progress towards non-degradation (Australian Environmental Council 1989).

While there has been no comprehensive assessment of the condition of NSW rivers, there is ample evidence of continuing degradation and the need for intervention to restore, or at least maintain, the existing condition (Mackay and Landsberg 1992).

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10.0 GLOSSARY OF TERMS

AEROBIC:

Living or active in the presence of free oxygen. An aerobic process is one taking place in the presence of free oxygen.

ANAEROBIC:

Living or active in the absence of free oxygen. An anaerobic process is one taking place in the absence of free oxygen.

EUTROPHICATION:

High organic production due to nutrient enrichment. Can cause excessive growths of algae or macrophytes which may eventually die and decay causing oxygen depletion.

BENTHIC FAUNA:

Pertaining to animals living on the bottom or bed of a river, lake or the ocean etc.

BIOACCUMULATION:

Accumulation of toxic elements or compounds in body tissues which can pass from one organism to another through the food chain. These compounds are then concentrated in the bodies of the predators to such a degree that they become toxic to the predator.

BIOPHYSICAL:

Biological and physical components of the environment.

BOITA:

All organisms including flora and fauna.

DETERMINAND:

A general name for a characteristic or aspect of water quality, usually a feature which can be described numerically as a result of scientific measurement.

FUNCTIONAL DESCRIBERS:

Abiotic and biotic variables that reflect alterations in ecosystem function and sucession through changes in their concentration or abundance, including the appearance and extinction of organisms or groups of organisms.

FUNCTIONAL FEEDING GROUPS:

Macroinvertebrates that are grouped on the basis of their different feeding mechanisms and morphology of their mouthparts. This results from the variety of food sources and habitat types along a river from the upstream sites to the broader floodplain reaches. Funtional feeding groups include collectors, filterers, predators, scrapers and shredders.

LOTIC:

Flowing or running water systems, refering to rivers and streams. Lentic systems refer to still or non-flowing environments.

PHYSICOCHEMICAL:

Pertains to physical and chemical parameters.

RIFFLE:

A length of a waterway where water of shallow depth flows rapidly over stones and river gravel.

RIPARIAN:

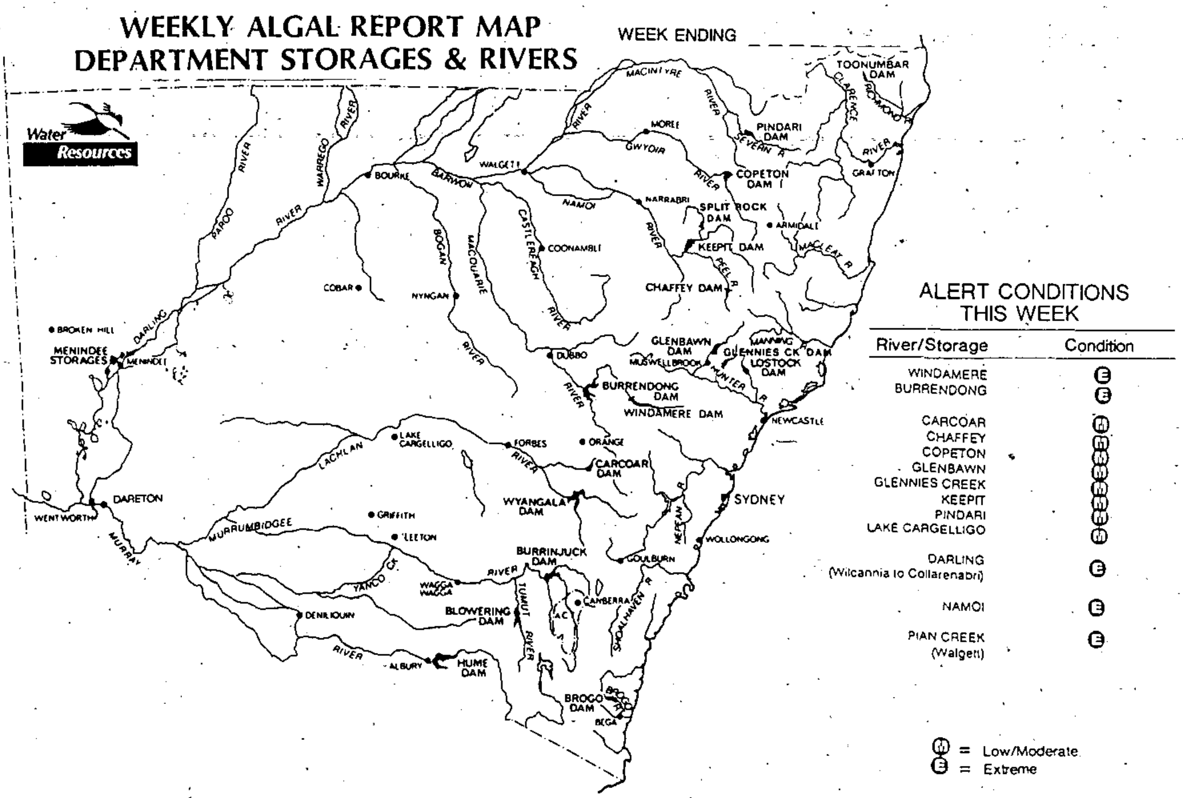
Pertaining to the bank of a waterway or other waterbody.

TROPHIC LEVEL:

1. The nutrient content of a waterbody, in particular the quantity of nitrogen and phosphorus determines trophic status.

2. Any of a series of distinct feeding or nourishment levels in a food chain, such as primary producers (plants) are trophic level one; herbivors are trophic level two etc.

APPENDIX 1: BLUE-GREEN ALGAE TASK FORCE (1992) WEEKLY ALGAL REPORT



APPENDIX 2: MACKEY ET AL (1988) DOUBLE MASS CURVE TECHNIQUE

Double mass curve for actual and estimated natural flow to South Australia.

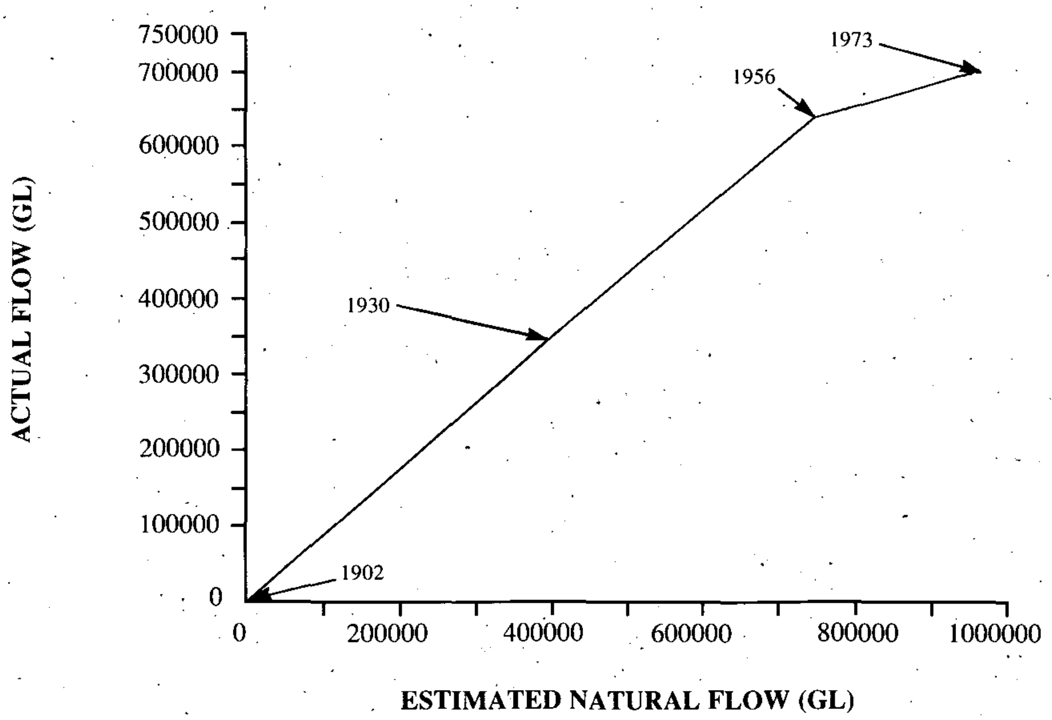


TABLE 1: WATER QUALITY INDICATORS

WATER QUALITY INDICATORS	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
PHOSPHORUS	· Systems potential for algae and macrophyte production · Driving force in blue-green algae problem	· Residue of fertilisation and other farming practices · Effluents from urban and industrial areas · Problem increased by warm and bright sunshine	· Trends may be established with longterm monitoring in regions with low natural background levels (generally P is rare in the geology and soils of NSW) · Sediment interphase relationships need also to be understood	· Total phosphorus (as P, mg/L) · Filterable reactive phosphorus (FRP) · Criterian level to prevent nuisance plant growths in freshwater is 0·05 mg/L (SPCC 1990)	·Total nutrients
TURBIDITY	· Physical - Presence of suspended and colloidal substances of various origins · Biological - Light penetration for photosynthesis · Direct impacts on flora and fauna (eg blocking fish gills)	· Natural - Geology, soils, climate patterns, weathering, eroision, storm and flood events · Increases downstream · Unnatural - Land clearing, cropping, grazing, road building, urban development, carp	· Data available from monitoring programs · Trends are difficult to establish due to natural variability · Potential to monitor large areas using satellite sensors to identify surface suspended sediments	· Nephelometric Turbidity Units - NTU using a nephelometer · Secchi depth	· Land use, eg urban areas increased downstream turbidity
CONDUCTIVITY	· Physical - Concentration of salts or major ions in solution · Biological - Potential impacts on aquatic and riparian vegetation and aquatic fauna · Social - Impacts on water users	· Chlorides (sodium bicarbonate and sodium chloride), sulphates and bicarbonates of potassium, calcium, magnesium and sodium · Geology and soils in the catchment · Season and flow influences cause highly variable conditions	· Trends may be established with lond data records and removal of seasonal and irregular factors	· $uS\ cm^{-1}$ at 25 degrees C using conductivity meters · Temperature measured with salinity · milli-siemens (mS) per metre	-
BIOCHEMICAL OXYGEN DEMAND (BOD)	· Indicator of organic pollution (See also Dissolved Oxygen)	· Organic pollution · Oxygen consumption by microorganisms	· Problems associated with the BOD test can be eliminated, therby retaining confidence in its use· (eg effect of algae on test) variability still needs to be accounted for	· mg/L - BOD test · BOD (ATU) - The effect of more oxygen being taken up by ammonia in the test than in natural water is suppressed by adding a chemical (allylthiourea) to the sample of water for testing · Without ATU the BOD is "uninhibited"	-
DISSOLVED OXYGEN (D.O.)	· Indicates the biotic status and structure of a water body · Indicates some dominant processes (such as which chemical will dominate and therefore affect phytoplankton) · Indicates the destruction of organic substances which may result in low D.O. levels due to eutrophication (intensity of self purification) · Indicates likely stress on organisms where there is low D.O.	· Natural: Temperature, aeration/ turbulence · Unnatural: Low D.O. due to nutrient enrichment, eutrophication mining activities, sewage effluent	· Diurnal, temporal and spatial variability, therefore whole river or estuary system trends cannot be determined	· % saturation · ug/L · Parts per million · Dissolved oxygen meters	· Temperature influences the soluability of D.O.

TABLE 1: WATER QUALITY INDICATORS *CONTINUED*

WATER QUALITY INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
TEMPERATURE	· Indicates trend and tendancies in changes in water quality · Temperature levels suitable for fish growth, production rates and reproduction, as well as other biota · Indicates the potential for soluability of dissolved gases	· Natural: climate, weather, shading, depth · Unnatural: impoundment water releases, power plants, industrial outflows	· Diurnal, depth, temporal and spatial variability, therefore whole river system trends cannot be determined · Most value for use below known sources of potential thermal pollution, (eg power plants, dams) · Temperature is necessary for conductivity measurement and is important for the interpretation of other parameters particularly biological data	· Degrees Celcius · Electronic probes	-
TOTAL NITROGEN AND NITRATES	· Indicates general nutrient changes in river water quality and is used specifically for monitoring sewerage treatment plant effluents · Low N:P ratios may indicate the potential for blue-green algal blooms (as well as other complex interactions)	· Natural: non-conservative element transforming in both directions between ionic and gaseous forms and is mediated primarily by micro-organsims · Unnatural: Sewerage treatment works, landuse, urban wastewaters, irrigation drainage	· Most cost effective on a Statewide basis to moniter below point sources of nutrient, however for specific issues such as blue-green algae it is useful to know N:P ratios and therefore should be monitered in some cases for specific purposes	· Total Kjeldahl N (mg/L) · Oxidised N (mg/L) · Ammonialical N (mg/L) · To prevent excessive growths of plant life in rivers the criterion of 0·05 mg N/L has been set	-
pH	· Alkalinity or acidity of water · May indicate direct changes in water quality, or point to the presence or harmful pollutants · May indicate conditions suitable for blue-green algal bloom or other instream processes	· Mineral content of the water and hence the nature of mineral species present in the catchment · Biological activity in the water · Industry · Mining discharge, acid mine drainage	· Necessary for analysis of other indicators (such as blue-green algae)	· Standard pH scale, rivers usually 6·0 - 9·0 units	-
TOTAL COLIFORMS AND E.coli	· Faecal contamination of water by warm blooded animals · Microbiological quality of effluents for drinking water and at recreation sites	· Natural: Faecal coliforms have natural background levels and are free living in the soil and on vegetation · Heavy rainfall and runoff · Unnatural: Levels dangerous to human health may result from sewerage treatment effluents and faeces from stock grazing along the river (increased by heavy rainfall and runoff)	· Generally monitored for water supply and recreation sites · Results take time to determine therefore the problem is not immediately detectable	· Total coliform numbers and *E.coli* counts · Counts are recorded as cells / 100 mL, colony forming · For domestic water supply with chlorination, fewer than 5% of samples should contain more than 10 *E.coli* cells / 100mL · Total Coliforms - 100 cells / 100mL	· Rapid defined substrate technology - a new simple and rapid method for determining total coliforms and *E. coli*

TABLE 1: WATER QUALITY INDICATORS *CONTINUED*

WATER QUALITY INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
TOXIC CHEMICALS	· Point and diffuse sources of chemical pollutants	· Industrial discharges, urban runoff, municipal discharges, combined sewer overflows, agricultural runoff, sivicultural runoff, transportation spills, mining discharges	· Limited number of stations below major point sources at frequent intervals	· Varies depending on chemical · Pesticides have a detection limit of 0·02 ug/L	· Monitoring chemical associated siteand point sources
HEAVY METALS	· Point and diffuse sources of heavy metal pollutants	· Natural sources in geology of the catchment · Mining discharges, acid mine drainage, industrial discharges, municipal discharges, urban runoff, natural sources, irrigation drainage	· The most cost effective monitoring would involve a limited number of stations below major sources, and monitered frequently (monthly) to provide a more comprehensive picture of quality variation · In view of low concentrations in water any proposal to monitor indicator organisms should be examined carefully, however it may be more expensive and difficult to interpret at this stage	· Varies depending on heavy metal · Generally mg/L · Monitored in water, sediments or indicator organisms	· Monitoring heavy metal associated site and point sources
CHLOROPHYLL	· Used to estimate the phytoplankton standing crop	· Limited by plant nutrients, turbidity · Strongly influenced by flow, high flows reduce retention time	· Chlorophyll levels are not a suitable measure of the trophic conditions in tributary and small upper catchment sites due to the importance of other forms of plant life, such as macrophytes and benthic algae	· ug/L · Blooms are arbitarily defined as concentrations greater than 20 ug/L	-
OIL OR CHEMICAL SPILLS	· An increasing trend in the occurence of oil or chemical spills indicates decreasing environmental quality	· Accidental spills · Neglegence · Equipment, machinery or safeguard failure	· NSW EPA and DWR keep Statewide datadases	· Incident reporting and assessment of trends	· Land Use, particularly oil and chemical associated industries · Fish Kills · Oil residues on biota
SEDIMENT ANALYSIS	· Indicates the composition of sediments and the amount of nutrients that potentially could be released	· Depositional environments such as estuaries areas of decreased flow velocity accumulate sediments and nutrients	· Important parameters for the assessment of the total nutrient environment	· % fines · total organic carbon (TOC) · total Kjeldahl Nitrogen · total phosphorus	-

TABLE 2: ECOLOGICAL INDICATORS

ECOLOGICAL INDICATORS	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
RIPARIAN VEGETATION	· Bank and verge stability · Buffering stream from sediment and pollutants · Provision of habitat for terrestrial and instream fauna (via leaf litter fall and insect fall)	· Natural - Hydrology and flooding regime · Water availability and plant adaption to this zone · Unnatural - Clearing, cropping, grazing, stock access, weeds, industrial activity, roads and access, river regulation	· Air photo, Spot satelite potential · Costly on a State basis but necessary · Ground truthing and field survey data to determine species associations, ground covers and understorey density may be available for some regions	· Presence/absence and extent on a Statewide basis · Manual air photo interpretation · Ground truthing , field survey plots and transect techniques for detailed studies of condition	· Revegetation programs · Reported riparian disturbances · Protective riparian zoning
WETLANDS	· Trend in areas of wetlands, their number, type and condition	· Natural - Geomorphology, hydrology and flow characteristics · Unnatural - Clearing, river regulation, water extraction, land reclaimation	· Air photo and satelite imagery potential · The condition of wetland is more difficult and costly to determine on a statewide basis · Inherent indeterminant boundaries create problems for estimating wetland loss	· State wetland inventory needed · Air photo or satelite imagery · Digital geographic overlays based on wetland soil and vegetation maps and areas of inundation	-
WETLANDS AND RIPARIAN ZONE (Ecosystem processes and functions; eg: quality of understorey riparian vegetation)	· As well as trends in area of wetlands and other areas of environmental significance, other information such as ecosystem functioning and condition may be required for assessment _reporting and management · Other important processes and features may also require monitoring such as wetland water balance or quality of understorey riparian vegetation	· Wetlands: see Core Indicators; · Wetlands functions and values include: nutrient transfers and cycling, maintaining water quality, providing habitat, flood migration, enhancing groundwater recharge, aesthetic values, relationship to main watercourse · Riparian: see Core Indicators; · Ecological processes and riparian buffer effectiveness are features that may be assessed with a detailed study	· Only areas of high environmental significance may be assessed · Trends in ecosystem processes and functioning information may be costly to obtain, however, necessary for management in some areas · High variability in wetland and riparian ecosystem make trends difficult to establish in relation to ecosystem functioning	· Wetlands : Water balance models, inflow hydrographs, ecological studies, conservation status rare and endangered species · Riparian : Density of groundcovers and understorey vegetation · Buffering effectiveness studies · Ecological studies, conservation status, recovery potential	-
FISH (Abundance/species)	· Changes in the abundance or occurance of species may indicate or reflect changes in the river system · Presence of rare, threatened or restricted species may indicate a stream in relatively good condition or a stream which should maintained or improved in quality	· Natural: Habitat diversity, natural environmental flows and floods, water quality, undisturbed stream and riparian zone · Unnatural: Loss of habitat, loss of natural flows, barriers to movement, pollutants, fishing pressure, introduced species	· Whole river system trends on a statewide basis can not be determined · Presence/absence data for river system may be useful and available; species lists and information on their ranges, preferred habitats, and breeding requirements also important	· Catch data from fisheries · Individual species as indicators · Recreational fishing surveys · Research studies · Trends in the occurence or rare, endangered or threatened species · Species lists for initial studies · Ratios of exotics to natives	-

TABLE 2: ECOLOGICAL INDICATORS *CONTINUED*

ECOLOGICAL INDICATORS continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
MACROINVERTEBRATES	· The extent to which the community of the watercourse falls short of what would be expected in an unpolluted or undisturbed system (ie, ratio of observed to predicted status)	· Longitudinal changes in stream ecosystems from headwaters to estuaries · Flow variations · Pollutants (mouthpart deformaties) · River regulation · Riparian and instream vegetation · Substrate and habitat structure · Biotic interactions	· Has potential to be cost effective and provide useful management information after a development phase · Baseline conditions are not known · Currently there a lack of theoretical basis for community responses to given perturbations (eg seasonal variability, human impacts) · Less replicates required than other water quality measures as the biota is measured directly · Requires robust statistical techniques and initial taxonomic expertise · May require identification to species level	· Standardisation of methods required · Methods should consider ease of taxonomic identification and sampling, availability of taxonomic expertise, selecting species that are abundant and diverse and respond to perturbations at a convienent and detectable scale · Selection of indicator taxa · Taxonomic reduction of the total data · Analysis of functional feeding groups · Community similarity measures	-
AQUATIC VEGETATION (Extent/Type/Weed)	· Changes in the biomass of aquatic macrophytes may indicate nutrient changes to the system · Normal coverage of macrophytes may indicate a stream in good condition with good cover and habitat for fish and invertebrates · Excessive aquatic plants indicate nutrient rich water and sediments or the introduction of exotic species	· Nutrient status and flow conditions · Loss of aquatic macrophytes may result from river management works, extractive industries, sedimentation and introduced species	· Comparison of photographs overtime at key sites may highlight trends · Variability in season and between region and location along the river	· No standard methods · % cover may be used such as: zero or > 80% cover poor; 5-20% cover - moderate; 30-60% cover - good · Percentage and extent of exotics · Field observation	· Nutrients
EXCESSIVE ALGAL OR MACROPHYTE GROWTH	· Indicates nutrient rich waters and associated favourable conditions such as warm temperatures, calm water and relatively low turbidity (low turbidity not necessary for blue-green algal blooms)	· Increased nutrient imputs · Reduced shading · Calm and warm water conditions	· Major issue which should be monitored to assess the potential for blooms or excessive macrophyte growth · Their incidence should be fully reported on and assessed	· <u>Algae</u>: Biomass and species composition (proportions of green/blue-green/diatom) · Phytoplankton (chlorophylla) · Cell counts in water sample · Incedent reporting and assessment · <u>Macrophytes</u>: extent, species, exotics and location	· Nutrients

TABLE 2: ECOLOGICAL INDICATORS *CONTINUED*

ECOLOGICAL INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
HABITAT DIVERSITY (River and Floodplain)	· High habitat diversity indicates a stream in good condition · Trends in habitat diversity at key sites · Changes in usable habitat for fish or other fauna	· Geomorphology, fluvial features (such as billabongs), undercut banks, aquatic macrophytes, riparian vegetation, snags, boulders, substrate type, deep pools, riffles · Flow variations (natural and unnatural) · Sedimentation (pool infilling) · Vegetation removal · Extractive industries · Flooding regime	· May be assessed qualitatively using characteristics such as bed composition, cover for fish, pool:riffle sequence, water depth, and rated from poor to excellent · Broad system changes in habitat diversity cannot be assessed, however may be monitored at key sites · A stream section may have naturally low habitat diversity	· Standardised field observation sheets, rating scales from very poor to excellent	· Pool:riffle sequence · Width:depth ratio
FISH KILLS	· Assessing trends in the rate of fish kills may indicate trends in river quality · Indicates water quality conditions (eg low DO) being unfavourable for fish at the time of the fish kill	· Critically low dissolved oxygen levels · Toxic chemicals	· Records of fish kills, their frequency of occurence and the causes are generally kept for each region	· Incident reporting and assessment of trends	· Dissolved 02 · Toxic chemical spills
WETLAND BIRD BREEDING OR DEATH EVENTS	· Natural bird breeding events may indicate an adequate flooding regime for that specific purpose in that year · A failed event may indicate a loss of environmental water to support the complete breeding cycle · Failed events may also be a natural occurence	· Natural wetland flooding regimes and their habitat · Failed events may result from a rapid recession of water in the colony, naturally due to a small flood or artifically due to loss of water through river regulation and extraction for irrigation · A slow natural flood recession rate is required for a successful breeding event	· As waterbird breeding events have environmental significance and are a concern to the community, they are generally monitored and reported on	· Incident reporting and assessment in major bird breeding wetlands	· Wetlands area, extent, condition · Flow characteristics and flood recession rates in wetlands
OTHER FAUNA (Abundance/species/breeding)	· Studies may indicate changes or impacts on fauna which are particularly associated with the stream or riparian zone · Trends in the frequency of occurence of rare, endangered or special fauna (eg platypus) may broadly indicate changes to the river system	· <u>Natural</u>: Adaption to highly the variable nature of fluvial ecosystems in Australia · <u>Unnatural</u>: Loss of habitat, loss of natural flows, pollutants, introduced species	· Presence/absence and breeding of important species would be useful for management · May be obtained from interest groups, research bodies or landholders	· Trends in the presence and abundance of species · Platypus sighting records and assessment of their habitats	· Habitat diversity

TABLE 3: GEOMORPHIC INDICATORS

GEOMORPHIC INDICATORS	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
BED EROSION (Aggradation/degradation)	· Bed degradation indicates a lowering or deepening of the river level - severe erosion can undermine bridges and other structures as well as river banks causing them to collapse · Bed aggradation indicates a raising of the river bed usually due to an influx of coarse sediments or a reduction in flows - usually indicates severe bank and/ or bed erosion upstream · Both indicate a more uniform bed with reduced habitat diversity, pool: riffle sequence etc	· Natural: geomorphology, bed composition, discharge increases (secular increases in rainfall), stream gradient, sediment availability · Unnatural: Bed lowering by extractive industries, increased discharge and water velocity, sediment increases, river regulation	· Not feasible to measure on a Statewide basis however, a major issue which which should be assessed at key sites or in areas of known erosion problems · Essential for monitoring upstream and downstream of sand and gravel extraction sites or where extensive river training works have been undertaken	· Metres measured on vertical cross sections taken at different time intervals · Assessable at "headcuts", at bridge piers and other structures, or at junctions with tributary streams · Metres measured on vertical long profiles taken at different time intervals	· Increases to bank erosion (generally more visible)
BANK EROSION (Type/rate/extent)	· Accelerated bank erosion indicates changes to flows (volume, velocity or direction) and/ or a decrease in protective vegetation · Indicates changes to the width/ depth ratios and pool: riffle sequence resulting in reduced habitat diversity	· Natural: geomorphology, dominant soil types, long term climatic patterns, water velocities, increased discharge · Unnatural: Loss of riparian vegetation and attached aquatic macrophytes, river regulation, extractive industries, increased frequency of localised disturbences, increased discharge and velocities	(As bed erosion)	· Metres measured on vertical cross sections taken at different time intervals · Metres measured in plan form from air photos · Metres of additional bridge construction · Metres measured from survey pegs placed at set intervals from the top of the banks	· Decreased riparian vegetation
GULLYING	· Increasing gullying indicates a degrading catchment and decreased water quality from sedimentation and turbidity	· Vegetation clearing · High rainfall events	· There are large areas involved for Statewide assessment and there is high seasonal and spatial variability in gullying	· No standard methods for a Statewide assessment . Presence/ absence/ severity	-

TABLE 3: GEOMORPHIC INDICATORS *CONTINUED*

GEOMORPHIC INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
WIDTH : DEPTH RATIO	· Changes to the width:depth ratio may indicate excessive erosion or removal of riparian vegetation upstream	· Natural: Discharge, type of bed material, land type, stream size, distance down stream · Unnatural: Excessive erosion, extractive industries, riparian vegetation loss	· May be assessed at key sites · Comparison of photographs at key sites may highlight trends · W:D ratios change naturally from the upper catchment tributaries to the downstream reaches	· No standards set for optimal width/depths for each river size and type for statewide application · Field observation · Measurement using river transects for width and depth	· Erosion
POOL/ RIFFLE SEQUENCE	· A mixture of pools and riffles indicates a stream in good condition with a diversity of habitats · All pool or all riffle may indicate a stream in poor condition (depending on stream size) · Infilling of pools may indicate erosion problems upstream	· Natural erosion processes and flow dynamics · Geomorphology and substrate type · Loss of sequence may result from severe erosion, stream management works and removal of riparian and aquatic vegetation	· May be assessed at key sites · Qualitative assessment · Cannot be assessed on a state wide basis · Comparison of photographs up and downstream at key sites may highlight trends	· No standard assessment method · Field observation · Proportion of pools to riffles such as: . minor streams - 100% pool or riffle is very poor; through 70 - 80% pool or riffle is moderate; and 50% pool or riffle - excellent . major streams - Intermittent pool or very shallow - poor; 100% pools moderate; some riffles - good	· Habitat Diversity
ESTUARINE SILTATION (Non marine)	· Quantity of weathered and eroded material deposited and moved through an estuary · The distribution of sediments due to esturine hydrodynamics	· Geology and soils of the catchment · Climate, weathering and erosion · Degree of disturbance in the catchment · Hydrodynamics and morphology of the estuary · Location within the tidal range	· Important indicator for the community due to impacts on navigation, ecology · Difficult to quantify inputs due to variability - the majority of sediment are deposited during flood flows	· Marker horizons · Sediment traps	-

TABLE 4: HYDROLOGIC INDICATORS

HYDROLOGIC INDICATORS	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
FLOW CHARACTERISTICS	· Change in flow frequency and magnitude · Change in recession rates for floods · Changes to the area of wetted perimeter for rivers, floodplains and wetland during both high and low flows	· Long-term climate and weather · Floodplain vegetation - flood mitigation, area of wetlands · River regulation, irrigation releases, extraction of water, catchment changes	· Long-term data records and robust statistical techniques for hydrologic simulations · Requires volumes diverted and volumes of input (eg inter-catchment transfers)	· Double mass curve technique · Flow duration curves · Flood recession curve analysis · Simulated daily models of flows · Rainfall/ runoff studies such as Monash modelling · 1 in 100 year floodplain	-
WATER TABLE AND WATER LOGGING	· Indicates rising watertables and the potential for salinity and waterlogging in agricultural land · Trends in the areas of salinity and waterlogging may indicate changes in the quality of agricultural land · Rising watertables may indicate increased river salinity	· Intensive irrigation resulting in groundwater rising to the soil surface · <u>Salinity</u>: saline groundwater accessions to streams particularly during low flows · Salinisation in the root zone of crops and floodplain vegetation · <u>Waterlogging</u>: saturation of the top soil layers, depriving oxygen to plant roots	· Most effective to monitor only in areas subject to intensive irrigation and areas of known salinity and waterlogging · Areas of salinity or waterlogging problems may be too costly and difficult to establish trends	· Series of bores in major aquifers sampled at frequent intervals (eg monthly) with measurements taken for depth of watertable and salinity · Groundwater rising above about 1 metre below the soil surface has been designated for salinity and waterlogging problems	-
TIDAL FLUSHING (Tidal movement and river inflows)	· Dispersion and net movement to the ocean of contaminants and sediments · Determination of the residence time of contaminants	· Tidal velocity occillations provide and important mechanism for longitudinal dispersion of pollutants · Net seaward flux due to freshwater flow provides an important flushing action in estuaries · Mixing and dispersion is critically dependant upon the type of salinity intrusion found in the estuary	· There is high variability of parameters · There is incomplete mixing during each tidal cycle therefore pollutants brought in by the river are not necessarily flushed out · Difficulty in distinguishing different mixing mechanisms in regions of constant density from those in regions of variable density	· Hydrodyanmic assessments involving estuary cross sections to define material fluxes between estuarine compartments	-
ESTUARINE TIDAL LIMIT	· Indicates the inland extent of tidal influence · May indicate variations in discharge or changes in the course, depth or width of the downstream and estuarine reaches of the river	· Discharge variations (eg due to river regulation) · Major disturbances near the tidal limit such as sand and gravel extraction	· Naturally variable and flow dependant · Longterm trends may be established	· River cross sections	-

TABLE 5: HUMAN INDICATORS

HUMAN INDICATORS	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
LAND USE	· Can indicate location, type and possible extent of impacts on a river system	· Regional characteristics such as topography, water resources, climate and soils · Land use planning · Development pressures	· Data are available, however needs to be integrated into an information system that links land use to catchment and river related impacts	· Type/extent · Techniques · Production trends · Fertiliser useage · Pesticide useage · Land capability assessments · GIS integrating land use features that influence the river system (eg pollutant and land use computer mapping)	-
POPULATION	· Increasing population density indicates increased human activity density and is correlated with pollution and resource use	· Population is increaasing particularly around major urban centres and river systems, (eg Hawksberry-Nepean river system near Sydney)	· Catchment boundaries do not correspond with census districts, therefore estimating catchment and sub-catchment boundaries is difficult and time consuming	· Census data and population predictions based on growth rates	-
COMMUNITY ATTITUDES AND SURVEYS	· Community attitudes and surveys can: - provide information in relation to other indicators which is useful for management - indicate support for particular issues and changes in the way people may act in relation to the river	· Dominant agriculture or industries of a region can influence community attitudes · Community education and awareness of river management issues	· River management should include some form of appraisal to identify the way the community perceives management options and the way in which the public would like to see the river managed · Publicly contributed environmental information (eg surveys, volunteer work for biological databases) may offer a high profile and cost effectiveness for reporting · Survey question structure and target audience needs consideration and results need to be statistically sound	· Community surveys · Publicly contributed environmental information · Community consultation (draft documents for public comment, public meetings) and feedback on environmental issues and management	-
PLANNING AND ZONING	· Trends in the zoning or rezoning of impacting activities away from sensitive areas with increases in riparian protection zones and riparian buffers would indicate improved river condition	· Implementation and requirements of local and regional environment plans · New policy or legislative requirements, (eg Interim policy on Riparian Protection Zones)	· It may be difficult to quantify and compare trends in planning and zoning requirement in and between different areas · General trends may be reported on for each region	-	-

TABLE 5: HUMAN INDICATORS *CONTINUED*

HUMAN INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
RIVER REGULATION DAMS AND WEIRS	· Broad impacts by water users on the river system · Trends in the degree of river regulation · Location and associated impacts of dams and weirs	· Needs of water users for irrigation, domestic water supply and industry · Impacts include: altered flow volumes; altered seasonality of flow; increased rate of fall of river levels after flooding events; altered water quality; barriers to fauna movement (particularly fish migration); impacts on nutrient cycling; invertebrate production; macrophyte production; favouring exotic species	· Data available from regional Water Resources departments	· Reporting will generally be related to the numbers and types river regulation structures · Number, type, volumes, flow allocations, levels of water release, reregulation storages	-
NUMBER OF LICENCES AND VOLUMES DIVERTED	· Number of licences indicates their location and the capacity of the licencing system may be assessed · Volumes diverted indicates the amount of water extracted during normal regulated flows, the associated impacts and how many licences and what volumes may be sustainable for a river section	· Dependant on the licencing system, demand for water · Negative impacts associated with reduced environmental flows (as in Dams and Weirs)	· Data available from regional Water Resources departments	· Details of licenses in terms of area authorised, crops irrigated, monthly diversions	· Flow characteristics
CHANNELISATION AND DENSITY OF CHANNEL CROSSINGS	· Location and impacts of channelisation and channel crossings	· <u>Channelisation</u>: attempts to control erosion and maintain a channel for human uses · <u>Density of Channel Crossings</u>: increasing population and development and increases in the number of urban centres along a river or estuary	· Data available from various government departments · Generally trends may be reported on, possibly over a longer reporting period	· Trends in density and type	-
EXTRACTIVE INDUSTRIES	· Location and impacts of extractive industries	· Community needs for river aggregates, sand and gravel, ecomomic needs · Negative impacts of over extraction include damage to areas of significance, increased fine suspeded sediments downstream, increased riverbed and bank erosion, effects on the quallity and quantity of water taken into floodplain aquifers, loss of riparian vegetation, affects on riparian and aquatic habitats	· Information available from government agencies involved in extractive industries and impact assessments · Agencies keep data on extractive industries that are accessable for management purposes	· Number, type, volumes extracted	-

TABLE 5: HUMAN INDICATORS *CONTINUED*

HUMAN INDICATORS Continued	WHAT IS INDICATED ABOUT THE RIVER OR ESTUARY	CAUSES AND INFLUENCES	FEASIBILITY AND PRACTICALITY	UNITS AND STANDARD METHODS	ALTERNATE MEASURES
RIPARIAN FENCING	· Increasing extent of riparian fencing where it is required indicates improved riversystem and riparian zone condition · The erection of riparian fencing may indicate increasingly positive riparian landholder attitudes toward river management	· Management influences · Funding support · Landholder cooperation · TCM and Landcare/Rivercare support	· Fencing is expensive and different landholders will have different attitudes toward fencing	· Presence/absence · Trends in the length of stream with riparian fencing	· Riparian zone
RE-VEGETATION PROGRAMS AND NUMBER OF LANDCARE/ RIVERCARE GROUPS	· An increasing number of revegetation programs and Rivercare groups indicates increased community involvement which can lead to improved river quality	· Management influences · Community attitudes · Funding support · Landholder support · Trends may be related to differences in land use within each catchment	· Difficult to quantify and compare trends within and between regions	· General trends in number of revegetation programs and Rivercare groups on a regional and Statewide basis	-
RIVER RELATED HEALTH PROBLEMS	· May indicate trends in river associated health problems, epidemics or other diseases due to poor water quality for human uses	· Various causes such as excessive *E.coli*, Typhoid, Diptheria or other infections due to contact or consumption of water of poor quality for human uses	· Community health, safe river recreation areas and safe drinking water are important concerns that need to be reported on	· Incident reporting and assessment of trends	-

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