PART 2: Individual Water Quality Improvement Management Strategies

2.1 Description of Part 2

Part 2 of the WQIP is split into six key sections outlining the following:

I. Water quality issues

II. Ecological processes

III. Modelling

IV. Current state, values, targets, management strategies and costs for Wallis Lake

V. Current state, values, targets, management strategies and costs for Smiths Lake

VI. Current state, values, targets, management strategies and costs for Myall Lakes.

I, II and III are common to all three lakes and should be read to provide background to the individual lake actions (shown as IV, V and VI above).

2.2 Water quality issues

The suitability of water quality for desired uses has long been recognised as an important issue in Wallis, Smiths and Myall lakes. The hepatitis outbreak in Wallis Lake in 1997 and the toxic blue-green algal bloom in Myall Lakes in 1999 brought the issue of water quality pollution into the public arena, specifically highlighting the impacts that sediments, nutrients and faecal coliforms can have on the suitability of lake waters for particular uses.

As part of the CCI, community groups and individual stakeholders provided input on water quality issues that affect the uses of Wallis, Smiths and Myall lakes. Identifying water quality issues with the community allowed the revisiting and checking of issues identified previously through catchment management planning. The issues suggested and confirmed by the community have been collated and included in Appendix 4. Discussion of issues with the community was used as a platform for helping people come up with solutions for water quality improvement. The discussions about issues were also used as a way of checking that the issues being investigated through the CCI project were relevant and, where there were diversions, informing the development of new investigations.

Sources of water pollution that could threaten the suitability of water quality for users can be largely grouped into two categories: land-based impacts (e.g. urban development, roads, runoff, vegetation clearing, agricultural chemicals, stock access to waterways, sewage and septic discharges, erosion and sedimentation) and water-based impacts (e.g. boating, fishing, aquaculture, fish passage barriers and lake entrance management).

In the Great Lakes area there are two broad groupings of estuarine water uses that are dependent on suitable water quality: ecosystem protection and human exposure (contact and seafood consumption).

2.2.1 Land-based impacts

2.2.1.1 Ecosystem protection

Coastal lakes are unique, high biodiversity ecosystems that are sensitive to declining water quality and sedimentation, as they have limited exchange of ocean water and tidal flushing (Haine, Dela-Cruz & Scanes 2006). Coastal lakes are particularly affected by catchment runoff, which may be characterised by elevated nutrients and sediments as a result of inappropriate land use practices, sewage discharge and urban runoff.

The primary sources of these pollutants are human activities in catchments. Activities on the land – such as urban and rural development – can result in situations that provide an increased source of pollutants that are able to be washed off into drains, creeks and rivers and then delivered to coastal lakes during rainfall events.

In urban areas, pervious surfaces (e.g. forests and grassland) are replaced by impervious surfaces (e.g. roads and buildings). Pervious surfaces that would normally filter nutrients from the rainfall no longer function as filters, but collect and transport pollutants into lakes. In general, urban activities generate large amounts of nutrients in the long term with relatively little sediment, except during construction phases. Sediment delivered during construction phase can, however, have critical long-term impacts on ecological health.

Water quality can also be degraded through incorrect use of foreshore / open areas and riparian vegetation in urban areas. Destruction of riparian vegetation compromises the water filtering capacity and sediment stabilisation of these areas, thus impacting on water quality. A number of activities have been identified as increasing the pressure on significant foreshore vegetation within these natural urban areas, including: inappropriate use of riparian areas, trampling, clearing of vegetation and weed infestation, clearing vegetation for views, boat moorings, residential encroachment landscaping, fertiliser use, disposal of green waste, rubbish, and stormwater pollution.

Rural activities also have the potential to generate excess amounts of nutrients and sediments. Some rural activities can expose soils to erosion, resulting in large amounts of sediment and attached nutrients being transported into waterways. Other activities (e.g. intensive farming, cattle access to streams, inappropriate fertiliser use), if inappropriately managed, have the potential to generate an increased source of pollutants that can be washed off into drains, creeks and rivers. Sediments can also be eroded from stream banks and delivered to coastal lakes during runoff events.

Seagrasses and other bottom-growing plants and animals are extremely important components of estuarine ecosystems, providing food and shelter to a wide range of fish and other organisms including – for seagrasses – threatened seahorses and pipe fishes. There is a well-established relationship between water clarity and the depth that seagrass can grow to (and hence, the area of seagrass that can grow in the estuary). This relationship exists because as more sediments are washed into the lake (as a consequence of catchment activities that increase soil and gully erosion), the water becomes more murky (turbid) and transmits less light to the seagrasses that grow on the floor of the lake. If the seagrasses do not receive enough light to grow, they die. This can also happen if light is reduced by other factors such as: excessive algal growth in the water, which creates turbidity; or macroalgal (seaweed) growth on the seagrass leaves, which directly blocks light. Similarly, if seagrasses are physically covered by sediments washed into the water as a result of eroded soils, they are smothered and die.

Excess nutrients entering the lake from catchments can have a number of consequences for the ecology of the lake. The amount of algae that can grow is a direct consequence of the amount of nutrient brought into the lake from its catchment and other sources. The growth of algae occurs in two phases: an initial very high level (bloom) when nutrients are washed in following rain, and a reduced ongoing bloom from recycled nutrients. The major bloom rapidly consumes all the available nutrients in the water, and then slowly dies and reduces in intensity. As it dies, the algal cells with their absorbed nutrients fall to the lake floor and are recycled by microbes in the lake sediments. Over time, this store of nutrients in the sediments increases, and the nutrients recycled to the water column from sediments sustain a relatively high level (but smaller amount than the bloom) of algae between rainfall events.

2.2.1.2 Human exposure

The two main human exposure values that are affected by poor water quality are fisheries harvest (aquaculture, commercial wild harvest and recreational harvest) and contact recreation.

Poor water quality can affect fisheries production in many ways. Many commercially and recreationally important fish and shellfish species use seagrass beds in the estuaries of NSW as nursery and feeding grounds. This means that declines in the health and extent of seagrass as a result of increased sediment and nutrient loads will have a significant negative impact on commercial and recreational wild harvest fisheries. High volumes of oxygen-consuming organic matter in the water can also result in low dissolved oxygen levels and fish kills. Eutrophication, or algal blooms, can also be detrimental to many of the commercially and recreationally significant species.

Aquaculture can be severely affected if large amounts of pathogens (harmful bacteria and virus) are present in the water, as they can accumulate in filter feeding organisms such as oysters. The primary source of pathogens is from faecal matter – either human waste via treated effluent from licensed sewage discharge, poor onsite septic management and unplanned overflows, or from animal faeces. Animal faeces can be washed from the catchment into the rivers or lakes, or can be deposited directly, particularly by birds.

The main water quality impacts for contact recreation come from pathogens, with secondary concerns about abundance of algae – particularly harmful species (as in Myall Lakes in 1999) and by reductions in water clarity. The fundamental causes of algal blooms and poor clarity have been explained above (Section 2.2.1.1).

2.2.2 Water-based impacts

Although the original focus of the CCI was on addressing land-based impacts on sediments and nutrient loads and their impact on lake ecology, it has been recognised that there is a substantial level of public concern relating to water-based issues. Again, the uses of ecosystem protection and human exposure (contact and seafood consumption) can be threatened by water-based impacts.

2.2.2.1 Ecosystem protection

Many recreational uses of the lakes – such as fishing, waterskiing, water-based tourism and sightseeing – involve boating. Commercial fishers and oyster growers also use boats to undertake their business. Boating activities within the lakes have the potential to:

- damage aquatic habitats through propeller and anchoring impacts
- contribute to shoreline erosion from wave wash and direct impact of vehicles accessing the shore
- pollute through fuel spillage and disposal of waste.

Aquaculture activities, as water use activities, can have impacts on water quality, and are dependent on water quality for oyster harvest and handling requirements. The oyster industry can add to pollution of the waterways from poorly managed shore-based activities and the use of, or failure to remove, materials (such as the traditional tarred poles and trays). In addition to the potential impacts of boating activities, the fishing industry has the potential to damage ecologically sensitive aquatic habitats through commercial fishing practices, e.g. removal or damage of seagrass blades and reducing growing conditions by increasing turbidity or destabilising sediments (DPI NSW 2001[DG13]). It is noted in the *Estuary general fishery: environmental impact statement* that there is no data to determine the extent and magnitude of these kinds of impacts (DPI NSW 2001).

2.2.2.2 Human exposure

The main concern for human exposure values is the direct introduction of pathogens and faecal contamination into water by discharge of faeces and grey water from boats. This is particularly relevant when a large number of boats used for overnight accommodation are used in enclosed waters (e.g. Myall Lakes).

2.3 Catchment and estuary processes

The amount of nutrients and suspended solids in the water column of the Great Lakes water bodies reflects a number of processes that occur in the catchment, rivers and the estuaries:

- pollutant generation and transport into streams and rivers
- in-stream physical and biological processes that add or remove pollutants from streams
- hydrodynamic processes within the estuaries and lakes
- nutrient cycling and sediment settling mechanisms in the estuaries.

This section summarises general processes in catchments and estuaries that affect pollutant generation, delivery to, and movement in, estuaries. It is not a detailed analysis of processes but is intended to provide context to the later description of the current state of catchment and estuary health (Section 2.5 – Wallis Lake, Section 2.9 – Smiths Lake, Section 2.13 – Myall Lakes), and the development of ecological condition targets for each of the Great Lakes systems (Section 2.6 – Wallis Lake, Section 2.10 – Smiths Lake, Section 2.14 – Myall Lakes).

2.3.1 Catchment exports

Nutrient and pollutants that are exported from catchments into waterways can be from point or diffuse (non-point) sources. Point sources of pollution are spatially confined and typically human-induced discharges from a pipe or channel. As such, point sources are generally easily identified and regulated. Diffuse source pollution stems from multiple source areas, which are generally difficult to identify, quantify and control. Examples include pesticide spray drift into streams, leaching of nutrients through the soil surface into subsurface flow and erosion within the landscape.

Coastal development and urbanisation changes land surfaces, thus modifying hydrological and sedimentation regimes (Lee *et al*. 2006). Increased amounts of impervious surfaces such as roofs, roads, driveways and footpaths decrease permeability within a catchment, which in turn increases the amount of runoff generated during a storm event. Urban stormwater runoff collects pollutants that have accumulated within the catchment, and transports them downstream to the receiving waters. Urbanisation commonly results in up to a four-fold increase in stormwater pollutant loads entering local waterways.

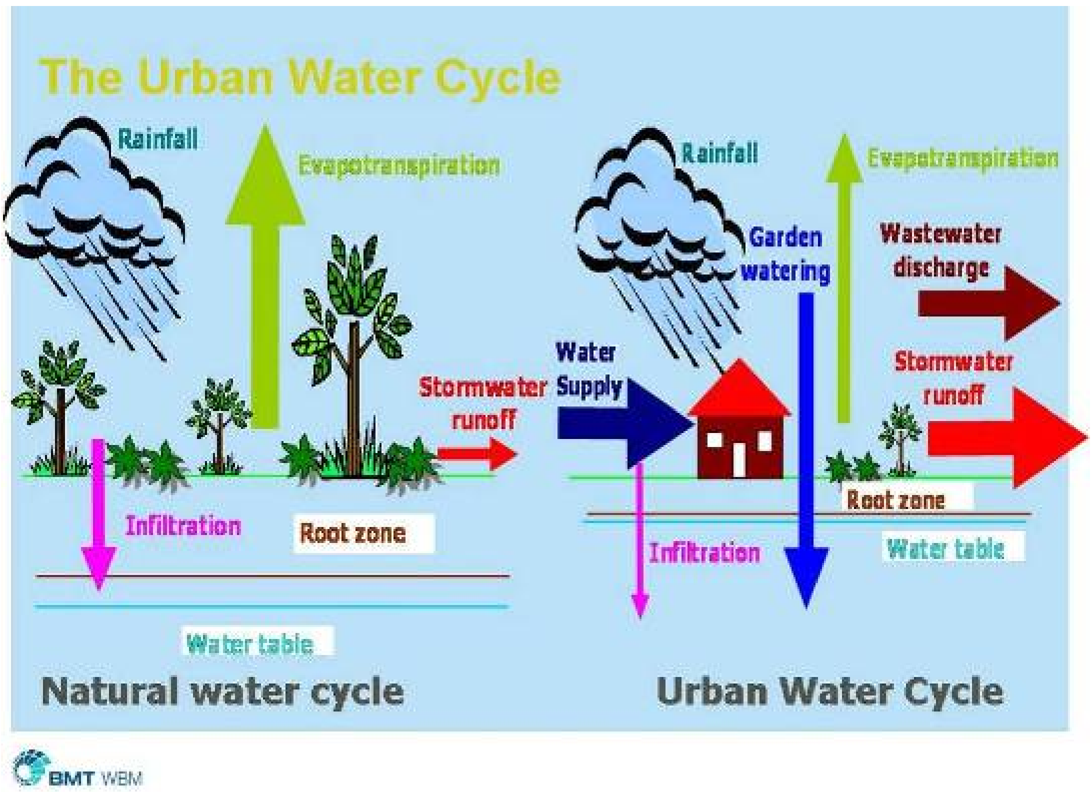


Figure 2.3.1. Conceptual diagram showing the difference between the natural water cycle and a modified urban water cycle. The widths of the arrows represent water volumes (Source: BMT WBM[DG14] **2008).**

Figure 2.3.1 shows the changes that occur in the water cycle when a catchment is urbanised. In a naturally vegetated catchment with very little or no impervious surfaces, minimal runoff occurs. The root zone of the vegetation is lower and the major loss of water is through evapotranspiration. However, in an urbanised catchment, there is less infiltration, a shallower root zone, and large amounts of runoff and wastewater are generated. Thus urban development typically has major impacts on volume, frequency and quality of runoff, resulting in associated ecosystem impacts[DG15].

There is a direct link between levels of pollution and the quantity of impervious surfaces within a catchment (France 2002; Novotny 1995). Impervious surfaces collect and accumulate pollution, thereby becoming a source during a rain event. As rainwater already contains nitrogen, elevated levels of nitrogen can occur when this rainwater is accumulated and mobilised by impervious surfaces.

In urban areas, stormwater treatment devices such as constructed wetlands, gross pollutant traps, bioretention pods, grass swales and other water-sensitive urban design features can reduce pollutant loads entering natural waterways.

A simple representation of the way in which diffuse sources of pollutants enter streams or rivers is shown in Figure 2.3.2. Rain falling on land can soak into the soil and flow towards the stream ('subsurface flow') carrying dissolved pollutants. Alternatively, it can flow along the soil surface ('overland flow'). Overland flow can cause erosion of the soil surface, and transport nutrients and sediment into the stream.

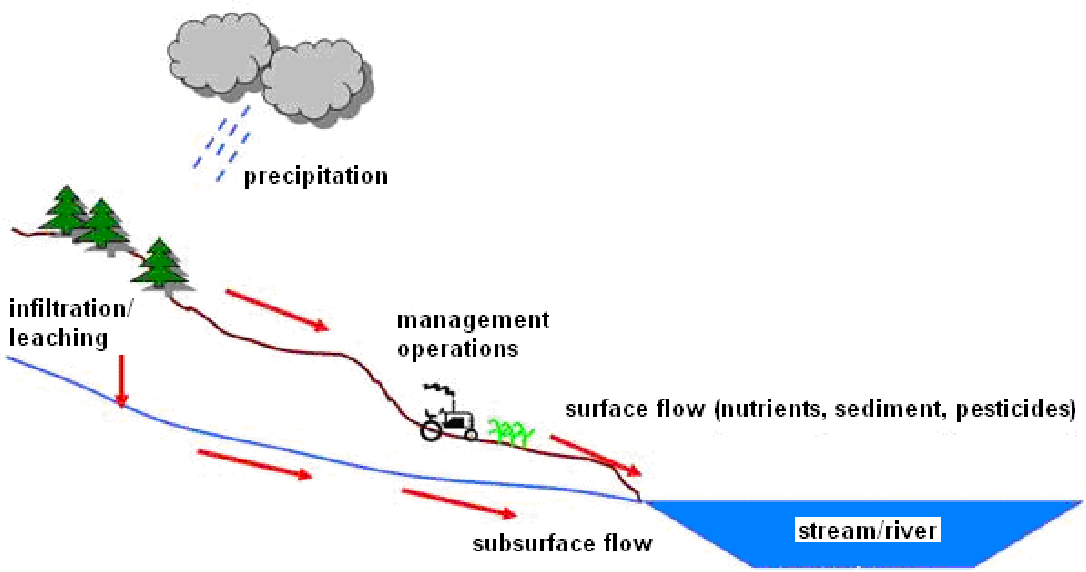


Figure 2.3.2. A conceptual diagram of generation of diffuse sources of pollutants and transport into streams / rivers via surface and subsurface flows (Source: Jocelyn Dela-Cruz, DECC).

Nutrients or pollutants that are leached past the root zone of vegetation can be transported through subsurface flow into streams and rivers, or infiltrate deeper into groundwater systems. The extent of leaching depends on soil type, climatic conditions and the susceptibility of the pollutant to leaching. Inorganic forms of phosphorus tend to adhere strongly to the surface of soil particles and are not often leached, except in very sandy soils. Conversely, mineral nitrogen does not interact strongly with soil surfaces and is much more prone to leaching. Leaching can be controlled to an extent by timing fertiliser applications with periods of nutrient uptake by vegetation.

Alternatively, nutrients and pollutants can enter stream networks through erosion and sediment transport processes. These processes involve:

- *detachment:* the process whereby the cohesive forces between soil or sediment particles are broken by rainfall impact or flows over the surface of the particles
- *transport:* removal of particles from the point of detachment and entrainment into a fluid flow (air or water)
- *deposition:* settling of particles from the flow.

More than one process is usually in action at any one time within a single event. The susceptibility of land to erosion is controlled by soil characteristics, topography (e.g. slope), climate (e.g. rainfall intensity), and how we manage the land and its vegetation.

Fine-textured soils tend to have a strong bond between particles (‘cohesive strength’) and are resistant to detachment by overland flow. Coarse-textured soils have less cohesive strength, although their mass and likely higher infiltration increases these soils’ resistance to detachment. Soils that are well aggregated – that is, where the soil particles form clumps – have a higher resistance to detachment than soils with ‘poor structure’. Least resistant to erosion are soils with moderate silt or fine sand contents. Soils that are prone to erosion are often termed ‘erodible’.

Topography influences erosion and deposition of sediment by its control on the movement of water through the landscape. It defines the direction in which water flows within the landscape and how quickly it flows into stream networks. Steeply sloping lands are often prone to erosion, as rain falling on the soil surface can flow downslope more rapidly and with greater erosive power. Not all sediment and attached pollutants that are eroded from the soil surface will be transported into streams. As flow velocities decrease due to, for example, decreases in slope, the heavier sediments will start to drop out of the flow and be deposited within the landscape.

Maintaining vegetation can reduce the susceptibility of land to erosion by preserving soil structure and cohesiveness (e.g. through presence of roots and organic matter), and reducing the velocity of rainfall drops or overland flow (and hence detachment).

Where we place infrastructure in catchments can alter the movement of water through the landscape and impact erosion and sediment transport. For example, poorly constructed unpaved roads can create preferential flow paths that concentrate water and speed up its flow downslope, which can lead to higher sediment exports. Conversely, infrastructure, such as farm dams, can trap sediment from water flowing into dams.

2.3.2 In-stream processes

In a stream, sediments and nutrients can be lost and gained from the water column. In-stream erosion can add more pollutants to the water flowing towards the lake. Settling processes can remove from the water column, pollutants that are attached to the soil particles, as can in-stream attenuation processes (e.g. denitrification or biological nutrient uptake). Nutrients retained within the stream network may in time be remobilised and exported to estuaries.

Human influences on in-stream transport of nutrients and sediment occur in a number of ways. Altering geomorphic processes (e.g. channel straightening, weirs) can change how quickly water moves through the network, and this has impacts on stream bank and bed erosion, pollutant transport, and in-stream deposition. Management of riparian zones – the land adjoining, directly influencing or influenced by a stream – will affect how susceptible stream banks are to erosion.

2.3.3 Hydrodynamic processes

Once in the estuary, tides, catchment inflows and winds all affect how water and pollutants move through the system. The way in which water and pollutants move depends to some extent on the type of water body it moves into. The Great Lakes systems can be classified as:

- *coastal lakes:* Smiths Lake, Coomba Bay and Southern Wallis Lake
- *river estuaries:* Pipers Creek and the tidal reaches of the Wallamba, Wang Wauk, Coolongolook and the Upper Myall rivers
- *(largely) freshwater lakes:* Myall Lake, Boolambayte Lake, Two-Mile Lake and Bombah Broadwater.

See Figures 2.5.1 (Wallis Lake), 2.8.1 (Smiths Lake) and 2.12.1 (Myall Lakes) for locations of these areas. Many of the processes that control the amount of nutrients and sediment in the water column are relevant to all three.

2.3.3.1 Coastal lakes

Coastal lakes can be simply thought of as having two zones: the shallow margins and the deeper central basin (Figure 2.3.3). The margin ecosystems are structured by the substratum available (rocky or sand / mud), and the presence of large attached plants such as large algae and seagrasses, and other rooted plants. The extent of the attached plant communities is governed by physical factors, such as sediment stability, resulting from wave and current erosion, and by the availability of light for photosynthesis. Rooted plants also bind sediments and protect them from erosion.

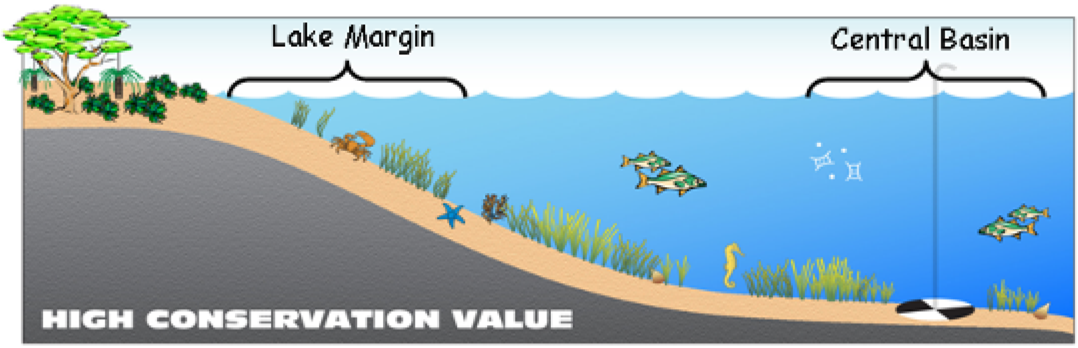


Figure 2.3.3. Zones in a coastal lake: Lake margin and central basin (Source: DECC[DG16]).

Human impacts on lake ecosystems result from physical destruction (dredging, reclamation, hardening shorelines), changes to light climate, addition of nutrients and the addition of toxins. In the Great Lakes, there are no identified issues with toxins, but all the other causes of impacts are present.

2.3.3.2 River estuaries

Coastal river estuary ecosystems contain many of the same ecological elements as coastal lakes, but they are much more strongly affected by physical processes such as tides, currents and river inflows. There are naturally occurring patterns in some water chemistry variables resulting from these physical processes. As fresh river water enters the estuary it tends to ride above the more saline estuary water (due to differences in density), forming a surface layer (Figure 2.3.4). As the waters gradually mix, the chemistry of the salt waters cause many of the particles in the river water to gather together (flocculate) and eventually settle out. This leads to a natural turbidity maximum in the upper estuary. Freshwater algae from the river decline in abundance near the saline waters, and presumably form a strong source of nutrients and carbon in the upper and middle estuary. Sea water from the incoming tides is denser than the estuary water and tends to move into the estuary along the floor, causing another layering effect. This water tends to be very clear.

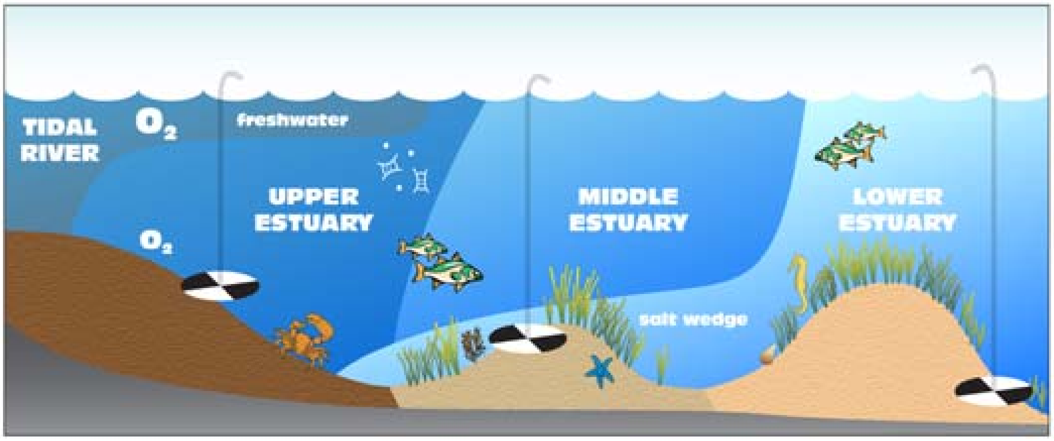


Figure 2.3.4. Distinct zones in a river estuary, defined by the interaction between fresh water and salt water in the water profile: Tidal River, Upper Estuary, Middle Estuary and Lower Estuary (Source: DECC).

Estuaries are naturally variable, so they are best described in sections. In addition to the tidal freshwater river, we recognise three distinct zones within barrier riverine estuaries, with naturally different water quality and ecological characteristics (Figure 2.3.5). The zones are distinguished primarily by the structure of the channel and estuary floor. Lower parts of estuaries are generally shallow, with many sand bars, shallows and islands. Middle parts of estuaries gradually become deeper and more channelised with fewer shoals. They tend to be the deepest parts of the estuary. The upper estuary is characterised by a single channel of moderate depth with relatively steep banks.

In the Great Lakes system, various parts of the waterways have been classified by the Department of Environment and Climate Change (DECC) as follows, based on average salinity:

- Lower Estuary – Wallis Lake entrance, Wallis Lake East/West Channels, Lower Wallamba River, and Lower Coolongolook/Wang Wauk rivers
- Middle Estuary – Pipers Creek, Mid Wallamba River and Mid Coolongolook/Wang Wauk rivers, and Myall River upstream of Bombah Broadwater
- Upper Estuary – Upper Wallamba River.

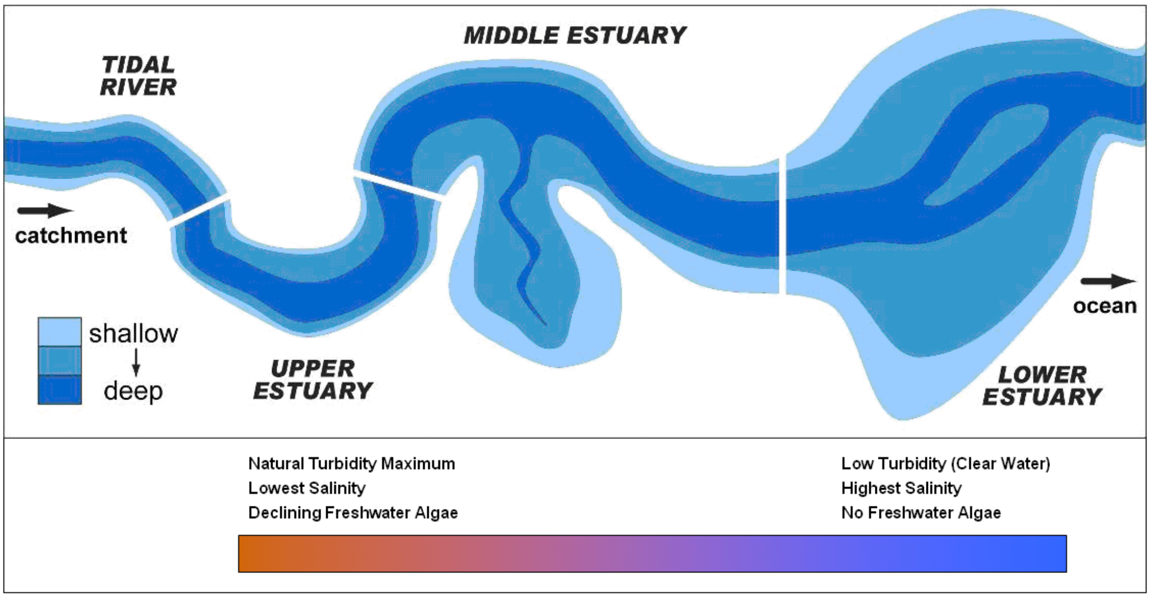


Figure 2.3.5. Distinct zones in a river estuary of tidal river, upper estuary, middle estuary and lower estuary – as defined through estuary depth, width, turbidity, salinity and algae (Source: Adapted from Scanes 2007).

As with coastal lakes, ecosystems in the estuary are structured initially by the long-term salinity regime, and then by the substratum available (rocky or sand / mud) and biological interactions including the presence of large attached plants such as large algae and seagrasses, and other rooted plants. The values of large attached plants and riparian vegetation are the same as those described in the coastal lake section.

The nature of human impacts on coastal river estuarine systems is very similar to those on coastal lakes. These impacts result from physical destruction (dredging, reclamation, hardening shorelines, bank erosion), changes to light climate, additions of nutrients and additions of toxins. In the Great Lakes, there are no identified issues with toxins, but all the other causes of impacts are present in coastal river estuarine systems.

2.3.3.3 Freshwater systems

Myall Lake, Boolambayte Lake and Two Mile Lake are different from Smiths Lake and the main body of Wallis Lake because they are essentially freshwater systems. Bombah Broadwater has characteristics that are similar to other coastal lake (e.g. more saline) because it is influenced by the ocean through the lower Myall River. Although, Bombah Broadwater still appears to have more in common with the other Myall lakes systems than Smiths and Wallis lakes.

The ecology of the Myall Lakes system is complex and poorly understood. However, conceptual understanding of ecosystems of this type suggests that they are threatened by increased turbidity (decreased light penetration) and excessive nutrients (algal blooms, low phosphorus tolerance by charophytes).

2.3.4 Nutrient cycling and settling processes

Nutrient cycling processes in the lakes and river estuaries affect the form and amount of nutrients in the water column. A simple diagram showing the complex network of biogeochemical processes at play in the water body is shown in Figure 2.3.6. These processes involve biological (plant and bacterial) activity, and are affected by light and nutrient availability, temperature and sedimentation.

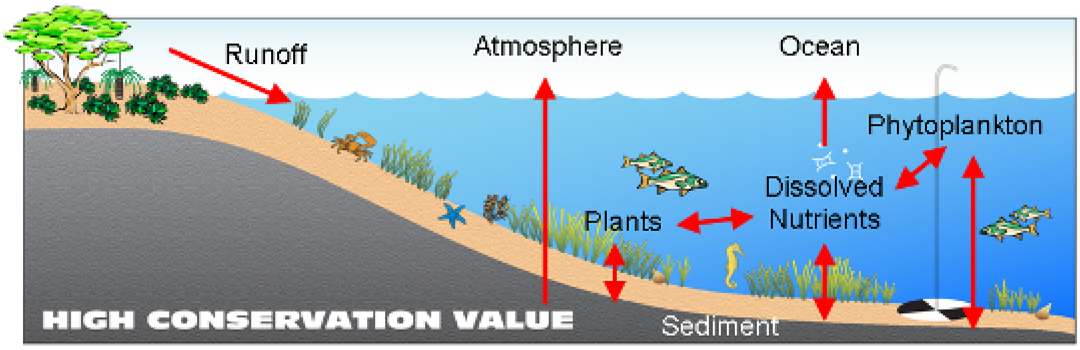


Figure 2.3.6. A conceptual diagram of nutrient cycling processes in coastal lakes and coastal river estuaries (Source: DECC).

Nutrients in the water column are sourced primarily from catchment runoff, but also from rainfall inputs and the decay of plant biomass in the water and sediments. Losses of nutrients from the water column occur through outflows to the ocean, burial in sediments and, for nitrogen, the production of N_2 in sediments ('denitrification'), which is then lost to the atmosphere.

Aquatic plants take up nutrients from the water column. These plants can be attached to the sediment (benthic) or free-floating, and microscopically small (e.g. phytoplankton). Two major nutrients that are necessary for the growth of plants are nitrogen and phosphorus. In aquatic ecosystems, either one or both can limit the ability of plants to grow if they are in short supply. Most estuaries in NSW are thought to be nitrogen limited, although there is evidence that some (e.g. Myall Lakes) are phosphorus limited.

In water, nitrogen and phosphorus are found in many different forms but can be thought of as existing in three main categories: dissolved inorganic, dissolved organic and particulate (Table 2.3.1). The sum of all these categories becomes the 'total' nutrient pool (TN, TP). The form that a nutrient is in plays a large part in whether it is readily available to stimulate nuisance plant growth ('active'). Dissolved inorganic forms (DIN, DIP) are known to be very active and can readily stimulate algal growth if prevailing conditions such as available light, temperature and salinity are favourable.

Table 2.3.1. Forms of nitrogen and phosphorus that can be found in coastal lakes and river estuary waters, and their likely short-term bioavailability to stimulate algal growth.

Category	Description	Bioavailability
Dissolved inorganic	Chemically bound to carbon, and include urea and amino acids	Immediate
Dissolved organic	Commonly derived from some animal or plant product, which may be living, dead, fragmented, excreted (urine, faeces) or exuded (mucus, enzymes, etc.)	Depends on the compound, e.g. brown tannin stains from tea-tree swamps are completely inactive dissolved organics Reactivity not known for many compounds
Particulate	Constitutes a solid fragment, which can be some animal or plant product such as fish flesh, leaf fragments and algal cells; or non-living particles such as soil	Not immediately

The growth of bottom-dwelling plants like seagrass, charophytes and *Najas marina* is controlled largely by the amount of light that penetrates through the water column. Light penetration is affected by:

- *water clarity:* nutrients, sediment and algae in the water column can block light from reaching bottom-dwelling plants
- *bathymetry:* how water depth varies within the lake defines the area of the lake bottom that is within a depth range that suits the bottom-dwelling plants
- *the stability of the lake bottom:* bottom-dwelling plants are not able to grow in dynamic channels or on shallow sand flats that are subject to wave action.

As catchments are developed, more sediments are washed into the estuary by rivers and creeks. The suspended sediments have an immediate but short-term (days) impact as the runoff water mixes with the estuarine water. The suspended particles eventually settle to the bottom but they are prone to long-term (months to years) resuspension by wind-induced currents and waves. These suspended sediments make the water murky (turbid) and reduce the depth that light can penetrate through the water. If the seagrasses and other plants that live on the estuary bottom can no longer get sufficient light, they die. If the seagrasses die, then all the invertebrates and fish associated with the seagrasses have nowhere to live, and their abundance is also reduced.

Lower levels of nutrient runoff favour slow-growing macrobenthic plants such as seagrass. Excess nutrients in catchment runoff can stimulate the excessive growth of planktonic algae, and in shallow water the excessive growth of nuisance macroalgae in and around seagrass beds. The macroalgal growth also shades seagrass, adding an additional growth stress for the seagrass. The stimulated growth of nuisance algae and the accelerated loss of seagrass results in large build-ups of decaying plant matter in the water.

In areas where the natural shoreline shape has been altered (usually made more vertical) this decaying matter accumulates in large amounts. A small amount of decaying seagrass is natural and forms an essential nutrient recycling pathway. Excessive decaying plant matter, however, strips oxygen from the water and sediments, and may exclude most animal life. The stratification of the upper estuary can, at times, prevent exchange of oxygen between deeper waters and the surface. If this is combined with large amounts of organic matter from the catchment and algal blooms, then it can result in complete deoxygenation of waters, with associated fish kills. This is common in NSW northern rivers following large floods.

2.3.5 Modelling catchment and estuary processes in the Great Lakes CCI

To further understand how actions in catchments affect ecological conditions in the Great Lakes, models of the catchment and estuary processes were built. Outputs from these models were used to build a decision support system (DSS), which was used to support the development of this Plan.

The CCI component projects, and their input to development of models and the DSS, are shown in Figure 2.3.7. The catchment models (AnnAGNPS and MUSIC) were used to construct the DSS data base and – together with outputs from the management planning and research projects, and stakeholder and community input – guide the functionality of the DSS model base. The estuary modelling component developed by DECC and based on estuary mixing (hydrodynamic) and ecological response models has been replicated in the DSS.

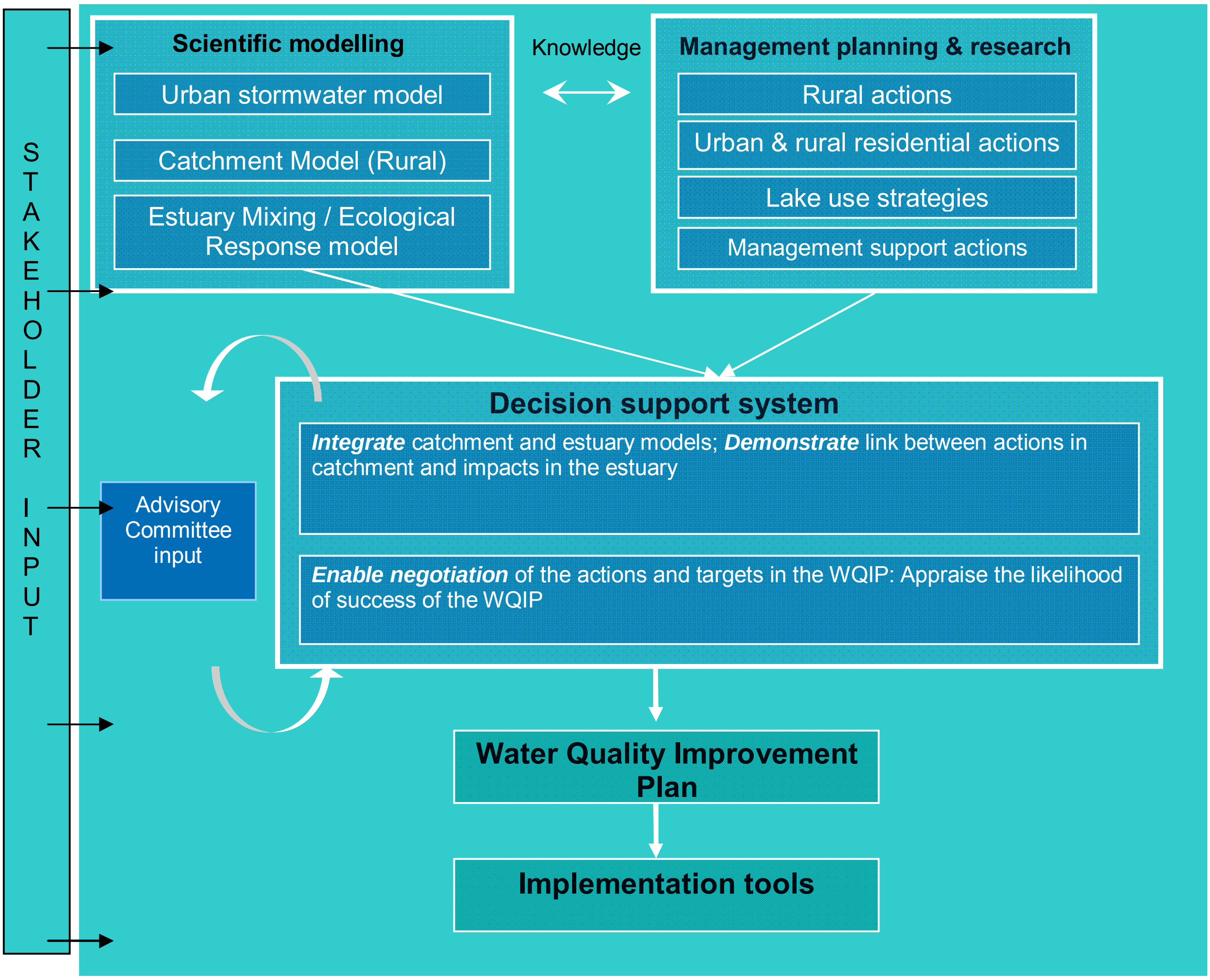


Figure 2.3.7. Scientific modelling of catchment and estuary processes were used to construct the data base for the Great Lakes CCI Decision Support System (DSS) and, together with outputs from management planning and research projects, guided the DSS functions.

The following text summarises models developed for the Great Lakes CCI. Further details can be found in Appendix 5.

2.3.5.1 Catchment exports

Catchment flow volumes and exports of total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS) have been calculated for each of the Great Lakes catchments using outputs from agricultural and urban water quality models. Staff at DECC[NB17] Waters and Catchment Science undertook a program of field measurements of nutrients and flow from different land use types. They then used the water quality model Annualised Agricultural Non-Point Source pollution (AnnAGNPS), which was calibrated to rural areas of the Great Lakes catchments to explore the impacts of changing rural lands management practices on TN, TP and TSS exports, and catchment water yield. Consultants at BMT WBM used the Model for Urban Stormwater

Improvement Conceptualisation (MUSIC) to relate flow, nutrient and sediment exports to actions occurring in urban sub-catchments.

Outputs of the models represent current catchment conditions, which include:

- climate represented by average annual rainfall and scenarios for wet and dry periods
- land condition, characterised by slope and soil erodibility
- land management
- land use.

These parameters were used to develop mean flow volumes (ML/ha/year) and mean 'export' rates for TN (kg/ha/year), TP (kg/ha/year), and TSS (tonnes/ha/year) for different land use classes in a sub-catchment. These export rates were calculated for erodible and non-erodible soils, and by slope class (high slope is greater than or equal to 20%, low slope is less than 20%), and were incorporated into the decision support system (DSS) developed by iCAM as part of the Great Lakes CCI project.

The rural land use model (AnnAGNPS) used 18 land use classes for the Great Lakes catchments. When no significant difference in annual rates of runoff volumes and nutrient loads (TN, TP and TSS) were recorded, land uses were combined. The combined classes that were used in the DSS, and discussed throughout this document, are shown in Table 2.3.2.

Table 2.3.2. Land use classes used in the rural land use model AnnAGNPS and as represented in combined classes in the Great Lakes CCI DSS.

Simplified DSS land use class	AnnAGNPS model classes
Protected vegetation	• National park • Strict nature reserves
Forestry	• Hardwood production • Production forestry • State forest
Native vegetation	• Remnant native cover • Riparian vegetation
Unimproved pasture	• Native / exotic pasture mosaic
Improved pasture	• Pasture legume / grass mixture • Irrigated sown grasses • Irrigated legume / grass mixture
Roads	• Roads
Rural residential	• Rural residential
Urban residential *	• Urban residential • Recreation
Manufacturing	• Manufacturing
Quarries	• Quarries
Cleared land	• Cleared land

* Export rates for urban residential land were determined from MUSIC model results for urban sub-catchments in the Great Lakes.

Descriptions of these land uses and the Australian Land Use and Management (ALUM) classification for each of these categories are outlined in Appendix 6.

2.3.5.2 Hydrodynamics and ecological response

Hydrodynamic modelling was used for two fundamental purposes:

- to calculate how material in runoff from different parts of the catchment moves within the lakes, and mixes with ocean water and direct rainfall
- to calculate catchment runoff volumes based on records of water level in Smiths and Myall lakes.

In the case of Smiths Lake, the model was also used to assess lake response to different entrance-opening scenarios.

Given the different hydrological characteristics of the three lakes and different amounts of measured data for each, separate models were developed (Table 2.3.3). For all three systems, catchments were divided into many sub-catchments according to drainage patterns and land use. The outlets of various groups of sub-catchments were aggregated according to the proximity of their discharges into the lake. These locations became the inputs for the ecological response models.

Table 2.3.3. Modelled hydrodynamic features of the Wallis, Smiths and Myall lakes.

System	Description
Wallis Lake	Two-dimensional hydrodynamic model driven by catchment inflows, oceanic tides and wind, with a spatial resolution of 100 m x 100 m. The estuarine part of major rivers entering the lake is represented as one-dimensional models linked to the lake model.
Smiths Lake	Hydrological model driven by rainfall, runoff, evaporation and entrance opening, and utilising continuous records of water height. The model has no internal structure except that dictated by bathymetry. The single box model was used, as the system was considered relatively well mixed.
Myall Lakes	Two-dimensional hydrodynamic model driven by catchment inflows, oceanic tides and wind, with a spatial resolution of 250 m x 250 m. The model is linked to a one-dimensional model of the lower Myall river.

As described earlier in the ecological processes section, eutrophication or nuisance algal growth is influenced by the amount of light penetrating the water, the amount of useful plant organisms such as seagrass and the amount of chlorophyll-a in the water. The estuary model has established relationships between these aspects.

In the estuary models this relationship relates loads from the catchment to the expansion and contraction of nuisance aquatic plants (represented by chlorophyll-a levels), and plants representative of healthy ecosystems (seagrass and charophytes).

The estuary models were able to provide a link between catchment nutrient loads (expressed as total nitrogen (TN) inputs) and chlorophyll-a, [DG18]enabling a catchment load to be identified for nitrogen. The models were unable to quantitatively link the catchment sediment outputs with measured water clarity, though there was an obvious qualitative link – water clarity decreased when catchment sediment loads increased. The modelling did, however, clearly link water clarity (Secchi depth) and the depth to which seagrass survives, thus enabling a prediction of effects on seagrass extent from the water clarity data. The link between catchment nutrient load and estuary chlorophyll is thus the primary focus for many of the Plan Ecological Condition Targets, with the assumption that actions which control nutrient exports from catchments will usually also control sediments, and thus contribute positively to protecting water clarity and seagrass extent targets.

2.3.5.3 Model limitations, process representation and scale issues

The spatial scales at which the catchment models, estuary models and the DSS operate have implications for how processes occurring in the catchment and estuary are represented. This in turn impacts on the ability of the CCI modelling to show impacts of catchment management actions. Examples of the model limitations include:

- the benefits of healthy riparian zones on water quality and ecology in streams and rivers cannot be shown with the CCI models – it is only possible to model the impact of these management actions on chlorophyll-a and seagrass or charophytes in the estuary [1]
- the DSS only considers average annual conditions and so cannot be used to consider temporal aspects such as seasonal variability or events
- not all catchment and estuary processes could be modelled in detail due primarily to data and resource limitations. For example, to represent detailed biogeochemical processes in the estuaries requires extensive temporal and spatial datasets, which were not available.

Areas of further research addressing these limitations have been identified for the Great Lakes catchments and estuaries as part of the Plan's Adaptive Management Strategy (see Section 3.9 and Appendix 7).

More detail on model limitations and the reasons behind them can be found in Appendix 5.

1 Monitoring by DECC Waters and Catchment Science, undertaken as part of the CCI project, demonstrated the benefits of riparian vegetation on streams and rivers, showing distinct differences (Haine, Dela-Cruz & Scanes in prep). Where healthy riparian vegetation exists there is greater abundance and diversity of macroinvertebrates and fish species in the streams compared with streams with no (or limited) riparian vegetation.

2.3.5.4 Estimates of model reliability and reasonable assurance statements

This section documents the level of certainty around the modelling and analysis described in the Plan, and the implications this has on the accuracy of predicted effects. Specific information on the reliability of the CCI models, and the DSS and data collection and calibration procedures, are provided in Appendix 5.

Ecological Condition Targets presented in this Plan are based on assumptions derived from discussions with community members and Council, as well as modelling and analysis. Underlying this information are beliefs about the degree and timing of uptake of different management actions, the resources required for each program of actions, and the effectiveness of actions. Given the difficulty of predicting future trends in urban and rural communities, there is inherent uncertainty in many of these assumptions. This uncertainty means that while we are relatively confident that the changes we predict over the short term (seven years) would be realised if the Plan is fully implemented (in terms of the magnitude and direction of change estimated), estimates of changes over a longer time frame carry a much higher degree of uncertainty. It is also acknowledged that it is unlikely that the Plan will be implemented in exactly the way that is envisioned here (i.e. the timing and extent of implemented actions may differ from that proposed in the Plan). These factors will all affect the accuracy of predicted effects in this Plan.

As with all modelling projects, there is considerable uncertainty and error associated with the outputs from each model and the DSS used to construct this Plan. Uncertainty and errors arise from many sources, including model structure, input data and scenario development. Models represent our understanding of real processes and, to some degree, all models simplify the ‘real world’. Uncertainties can arise due to imperfect knowledge about the processes at play (and their relative importance). Input data for the models can be difficult to measure and collate, particularly across large catchments and water bodies. The Great Lakes catchments, like most Australian catchments, have incomplete climate and water quality records, and limited catchment datasets (e.g. soils, land management practices). This is a potentially large source of uncertainty in the model results. Related to both model structure and data availability is the issue of limited knowledge of the catchment-scale impacts of different land management practices, including their effectiveness, and any temporal lags in impacts and of in-stream processes.

Modelling and analysis used to develop this Plan have been undertaken with due care, and in all cases represent the cutting edge of research and knowledge in the fields of catchment, urban stormwater and estuary modelling. Integrated models of this nature have been demonstrated to be accurate in terms of the direction and magnitude of impacts but are not assured as predictive models in the sense of accurately predicting precise future loads or concentrations. In order to limit the effect of any such inaccuracies and produce the most accurate predictions of potential changes in loads and concentrations under the Plan, the magnitude and direction of change from the modelling has been used in conjunction with measured data (rather than modelled data) wherever possible to predict concentrations.

The following statements of assurance can be made about the modelling and analysis underlying the Plan, and consequent statements made in the Plan about achievement of target levels or the impacts of various actions.

Statement 1: Modelling and analysis

The modelling and analysis have been undertaken to represent the best available scientific knowledge of processes operating in the catchment and lakes. This science represents a level of sophistication in knowledge that is unavailable in most lake and catchment systems, and which we believe will not be surpassed in the Great Lakes catchments over the next 5–10 years unless very significant investments in research are made.

Statement 2: Magnitude and direction of change

We believe that the targets presented are accurate in terms of the magnitude and direction of change predicted to result from the Plan. Accuracy in this context implies that, for example, if a change of 14.3% in a variable is predicted to result from a given set of actions, then the final change achieved could be expected to be between 10 and 20%, and would most probably be between 13 and 15%. In this way, small changes in the Plan (e.g. <5%) can be considered to be significantly different from larger changes (>10%).

Statement 3: Relative contribution of specific actions to achieving targets

We believe that statements about the relative contribution of specific actions to achieving targets are accurate in a qualitative sense. That is, the ranking of actions and relative magnitudes of their contributions are believed to be accurate. In this way, where two actions have contributions that differ by more than, say, 5%, we believe that the rank provided accurately represents the relative effectiveness of the action. Where actions differ in their contribution by a small magnitude or percentage then these actions can be considered to be most likely equally ranked in terms of effectiveness.

Example 1: If a scenario has an impact of 1.3% and another has an impact of 12.2%, then we can be sure that the 12.2% is really higher than the 1.3%. The second scenario is much more effective than the first scenario.

Example 2: For a given scenario impact, if we say that groundcover management is responsible for 25% of the change predicted for the scenario and the implementation of WSUD devices are responsible for 65%, then we are quite sure that the WSUD implementation is giving us more change than groundcover management.

However, if we say that groundcover management is responsible for 25% of the change predicted for the scenario and the implementation of WSUD devices are responsible for 27%, then we think that the effectiveness of these two actions are probably equivalent within the bounds of the possible errors.

Statement 4: Scenario assumptions and costings

Scenario assumptions and costings have been developed in close consultation with relevant community members and GLC staff. These assumptions and costings have been developed in good faith and accurately represent information provided to us by these groups. We are confident that these assumptions and costings represent the best available understanding of the potential uptake and cost of management actions. Given the general level of uncertainty in such assumptions and also their capacity to change over time, we recommend that these assumptions are re-evaluated regularly throughout the implementation of the Plan.

Measures to achieve required level of improvement

Given the level of uncertainty inherent to the recommendations in the WQIP, we have taken the following measures to ensure that the recommendations lead to at least the required level of improvement:

- Estimates of Ecological Condition Targets have been based on measured rather than modelled concentration data.
- A suite of protection actions has been recommended to prevent any deterioration in the condition of the lakes. Some of these actions could be expected to also improve water quality. These improvements have not been accounted for in the modelling and provide a buffer that can compensate for any overestimation of water quality improvements from Plan actions.

Estimates of impacts from the Plan actions using extremes of uncertainty in weather and generation rates were also produced. These estimates provided impacts of the same direction and magnitude, and in most cases were numerically very similar to those presented in the Plan. This provides confidence that the modelling results are robust to these sources of uncertainty.

2.4 Wallis Lake catchment description

This section provides a general overview of the lake and catchment. A more detailed description of the economic industries, land use types, land use changes and the ecological significance of the Wallis Lake catchment can be found in Appendix 8.

Wallis Lake is situated on the Lower Mid North Coast of New South Wales (152°30'E, 32°10'S). The lake has a total catchment area of 1,292.2 km^2 and a total waterway area of approximately 91.2 km^2 (Wallis Lake Estuary Management Committee, 2005). The Wallis Lake catchment can be divided into seven primary sub-catchments based on the major drainage networks: Coolongolook, Wallamba River, Lower Wallamba River, Wang Wauk, Wallingat, Wallis, Minimbah (Figure 2.4.1).

The catchment extends over three local government boundaries: Great Lakes Council (65%), Greater Taree City Council (30%) and Gloucester City Council (5%) (refer to Figure 1.3.1 for location of local government areas).

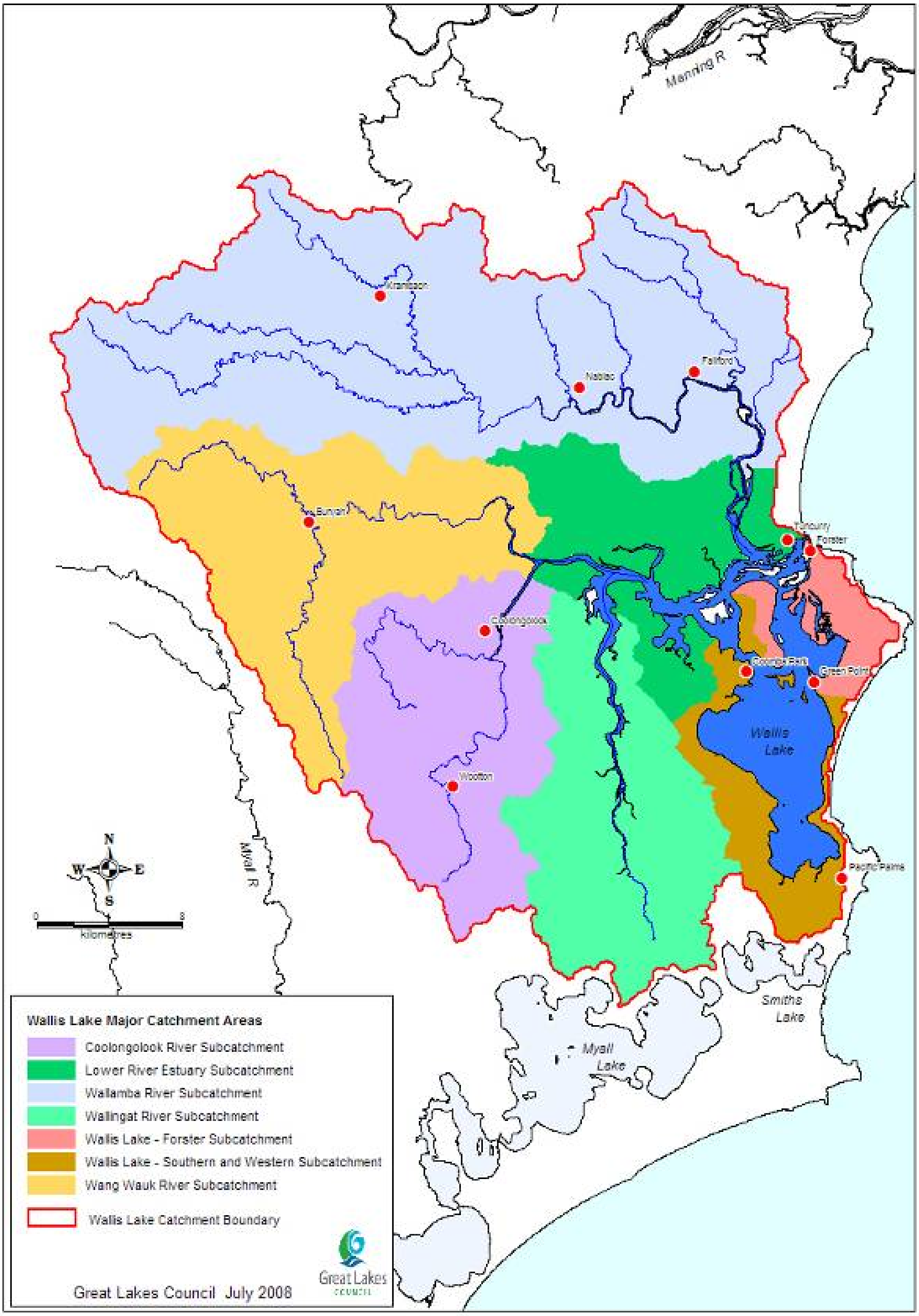


Figure 2.4.1. The seven primary sub-catchments of Wallis Lake Catchment.

The catchment has two broad topographical units: the coastal plain, and the inland ridges and valleys. Wallis Lake is situated in a shallow depression between the barrier dune system and the plain. The catchment soils are generally of low fertility: colluvial and erosional soil landscapes are the most common, and dominate the inland ridges and undulating grazing lands of the western catchment area.

The cultural heritage of Wallis Lake and its catchment includes a rich Aboriginal heritage and the significant land use changes under European settlement (see Appendix 8 for detail). The extent of vegetation and ecosystem modification attributable to Aboriginal land use within the Wallis Lake catchment is difficult to quantify. However, the arrival of European settlement defines a major alteration in catchment land use.

Early European records indicate that prior to settlement, the catchment was thickly vegetated: extensive stands of riverine rainforest lined most of the catchment's waterways, while old-growth eucalypt forest and woodland covered much of the remaining lowland slopes and ridge landscapes. The earliest European arrivals were timber cutters and the agricultural activity on the cleared lands included poultry, dairy and beef cattle production as early as the mid-1800s (Wallis Lake Catchment Plan Steering Committee 2003).

Today, dominant land use types and economic activities in the Wallis Lake catchment include agriculture, aquaculture, conservation and commercial forestry, urban and rural residential development, and the tourism and coastal retirement sectors. The most extensive land use type within the catchment is agricultural pasture (native, exotic and legume), followed by conservation and commercial forestry (Figure 2.4.2)

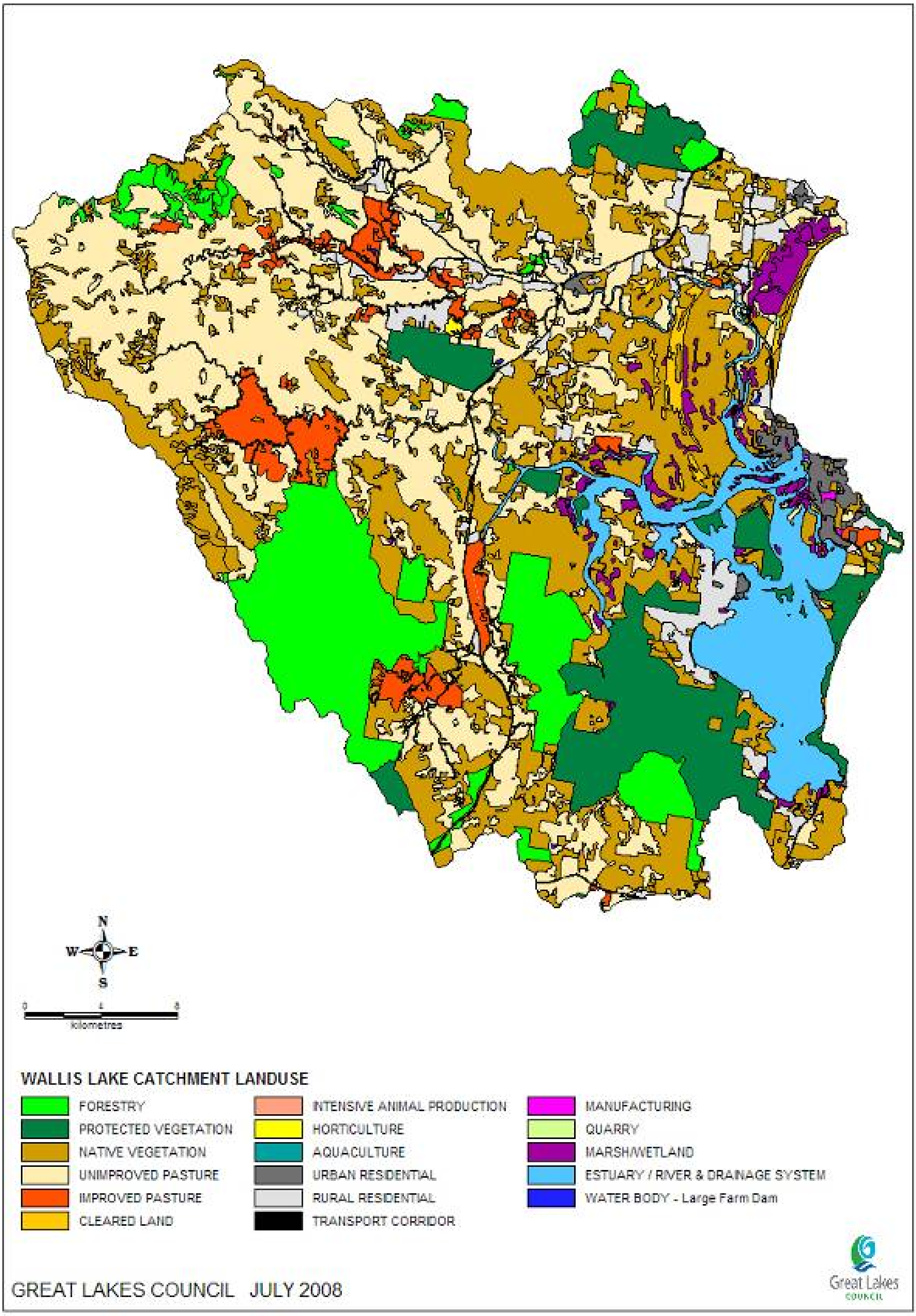


Figure 2.4.2. Modelled land use categories in the Wallis Lake Catchment. Please note the definitions for these land use categories in the text overleaf.

Privately-held native forest (managed for commercial plantation, conservation or grazing) also covers a considerable area of the catchment. Urban and rural residential development covers 70 km^2 – a significant and expanding portion of the catchment. The major urban settlements in the Wallis Lake catchment include Forster / Tuncurry (combined population of 18,800), Green Point, Coomba Park, Coolongolook and Nabiac (see Figure 2.4.1 for locations). Population numbers within the townships increase significantly during the summer holiday season.

Wallis Lake itself is widely used for recreational and commercial purposes. Recreational uses include fishing, swimming, paddling, picnicking, power boating and jet-skiing. Key lake-based economic industries include tourism, oyster production, commercial fishing and commercial cruise boats.

Discussion of the economic industries in the Wallis Lake catchment, and each land use type, are found in Appendix 8. This appendix also contains a description of land use change as well as the ecological significance of the Wallis Lake area. Additionally, Appendix 9 has more information on agricultural industries. In undertaking analysis for this Plan, detailed land uses have been grouped into several broader classifications. These classes are based on similar generation rates. Groupings used in the analysis are:

- **Forestry:** This group is comprised of: (1) Hardwood production, which is land managed for hardwood sawlogs or pulpwood; (2) Production forestry, which involves commercial production from native forests and related activities on public and private land; and (3) State forest.
- **Improved pasture:** This group is comprised of: (1) Pasture legume/grass mixture; (2) Irrigated sown grasses; and (3) Irrigated legume/grass mixture.
- **Native vegetation:** This group is comprised of: (1) Remnant native cover, which is land under native cover that is mainly unused (no prime use), or used for non-production or environmental purposes; and (2) Riparian vegetation.
- **Protected vegetation:** This group is comprised of: (1) National parks, which are protected areas managed mainly for ecosystem conservation and recreation; and (2) Strict nature reserves, which are protected areas managed mainly for science.
- **Unpaved roads:** All unpaved roads mapped for the Great Lakes catchments.
- **Unimproved pasture:** This land use type is native/exotic pasture mosaic, which is pasture with a substantial native species component despite extensive active modification or replacement of native vegetation (BRS 2006[DG19]).
- **Rural residential:** This land use is “characterised by agriculture in a peri-urban setting, where agriculture does not provide the primary source of income” (BRS 2006).

- **Urban residential:** This group is comprised of: (1) Urban residential (e.g. houses, flats, hotels); and (2) Recreation, which include parks, sports grounds, camping grounds, swimming pools, museums and places of worship (BRS 2006).

The groups and their Australian Land Use and Management (ALUM) classification (BRS 2006) are listed in Appendix 6. More details on features of these land uses can be accessed from http://adl.brs.gov.au/mapserv/landuse/alum_classification.html (viewed 24 July 2008).

Wallis Lake and its catchment provide an important ecological system for many reasons. The lake has the largest area of estuarine seagrass in NSW (33 km^2) in addition to 5.9 km^2 of salt marsh, an important and declining ecosystem (Department of Planning NSW 2006). The southern bays of Wallis Lake are in near-pristine condition with high biodiversity, including very rare brackish macrophyte and estuarine sponge communities (Section 2.5.2.6). The lake is listed as a wetland of national importance and is inhabited by over 30 JAMBA and CAMBA listed migratory and threatened bird species (Tuckerman 2001). The catchment has two national parks located within its boundary – the Wallingat National Park and the Booti Booti National Park – which support a diverse range of vegetation communities including littoral rainforest, coastal heath, coastal forests, cabbage palm forests and moist eucalypt forests.

By the late 1980s, a history of clearing of the catchment and riparian zones – and draining, infilling and mining of coastal wetlands and barrier dunes – had created problems of erosion, sedimentation and eutrophication in and around Wallis Lake. In response, landcare was introduced to the catchment in the early 1990s. Since the late 1990s, landholders have been increasingly encouraged by the Great Lakes Council and industry groups (such as Mid Coast Dairy Advancement Group) to participate in federal, state and regional programs to improve on-farm management.

Following a hepatitis A outbreak in Wallis Lake oysters (1996/97), Great Lakes Council and the NSW State Government developed the *Wallis Lake Catchment Management Plan* (2003) and Implementation Program. Further recommended actions were outlined in the *Wallis Lake Estuary Management Plan* (2005). Council, NSW State Government and groups such as landcare, coastcare and dunecare are actively implementing the recommended on-ground works in these plans as well as rivercare plans (2003 and 2005). Implementation has been supported by a rural incentive scheme set up through a partnership between Great Lakes Council and the Hunter-Central Rivers Catchment Management Authority. This has been followed more recently by support through the actions identified in the *Hunter-Central Rivers CMA Catchment Action Plan*. Plans are outlined in more detail in Appendix 29.

Catchment management outcomes have included: 81.6 km of protective fencing to control stock access to waterways and vegetation management areas; 25 off-stream stock watering systems to restrict direct stock access to waterways; 561 ha of native vegetation under protective management; 105,360 m^2 of erosion control measures; and 5.4 km^2 of wetland under acid sulfate management. In urban areas, the *Stormwater Management Plan* and *Healthy Lakes Program* has provided 107 litter baskets, seven gross pollutant traps and eight constructed wetlands retrofitted into residential catchments previously without stormwater treatment devices. These programs are discussed in more detail in Section 3.4.1 and Appendix 8.

2.5 Wallis Lake – Current state of catchment and estuary health

2.5.1 Wallis Lake segments and rivers

Wallis Lake operates as two largely non-interactive water bodies: the rivers and entrance channels, and the main part of the lake. Pollutants from the Wallamba, Coolongolook, Wang Wauk and Wallingat River sub-catchments that are transported by the rivers into the lake system during floods primarily stay in the main channel to the north of Wallis Island. The main body of the lake is largely influenced by its small perimeter catchment and anything that enters the lake from its catchment stays there. Pollutants from the urban catchments of Forster enter the Pipers Bay region of Wallis Lake and can influence the main body of the lake.

Condition in Wallis Lake is reported in this document for two zones (Figure 2.5.1):

- Pipers Bay
- the main body of Wallis Lake (referred in this Plan as Wallis Lake).

In addition to the non-tidal freshwater river, there are three distinct zones in the Wallis Lake riverine estuaries: Upper, Middle and Lower Estuary. Lower parts of estuaries are generally shallow, with many sand bars, shallows and islands. Middle parts of estuaries gradually become deeper and more channelised with fewer shoals. They tend to be the deepest parts of the estuary. The upper estuary is characterised by a single channel of moderate depth with relatively steep banks.

Condition in the riverine estuaries (Figure 2.5.1) is reported in this Plan for the:

- Lower River estuaries, which are comprised of the Lower Wallamba, Coolongolook and Wang Wauk River estuaries, the lake entrance, and the eastern and western channels (referred in this plan as the Lower Estuary)
- Middle Estuary of the Wallamba, Coolongolook and Wang Wauk River estuaries (referred in this plan as the Middle Estuary)
- Upper Estuary of the Wallamba River Estuary (referred in this plan as the Upper Estuary).

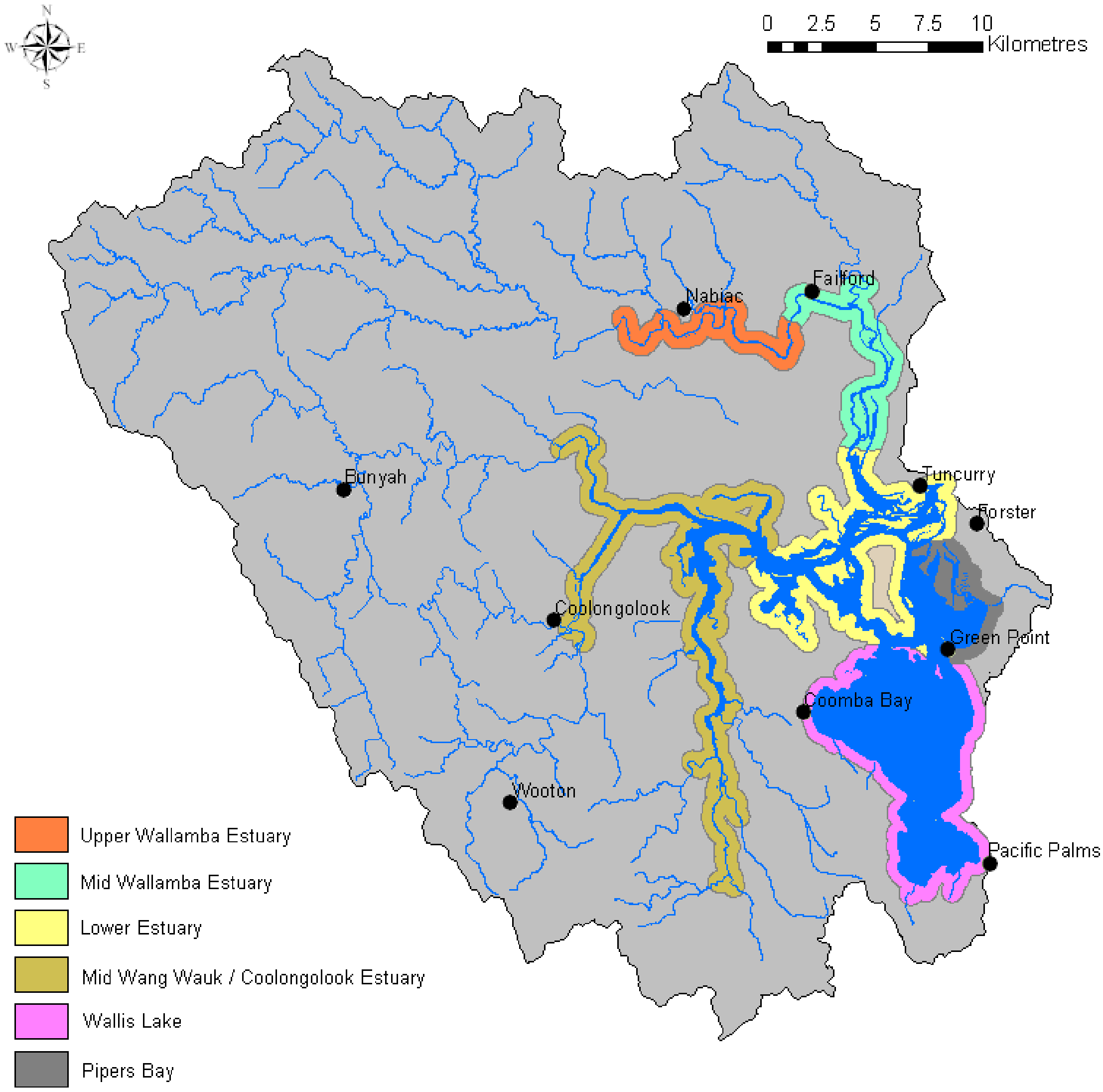


Figure 2.5.1. Zones in the Wallis Lake estuary used for modelling and analysis, and reporting on condition in this Plan. The Middle Estuary reported on in this plan comprises the Mid Wallamba Estuary and the Mid Wang Wauk / Coolongolook Estuary as shown in this figure.

2.5.2 Synthesis of research for Wallis Lake

2.5.2.1 Previous research

Wallis Lake and its rivers have been subject to many years of water quality and ecological research, monitoring and modelling. Projects have ranged from landholder-led water quality sampling in rivers to detailed research into the ecological processes involved in cycling nutrients between bottom sediments and the overlying water column. Projects such as these have helped to build our understanding of estuary processes and catchment inputs, many designed specifically to inform management plans such as the Wallis Lake Catchment and Estuary Plan.

The research, modelling and monitoring completed through the Great Lakes CCI builds on the knowledge of catchment inputs and estuary processes developed through past projects. Key project reports are listed below:

- Wallis Lake Catchment Management Plan (Great Lakes Council 2003[DG20])
- Wallis Lake Estuary Management Plan (Great Lakes Council 2005[DG21])
- Benthic Nutrient Fluxes in Wallis Lake (Smith *et al*. 2000[DG22])
- Tracers and Indicators of Estuarine Nutrients (Moore 2005[DG23])
- Seagrass Change Assessment Using Satellite Data for Wallis Lake (Dekker, Anstee & Brando 2003)[DG24]
- Forster Tuncurry and Wallis Lake Stormwater Management Study (Jelliffe 2000[DG25])
- Wallis Lake Estuary Processes Study (Webb, McKeown & Associates 1999)
- Identification of Urban and Rural Inputs to Sediments in Lake Wallis ([DG26]Logan, MacPhail, Fredericks, Smith & Heggie 2001)
- Forster Keys Canal Estate Hydraulics and Ecology – An Overview (Australian Water & Coastal Studies 1990[DG27])
- Wallis Lake Data Compilation Study (Geomarine 1996[DG28])
- Pipers Creek in Wallis Lake Waterway Improvement Study (Australian Water & Coastal Studies 1993[DG29])
- Wang Wauk River Catchment Community Water Quality Monitoring Program (Department of Land and Water Conservation on behalf of Wang Wauk River Catchment Landcare Group Inc. 2001[DG30])
- Lower Wallamba Rivercare Plan (Great Lakes Council 2003a[DG31]).

These past projects establish a strong foundation for the recommendations outlined in this WQIP. The CCI research described here explores a new area of modelling that links water quality changes in the catchment to the ecological response of the estuary. Details are outlined in the following section.

2.5.2.2 CCI research

A component of the CCI project was to develop, verify and apply predictive models to quantify pollutant loads entering the Great Lakes waterways, and the impact of these loads on ecological condition. The work focussed on the collection of relevant data on nutrient exports from specified land uses, effectiveness of management actions, nutrient cycling within stream networks, delivery to estuarine waters, and ecological and water quality implications within estuaries. DECC undertook catchment modelling and estuary modelling while BMT WBM developed detailed models of urban areas and pollutant treatments.

Specific tasks in the catchment modelling component of the CCI included:

- estimating and collating contaminant (nitrogen and phosphorus) loads using catchment modelling techniques
- validating / refining model estimates through event-based water quality and flow measurements
- modelling effects of applying management practices within treatment trains (reduction of loads from catchments)
- developing and implementing case studies to refine catchment modelling parameters to estimate nutrient loadings.

Specific tasks in the ecological modelling component were to:

- determine the broad drivers and responses of the aquatic ecosystems
- quantify nutrient cycling between estuary waters and sediments
- develop hydrological / physical-chemical / ecological models for each lake to assess the impact of contaminant loads from its catchment.

The broad drivers of the lake systems relate to nutrient and light availability. The response of the aquatic ecosystem depends on the expansion and contraction of nuisance aquatic plants (e.g. phytoplankton blooms) and plants indicative of a healthy ecosystem (e.g. charophytes and seagrass).

2.5.2.3 Catchment management research

DECC Waters and Catchment Science undertook monitoring of two types of management practices that are currently implemented on farming properties in the Great Lakes area – riparian fencing and off-stream watering – and compared them to properties that had not implemented either management practice. Properties where these actions had not been implemented had a greater proportional area of bare soil along the stream banks. While the monitoring data showed no discernable differences in the water quality (nutrient and sediment concentrations) of streams, it showed distinct differences in the biological condition of the streams (Haine, Dela-Cruz & Scanes in prep).

Properties that implemented off-stream watering and/or riparian fencing had a greater number of species and abundance of fish than those that had not implemented such a management practice. Streams on properties with riparian fencing also had greater overall diversity of fish than those without riparian fencing or off-stream watering. The difference in fish assemblages is due to improved stream habitat condition (i.e. more twigs and leaves, and trailing vegetation) which, in turn, is due to greater and better cover of vegetation along the stream banks (Haine, Dela-Cruz & Scanes in prep.).

A rural management practice project was undertaken by the Department of Primary Industries to provide a basis for developing policy, strategy and ultimately projects that will reduce the impact of rural land use on water quality within the Great Lakes CCI. The project was undertaken in three parts:

1. A literature review of the processes and management of sediments, nitrogen, phosphorus and faecal pathogens to provide a basis for assessing a wide range of strategies available to farmers
2. A survey of on-farm practices and conditions that may pose a risk to water quality. This was undertaken at two levels: an on-farm assessment of the three major industries – poultry (3), beef (6) and dairy (4) – and a wider survey of 44 beef farms, the largest industry by farm number, to gain a more representative sample
3. A brief simulation study of runoff, leaching and nitrate movement using Dairymod™.

The findings of this project are outlined in the Report 'Rural Management Practice Final Report'. The main findings and recommendations are:

- The main sources of sediments and nutrients are soil erosion, principal stream and gully erosion, and present the greatest threat during big rain events.
- Greatest funding needs to go to restoring riparian vegetation in a targeted way. A better result will be achieved by targeting high-risk areas rather than simply targeting willing farmers.
- Low groundcover after drought remains a threat. Drought strategies that are applicable to this area need to be further developed. Some issues are difficult to reconcile, i.e. the cost of grain feeding is high on the coast, and the definition of a drought is unclear.
- Inappropriate fertiliser use in agriculture can contribute nutrients such as phosphorous from superphosphate, and therefore fertilisers need to be applied appropriately.
- Dairy and poultry industries in the CCI area are higher nutrient users and need more intensive measures. However, they are small in area, i.e. less than 1% of the catchments. Support needs to be given to current industry lead programs to help farmers use best practice solutions.
- The issues associated with the concentrated use of poultry manure could be minimised by subsidising the transport and cost of chicken litter. This would assist with its wider distribution – so that it is not concentrated around the chicken sheds, and it is applied using best management practice guidelines. More industry negotiation and stakeholder engagement is required.
- Poultry litter should be applied according to the Department of Primary Industries best management practice guidelines.

- Farmer adoption is a key, thus programs should consider the whole farm needs, and facilitate both productivity and water quality outcomes.

2.5.2.4 Urban catchment management research

DECC Waters and Catchment Science studied the nutrient removal efficiency of Kularoo Drive Wetlands [DG32]in Forster, measuring all forms of the nutrients in the system. The removal efficiency was measured by the proportional change in concentration of each form of nutrient between inflow and outflow of the wetland. For example, a concentration of ammonia of 80 at the inflow and 40 at the outflow represents 50% removal efficiency. The changes in nutrient concentrations and suspended solids in Table 2.5.1 provide a good indication of the biogeochemical processes occurring within the wetland.

The wetland was effective in removing dissolved inorganic nitrogen (DIN) from the runoff (65% removed), which comprised approximately 30% of the total nitrogen inflow concentration. In contrast, the wetland was very ineffective at removing dissolved organic nitrogen. Greatest removal efficiency of dissolved organic nitrogen (DON) occurred during dry weather at 2%. During wet weather, the removal efficiency of DON was -20%, indicating that the wetland was a significant source of dissolved organic nitrogen. The remainder of the nitrogen was particulate. Overall, the average removal efficiency of total nitrogen (TN) was only 18% during wet weather.

Table 2.5.1. Pollutant removal by Kularoo Drive Wetlands, urban catchment management in the Wallis Lake catchment. Numbers are the percentage of pollutants removed by the wetland, compared to the total amount of pollutant that entered the wetland. The columns represent the amount removed of the total pool of nutrients, the target for best management practice and the amount of the biologically active nutrients (also known as inorganic nutrient) removed.

	% of all forms of sediment and nutrients that was removed (‘total nutrient’)	Best management practice target for nutrient removal, expressed as % total removed (CSIRO 2006)	% of biologically active forms of nutrients that was removed (‘inorganic nutrient’)
Nitrogen	18	45	65
Phosphorus	15	45	56
Suspended solids	42	80	

The wetland was effective in removing dissolved inorganic phosphorus (DIP) from catchment runoff, with greatest removal efficiencies occurring during wet weather (56%). DIP comprised about 26% of the total phosphorus inflow concentration. The Kularoo Drive Wetlands was a source of dissolved inorganic phosphorus (DOP) to downstream waters during both wet and dry weather, with removal efficiencies of -40 and -25% respectively; but DOP inflow concentrations only constituted 13% of TP inflow into the Kularoo Drive Wetlands. Particulate phosphorus made up almost 60% of the inflow loads to the wetlands. Wet weather removal efficiencies for Total Phosphorus were 15%. As shown in Table 2.5.1, 42% of the suspended solids were removed by Kularoo Drive Wetlands, demonstrating that the system is more efficient at removing particulates than nutrients. However, the wetlands did fall short of the target identified by CSIRO for similar systems (80%) (CSIRO 2006).

The nutrient removal efficiency for TN and TP was well short of the recommended Urban Best Management Practice (BMP) target of 45% (CSIRO 2006). Removal efficiencies of DIN and DIP are, however, greater than the 45% BMP target. DIN is regarded as the most biologically available fraction of total nitrogen inputs and the most likely constituent to impact receiving waters further downstream. The consequences of a poor (negative) removal efficiency for DON and DOP is unknown until more work is done to determine the activity status of the actual forms of DON and DOP in that system.

2.5.2.5 Water quality in Wallis Lake

DECC Waters and Catchment Science undertook sampling in Wallis Lake in 2006/07 to calibrate the estuary model and develop an understanding of the 'current' conditions in the lake. Constituents sampled were:

- concentrations of all forms of nitrogen and phosphorus, turbidity, Secchi depth, light profiles, salinity, water temperature
- chlorophyll-a concentrations (a measure of the amount of phytoplankton [algae]) in the water).

Water clarity and chlorophyll-a concentrations are considered by DECC to be a more appropriate measure of ecological condition than water quality parameters because they are direct measures of ecosystem status. Recent studies have shown that they were the only indicators linked to catchment disturbance (Scanes, Coade, Doherty & Hill[DG33] 2007).

It is well accepted in the literature that intensification of land use and removal of native vegetation leads to increases in the amount of nutrients and sediments washed down rivers to estuaries. The nutrients stimulate the growth of algae in estuaries (both microalgae in the water, and slimes and weeds around the lake edge) and the sediments reduce water clarity, resulting in reduced light to bottom-living plants such as seagrasses. In extreme conditions, the amount of algae in the water can significantly reduce water clarity as well, but this is unlikely in Wallis Lake. Chlorophyll-a is the main pigment present in all plants, including the microscopic algae that occur in all waterways, and provides a convenient means of estimating the amount of invisible microalgae in water samples. It is expressed as the concentration of the chlorophyll pigment per volume of water (i.e. μg/L). Turbidity is a measure of the amount of light scattered by particles in the water and is expressed as dimensionless ‘nephelometric turbidity units’ abbreviated as ‘NTU’. Secchi depth is a measure of light transmission through water, and is affected by particles in the water and by water colour. Measurement is made by lowering a standard black-and-white disk into the water and measuring the depth at which it becomes invisible to an observer above the disk.

Scanes, Coade, Doherty & Hill [DG34](2007) sampled 30 estuaries with differing amounts of catchment disturbance, and showed that chlorophyll-a concentrations and measures of water clarity were the best indicators of the effects of catchment disturbance on estuary condition.

Increases in the amount of algae and decreases in water clarity are early indicators that disruption to estuarine ecology is occurring. These disruptions could lead to harmful algal blooms, loss of habitat, reduced fish and seagrass abundance, loss of higher predators (e.g. birds, dolphins, sharks), and overall loss of biodiversity and estuary function. The WQIP uses abundance of microalgae (chlorophyll-a), water clarity (turbidity, Secchi depth) and the extent of seagrass as its primary indicators of estuary condition. Estuary Ecological Condition Targets (utilising trigger values) have been set for each of these indicators (Appendix 10). The estuary models were able to provide a link between catchment nutrient loads (expressed as total nitrogen (TN) inputs) and chlorophyll-a, enabling a catchment load to be identified for nitrogen[DG35]. The models were unable to quantitatively link the catchment sediment outputs with measured water clarity, though there was an obvious qualitative link – water clarity decreased when catchment sediment loads increased. The modelling did, however, clearly link water clarity (Secchi depth) and the depth to which seagrass survives, enabling a prediction of effects on seagrass extent from the water clarity data. The link between catchment nutrient load and estuary chlorophyll is thus the primary focus for many of the Plan Ecological Condition Targets, with the assumption that actions which control nutrient exports from catchments will usually also control sediments, and thus contribute positively to protecting water clarity and seagrass extent targets.

Data collected by DECC Waters and Catchment Science in 2006/07 were used to establish the current conditions within the estuary and compare current condition to the targets. Chlorophyll-a concentrations, averaged for each part of the lake, show elevated levels in Pipers Bay (2.7 μg/L), Pipers Creek (2.4–8.6 μg/L) and Coomba Bay (3.1 μg/L) compared to the southern bays of Wallis Lake (1.4 μg/L) (Figure 2.5.2). Upper and middle riverine estuaries have naturally higher concentrations of Chlorophyll-a, although levels in the Wallis system are elevated above natural conditions, particularly for the Wallamba River (Sections 2.5.3.4 and 2.5.3.5).

Turbidity was low in the southern and central Wallis Lake (0.9 NTU), but very high in Coomba Bay (15 NTU). Turbidity in the upper and middle estuaries was moderately elevated above target conditions (9–12 NTU). Secchi depth and seagrass depth limits followed a similar pattern – good in the central and southern lakes, and less than desirable (i.e. poorer) in Coomba Bay and the riverine estuaries.

Figure 2.5.2. Mean chlorophyll-a concentrations (μg/L) recorded in Wallis Lake estuary by DECC Waters and Catchment Science in 2006/07.

2.5.2.6 Ecology of Wallis Lake

The southern bays of Wallis Lake (i.e. south of Earps and Booti islands) have largely intact catchments, and research undertaken by DECC has highlighted the near-pristine condition of these bays. They support a wide variety of seagrass, healthy algae and brackish water plant (macrophyte) communities to a depth in excess of 3 m. All these benthic (bottom-dwelling) plant communities are dependent on clear, clean water with very low nutrient loads. Current measurements for the southern bays have average chlorophyll-a [DG36]concentrations less than 1 μg/L, turbidity below 2 NTU and water clarity (Secchi depths) in excess of 3 m. These near-pristine conditions have allowed the continued survival of the ecologically important seagrass and macrophyte communities, with their associated biodiversity, including the increasingly threatened estuarine sponges, in the southern parts of Wallis (Figures 2.5.3 and 2.5.4). These clear-water brackish macrophyte and sponge communities are, to the knowledge of DECC, mostly unique and endemic to Wallis Lake. Most of the Wallis Lake sponges are new to science and have not yet been formally named.

Figure 2.5.3. Estuarine sponges and diverse benthic algae in Wallis Lake. Top: Healthy clear-water ecosystems around Earps Island, showing estuarine sponges and diverse benthic algae. These areas adjoin diverse and healthy seagrass, algae and macrophyte beds; Middle: The brilliant blue sponge *Suberites* sp. occurs almost exclusively on seagrass and macrophyte beds near Talambar Point; Bottom: The bright green alga *Codium spongiosum* is susceptible to smothering by sediments (Source: DECC).[pt37]

Figure 2.5.4. Biodiversity in Wallis Lake. Top right: Pipe fish; Top left, bottom right: Colourful nudibranchs, and naked-gilled sea slugs; Bottom left: Sea hares (*Aplysia* sp.) live in the seagrass and macrophyte beds (Source: DECC).

A qualitative assessment of the modelled threats to each zone in the Wallis Lake waterways is shown in Table 2.5.2. The Wallamba sub-catchments have a large impact on the Upper Estuary and Middle Estuary of the Wallamba River, although impacts on the Lower Estuary [2] are partially mitigated by flushing with the ocean. These catchments have limited influence on Pipers Bay and Wallis Lake zones, which are most impacted by the Wallis Lake perimeter catchment (the southern and western sub-catchments, and Forster sub-catchments of Wallis Lake).

2 The Lower Estuary comprises the lower Wallamba, Coolongolook and Wang Wauk River estuaries, the lake entrance, and the eastern and western channels.

Table 2.5.2. Impact of Wallis Lake sub-catchment group pollutant exports on ecological condition in the Wallis Lake estuary zones.

Sub-catchment group	Upper Estuary (Wallamba)	Middle Estuary		Lower Estuary	Pipers Bay	Wallis Lake
		Wallamba	Coolongolook / Wang Wauk			
Wallamba	Large	Large	None to small	Small to moderate	None to small	None to small
Wang Wauk	None	None	Moderate to large	Small	None to small	None to small
Coolongolook	None	None	Moderate to large	Small	None to small	None to small
Wallingat	None	None	None to small	Small	None to small	Small
Lower Estuary	None	None	Small	Moderate	Small	Small to moderate
Wallis Lake – Southern and western sub-catchments	None	None	None to small	Small to moderate	Small	Large
Wallis Lake – Forster sub-catchments	None	None	None to small	Small to moderate	Large	Moderate

2.5.3 Ecological condition

The *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) is the basis for the majority of decisions about water quality management in NSW. ANZECC provides for three 'levels of protection' for aquatic ecosystems:

1. *High conservation value*: systems that have high ecological and / or conservation values, and are largely unmodified or have undergone little change. They are often found within national parks, conservation reserves or inaccessible locations.
2. *Slight to moderate disturbance*: systems that have undergone some changes but are not considered so degraded as to be highly disturbed. Aquatic biological diversity may have been affected to some degree, but the natural communities are still largely intact and functioning.
3. *Highly disturbed*: systems that have undergone considerable degradation. Natural communities are largely not functional and nuisance species such as algae may be present in large volumes.

DECC has defined the typical features of lakes and coastal river estuaries according to the three levels of protection – *High conservation value*, *Moderately disturbed* and *Heavily impacted*. These categories are the equivalent of the levels of protection described by ANZECC above. DECC then identified where the different zones of Wallis Lake fit in this scale (Appendix 10, Figures 2.5.5 and 2.5.6). Indicators of good ecosystem quality are high water clarity, low chlorophyll-a concentrations and very small amounts of green nuisance macroalgae among the seagrass.

This plan focuses on chlorophyll-a concentrations as the primary ecological indicator because the estuary models were able to provide a link between catchment nutrient loads (expressed as total nitrogen (TN) inputs) and chlorophyll-a. Water clarity and turbidity are still considered to be useful indicators. However, for the purposes of this plan, it is assumed that actions which control nutrient exports from catchments will usually also control sediments, and thus contribute positively to protecting water clarity and seagrass extent targets.

This section of text summarises the current condition of the estuary zones and relates them to the indicator levels for chlorophyll-a concentrations and turbidity defined by DECC (Appendix 10). Tables 2.5.3 to 2.5.7 show mean chlorophyll-a concentrations measured by DECC Waters and Catchment Science in 2006/07 and identify the order of change required to meet the indicator levels that would represent *High conservation value* and *Slightly to moderately disturbed*. Note that these measurements were taken over a relatively short period of time. The order of change required to meet the indicator levels assumes that the conditions in the lake or river estuaries are adequately represented by the samples.

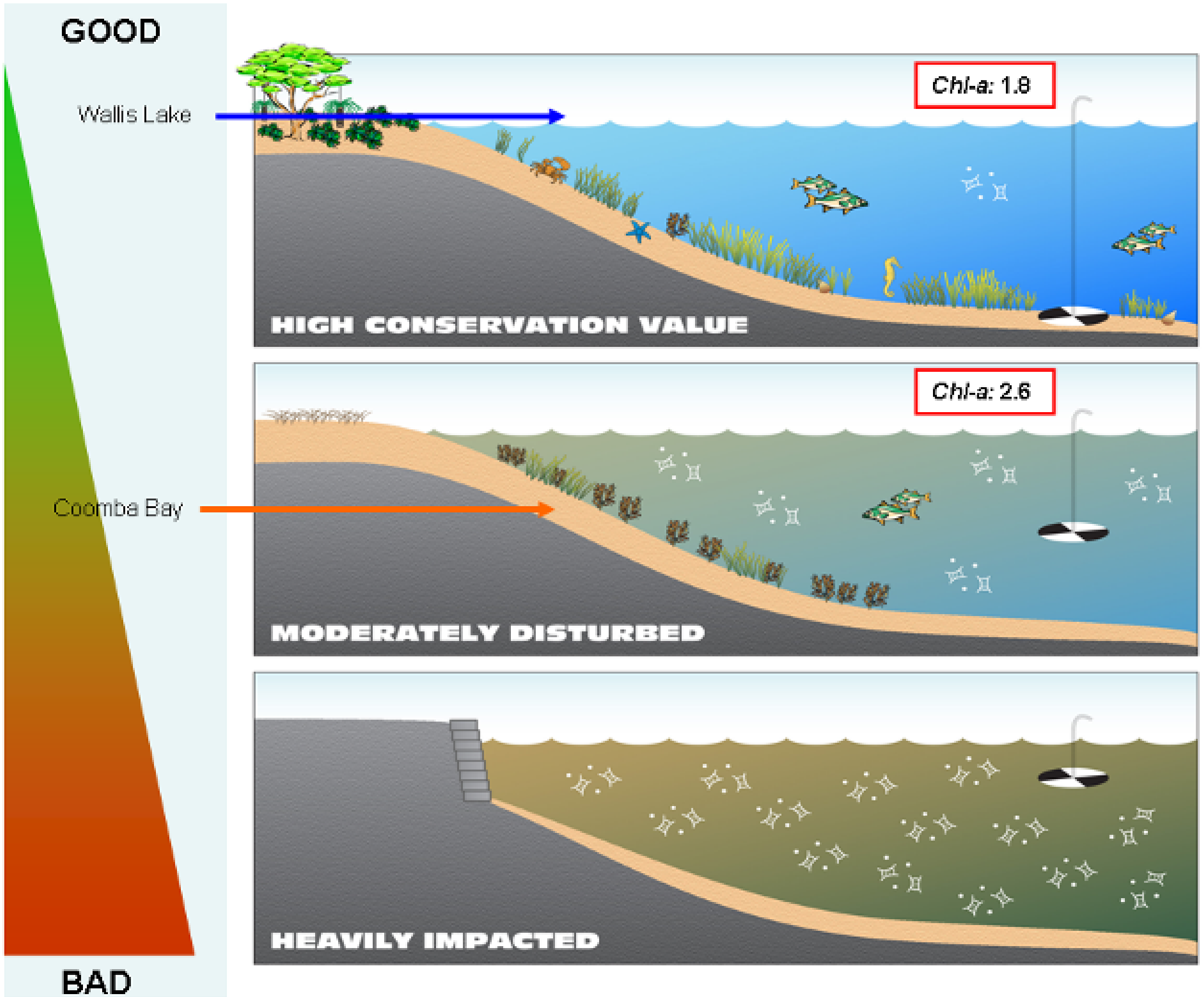


Figure 2.5.5. Current ecological condition of coastal lake water at Southern Wallis Lake and Coomba Bay. Indicative levels of chlorophyll-a concentrations (µg/L) are shown for these *High conservation value* and *Slightly to moderately disturbed* water bodies.

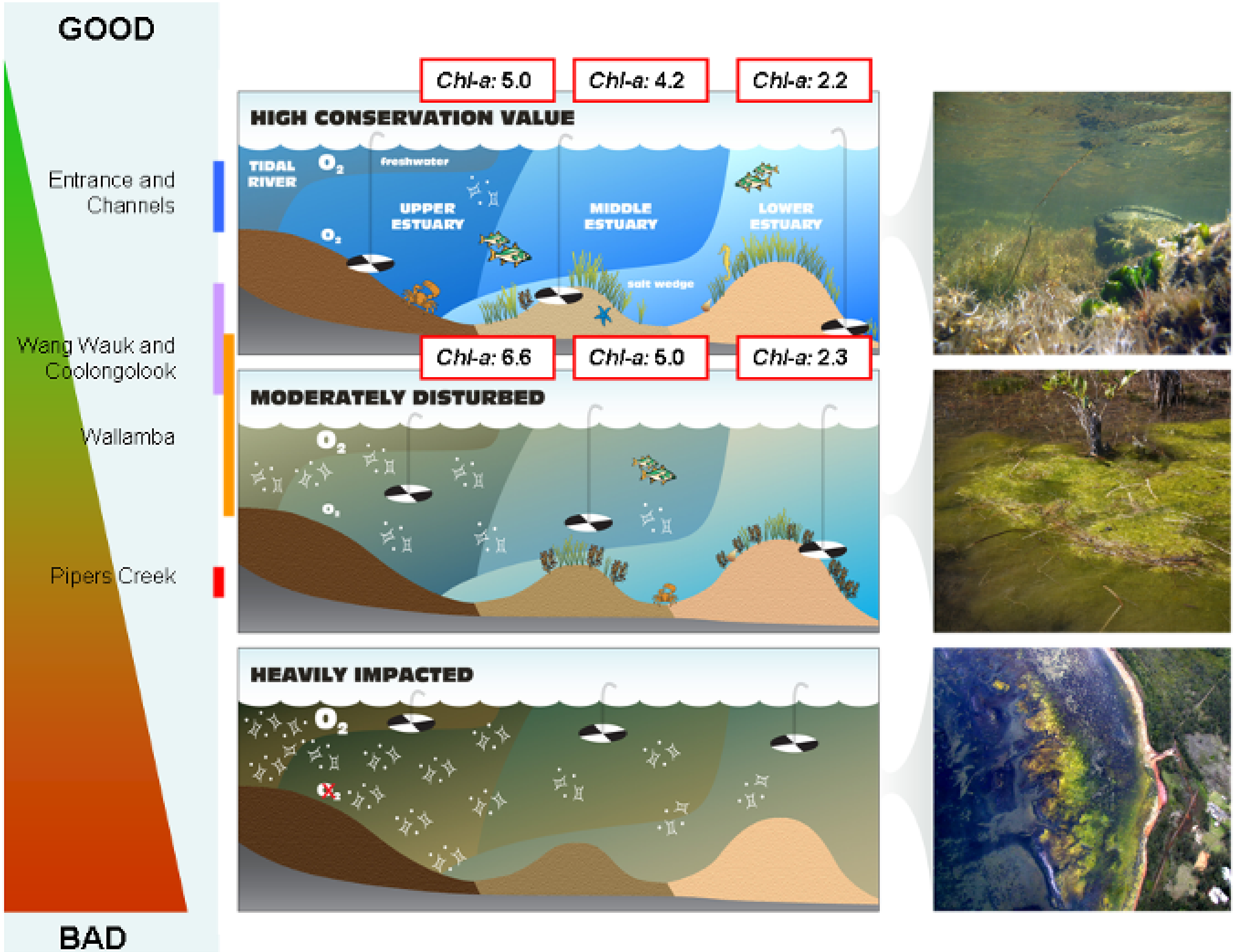


Figure 2.5.6. Current ecological condition of the river estuaries in Wallis Lake. Shows their proximity to the levels of chlorophyll-a concentrations (µg/L) representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. Chlorophyll-a concentrations are shown across three estuary zones: Upper, Middle and Lower Estuary.

2.5.3.1 Wallis Lake

The southern end of Wallis Lake is currently in a *High conservation value* or near-pristine state. It supports a wide variety of seagrass, healthy algae and brackish water plant (macrophyte) communities to a depth in excess of 3 m. All these benthic (bottom-dwelling) plant communities are dependent on clear, clean water with very low nutrient loads. These near-pristine conditions have allowed the continued survival of the ecologically important seagrass and macrophyte communities, with their associated biodiversity, including the increasingly threatened estuarine sponges.

Localised issues occur in the Coomba Bay, where chlorophyll-a measurements made by DECC Waters and Catchment Science in 2006/07 show elevated concentrations (3.1 μg/L) compared with the southern bays of the main Wallis Lake body (Table 2.5.3). A large gully estimated to be up to 300 m long, 3–4 m wide and 2 m deep contribute a large volume of sediment into the waters of the bay (Figure 2.5.7). Seagrass communities were killed due to burial as well as continual long-term turbidity (Figure 2.5.8). Only a narrow band of seagrass has managed to survive between the smothered area and depths where the turbid water prevents sufficient light from reaching the lake bed.

Details of this case study are provided in the Wallis Lake Case Studies Report (see Appendix 11).

Figure 2.5.7. An erosion gully feeding into Coomba Bay, Wallis Lake (Source: Great Lakes Council).

Figure 2.5.8. Coomba Bay, Wallis Lake, 7 June 2007 showing turbid (dirty) water, mud area and absence of seagrass. Seagrass is seen as a dark colour in the water. The sediment core on the right shows the dark sediments of the lake overlain with lighter sediments sourced from the gully (Source: DECC).

Table 2.5.3. Average chlorophyll-a concentrations (µg/L) recorded in southern Wallis Lake and Coomba Bay by DECC Waters and Catchment Science in 2006/07, and their relationship to indicator levels representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. See Figures 2.5.5 and 2.5.6 for more explanation of the meaning of these concentrations for ecological condition.

Waterbody	Measurements (µg/L)	High conservation value		Slightly to moderately disturbed	
		Indicator level [a]	Decrease to reach level (%)	Indicator level [a]	Decrease to reach level (%)
Wallis Lake	1.4	1.8	0.0	2.6	0.0
Coomba Bay	3.1	1.8	41.9	2.6	16.1

a: [DG38] For more information on how indicator levels were determined, see Appendix 10.

2.5.3.2 Pipers Bay

The Pipers Creek and Pipers Bay area is the receiving waters for the medium-density urban and light industrial developments on the eastern side of the Wallis Lake and includes the majority of the Forster urban area. Sub-catchments influencing Pipers Bay include HS17, HS18 and part of HS19 (Figure 2.5.9). Chlorophyll-a concentrations in Pipers Creek were among the highest measured anywhere in the system, averaging 8.6 µg/L and peaking at 12 µg/L (Table 2.5.4). The average value for Pipers Creek is five to six times greater than values expected for this type of environment and represents a significantly degraded ecosystem falling into the bottom end of the range for a moderately disturbed ecosystem (Figure 2.5.6). Large blooms of macroalgae are obvious on seagrass beds in the creek (Figure 2.5.10).

Figure 2.5.9. Forster sub-catchments draining into Wallis Lake. Pipers Creek and Bay are the receiving waters for sub-catchments HS17, HS18 and part of HS19.

Figure 2.5.10. Excessive growth of macroalgae over seagrass beds in Pipers Creek, Wallis Lake (Source: DECC).

In Pipers Creek the turbidity values were moderate, with values ranging between 4 and 6 NTU[pt39]. Seagrass only grows down to a depth of less than 2 m, which is more than 0.5 m shallower than would be expected for this type of environment.

The ecological indicators for Pipers Creek show that it is one of the most degraded parts of the Wallis Lake system. Measurements of the release of nutrients from sediments in Pipers Bay indicate that the system is under significant long-term stress. The large amounts of algae, both as chlorophyll-a and attached macroalgae, suggest that nutrient enrichment is the greatest problem in Pipers Creek. Turbidity from catchment soil loss is a secondary (although significant) issue.

Table 2.5.4. Average chlorophyll-a concentrations (µg/L) recorded in Pipers Creek and Pipers Bay, Wallis Lake, by DECC Waters and Catchment Science in 2006/07 and their relationship to indicator levels representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. See Figures 2.5.5 and 2.5.6 for more explanation of the meaning of these concentrations for ecological condition.

Waterbody	Measurements	High conservation value		Slightly to moderately disturbed	
		Level	Decrease to reach level (%)	Level	Decrease to reach level (%)
Pipers Creek	8.6	4.2	51.2	5.0	41.9
Pipers Bay	2.7	2.2	18.5	2.3	14.8

2.5.3.3 Lower Estuary

The Lower Estuary – comprised of the lower reaches of the Wallamba, Wang Wauk and Coolongolook River estuaries, the lake entrance, and the eastern and western channels – is where most of the aquaculture and lake-based recreation in Wallis Lake occurs. Despite receiving much of the catchment input of pollutants from the four major rivers (Wallamba, Wang Wauk, Coolongolook and Wallingat rivers), the region is in generally good condition as it is well flushed (i.e. there is significant tidal exchange with the ocean) compared with other parts of the system. Chlorophyll-a concentrations measured by DECC Waters and Catchment Science in 2006/07 were close to, or lower than, chlorophyll-a levels representative of *High conservation value* (Table 2.5.5).

Table 2.5.5. Average chlorophyll-a concentrations (µg/L) recorded in the lower estuary water bodies of Wallis Lake by DECC Waters and Catchment Science in 2006/2007 and their relationship to indicator levels representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. See Figures 2.5.5 and 2.5.6 for more explanation of the meaning of these concentrations for ecological condition.

Waterbody	Measurements	High conservation value		Slightly to moderately disturbed	
		Level	Decrease to reach level (%)	Level	Decrease to reach level (%)
Lower Wallamba	2.4	2.2	8.3	2.3	4.2
Lower Coolongolook / Wang Wauk	2.3	2.2	4.3	2.3	0.0
Entrance	1.3	2.2	0.0	2.3	0.0
East Channel	2.4	2.2	8.3	2.3	4.2
West Channel	1.7	2.2	0.0	2.3	0.0
Whole Area	1.9	2.2	0.0	2.3	0.0

2.5.3.4 Middle Estuary

While the Lower Estuary of the Wallamba, Wang Wauk and Coolongolook rivers have good ecological condition, the Middle Estuary of these rivers recorded higher levels of chlorophyll-a (Table 2.5.6). These areas naturally have higher turbidity and chlorophyll-a concentrations than the lower river estuaries, although their catchments have been significantly altered by human activities, which has resulted in elevated nutrient and sediment inputs.

The middle reach of the Wallamba river estuary has an ecological condition that is *Slightly to moderately disturbed*. The middle reach of the Coolongolook and Wang Wauk river estuary is also *Slightly to moderately disturbed*, although is in better condition than the middle reach of Wallamba River.

Table 2.5.6. Average chlorophyll-a concentrations (µg/L) recorded in the middle estuaries of Wallis Lake by DECC Waters and Catchment Science in 2006/07 and their relationship to indicator levels representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. See Figures 2.5.5 and 2.5.6 for more explanation of the meaning of these concentrations for ecological condition.

Waterbody	Measurements	High conservation value		Slightly to moderately disturbed	
		Level	Decrease to reach level (%)	Level	Decrease to reach level (%)
Mid Wallamba	5.3	4.2	20.8	5.0	5.7
Mid Coolongolook / Wang Wauk	4.9	4.2	14.3	5.0	0.0

2.5.3.5 Upper Estuary

While the Lower Estuary of the Wallamba River estuary has good ecological condition, the Upper and Middle Estuary recorded higher levels of chlorophyll-a (Table 2.5.7). These areas naturally have higher turbidity and chlorophyll-a concentrations than the lower river estuaries, although their catchments have been significantly altered by human activities, which has resulted in elevated nutrient and sediment inputs.

The upper reach of the Wallamba River estuary has an ecological condition that is *Slightly to moderately disturbed*. The degree of impact is higher in the middle estuary.

Table 2.5.7. Average chlorophyll-a concentrations (µg/L) recorded in the upper estuaries of the Wallis Lake system by DECC Waters and Catchment Science in 2006/07 and their relationship to indicator levels representative of *High conservation value* and *Slightly to moderately disturbed* water bodies. See Figures 2.5.5 and 2.5.6 for more explanation of the meaning of these concentrations for ecological condition.

Waterbody	**Measurements**	**High conservation value**		**Slightly to moderately disturbed**	
		Level	Decrease to reach level (%)	Level	Decrease to reach level (%)
Upper Wallamba	6.9	5.0	27.5	6.6	4.3

2.5.4 Hydrodynamics

The Wallis Lake hydrodynamic model describes how pollutant loads from sub-catchment groups mix and are moved throughout the Wallis Lake waterways and with the ocean. The two-dimensional hydrodynamic model is coupled to one-dimensional models that represent the major rivers branching from Wallis Lake. Inputs to the hydrodynamic model come from sub-catchment inputs to the lakes, rainfall and exchange with the ocean. To facilitate interpretation of this plan, the catchment export summaries in Sections 2.5.6 and 2.7 are grouped into the seven regions indicated in Table 2.5.8 (and Appendix 6).

The hydrodynamic model was used to predict total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) in the water column of Wallis Lake and the river estuaries.

The concentration of total nitrogen in the Wallis Lake system is shown in Figure 2.5.11 for a large event (21 October 2004) as well as a period of no rainfall (26 November 2002). Under both conditions, elevated TN concentrations tend to occur in the Lower Estuary zone and in the Pipers Bay zone. The latter area is poorly flushed and pollutants that are sourced from the (mainly) urban sub-catchments that drain into the waters tend to stay in the bay such that elevated concentrations are predicted even in dry conditions.

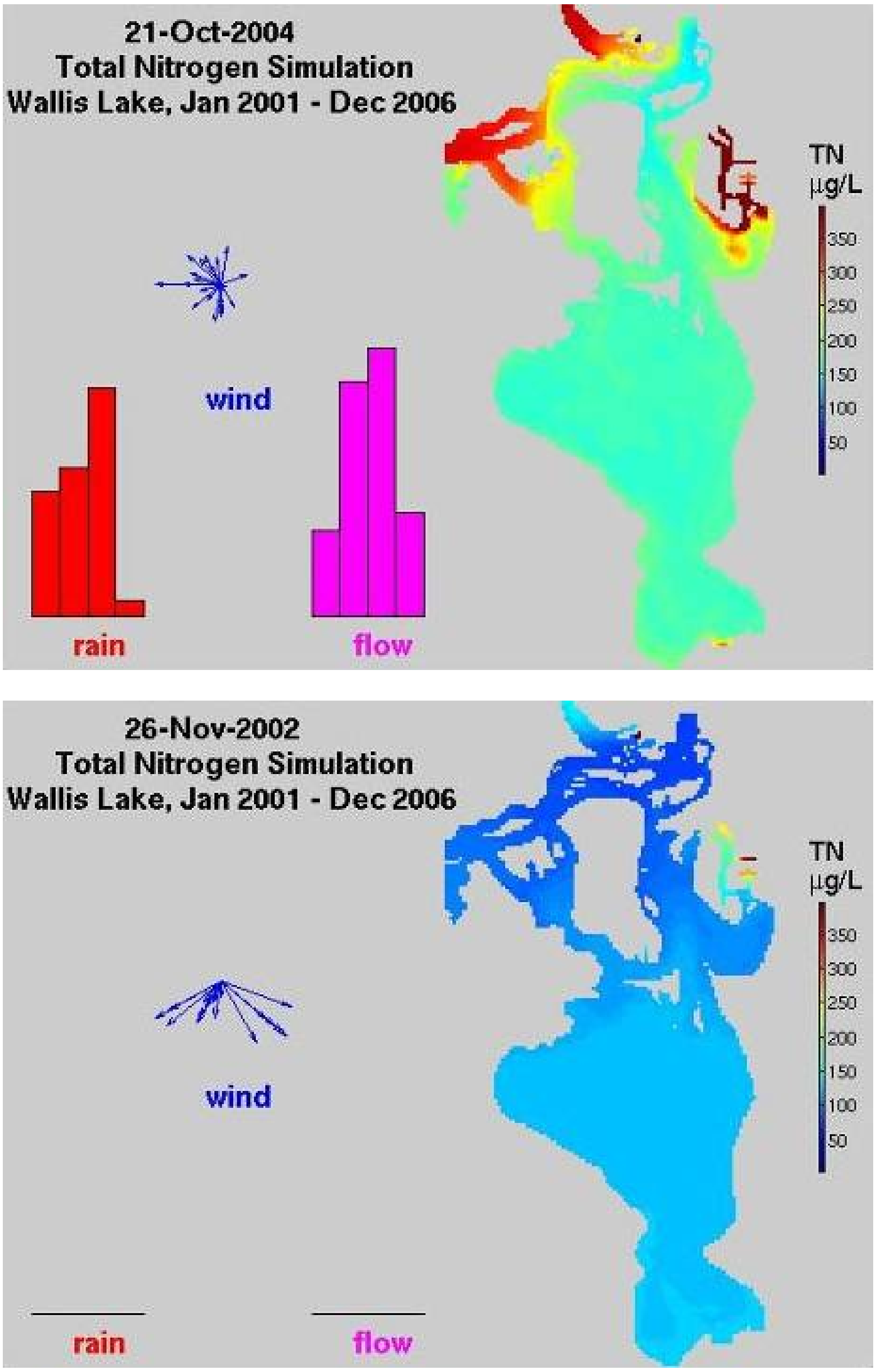


Figure 2.5.11. TN concentrations within the Lower Estuary and Wallis Lake for a large event (21 October 2004) and a dry period (26 November 2002).

The modelling shows clearly that the Lower Estuary [3] and Wallis Lake operate as two largely non-interactive water bodies. Pollutants from the wider catchment that are transported by the rivers into the Lower Estuary during floods generally stay in the main channel to the north of Wallis Island, with only a very small amount moving down the east or west channels towards Wallis Lake. There is relatively little exchange of water between the Wallis Lake and the Lower Estuary. This is illustrated for the 21 October 2004 event (Figure 2.5.11).

The low interaction between these parts of the estuary means that the main recreation and aquaculture areas in the Lower Estuary are strongly influenced by the wider river catchments, but that Wallis Lake itself is mainly influenced by its small perimeter catchment. It also means that any pollutants that enter Wallis Lake from its perimeter stay there. Within the Wallis Lake Zone (Section 2.5.1), there is only minimal mixing between the bays to the south of Earps and Booti islands, and the rest of the zone (Figure 2.5.12).

While there is minimal mixing between Wallis Lake and the Lower Estuary, the Pipers Bay zone does influence the Wallis Lake during high flow events. This highlights the need to manage pollutant loads in Pipers Creek and the bay, not only to rehabilitate that area, but also to protect the near-pristine and unique ecosystems of the southern end of Wallis Lake.

The risk that the largely urban sub-catchments of Forster pose to Wallis Lake is clearly demonstrated in Figure 2.5.13. This figure shows the impact of a wet period, 7–13 May 2001, as well as the ongoing effects of the event (up to 18 May 2001). Early in the period (7 May) TN concentrations are highest in the Lower Wallamba river reach of the Lower Estuary and Pipers Bay. The well-flushed part of the Lower Estuary – particularly the entrance, and eastern and western channels – show very low concentrations. By 10 May, TN is further elevated in the Wallamba and Coolongolook lower estuaries. Pipers Bay and the remaining lower estuary also show increased TN concentrations. Small, localised areas of elevated concentrations exist in the south-east of Wallis Lake due to inputs from its catchment area. A plume of nutrients from Pipers Bay starts to move in a southerly direction along the eastern shores of Wallis Lake. By 18 May, four days since rainfall, the plume extends below Green Point (refer to Figure 2.4.1 for locations).

While Figures 2.5.11 and 2.5.13 illustrate some of the behaviour of the estuary, it is important to note the variability of the response of the estuary. There is considerable variation between the impacts of events even with apparently similar rainfall conditions.

3 The Lower Estuary comprises the lower Wallamba, Coolongolook and Wang Wauk river estuaries, the lake entrance, and the eastern and western channels.

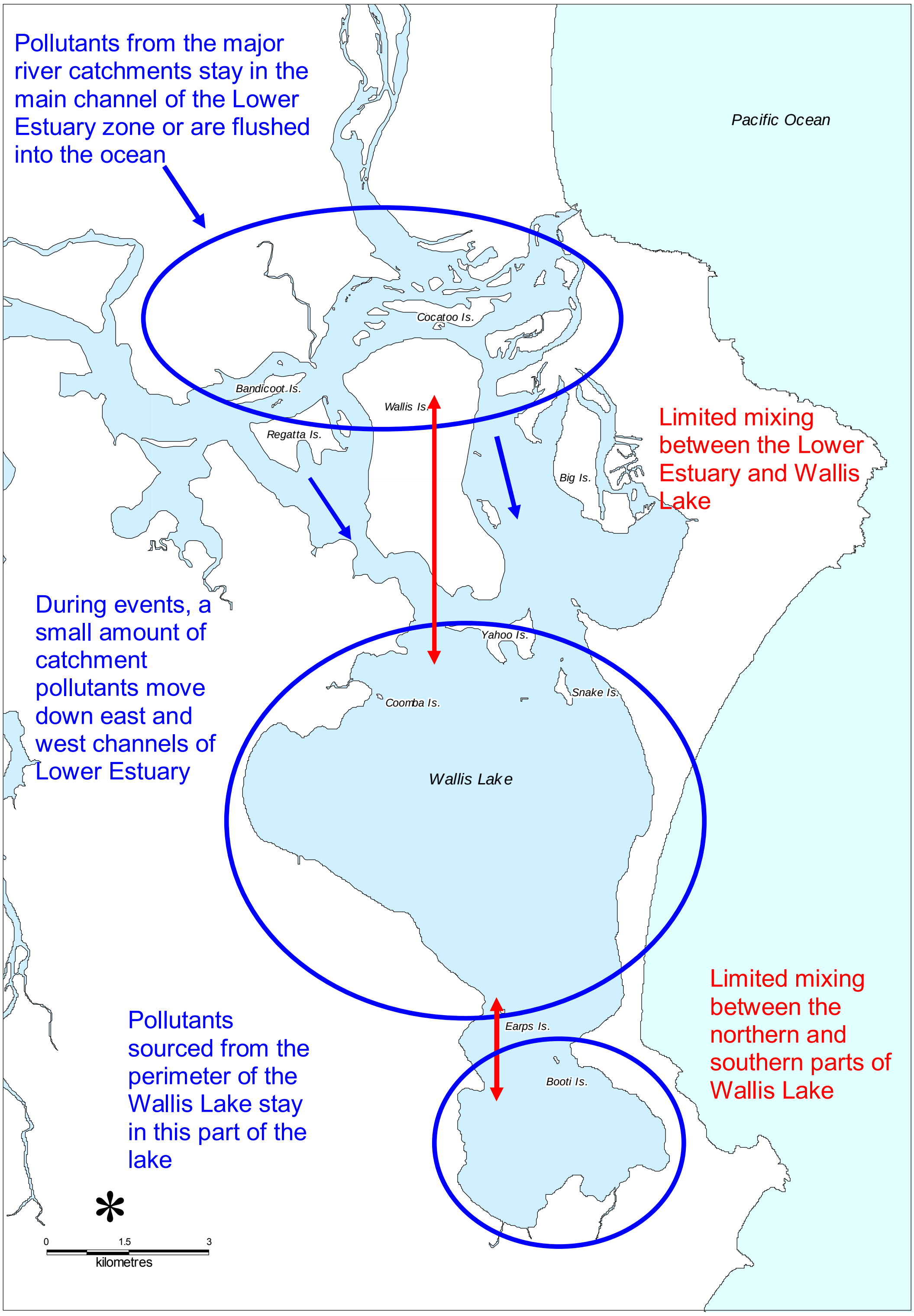


Figure 2.5.12. Wallis Lake and the complex of islands that restrict mixing of the waters in Wallis Lake with those of Southern Wallis Lake and the Lower Estuary.

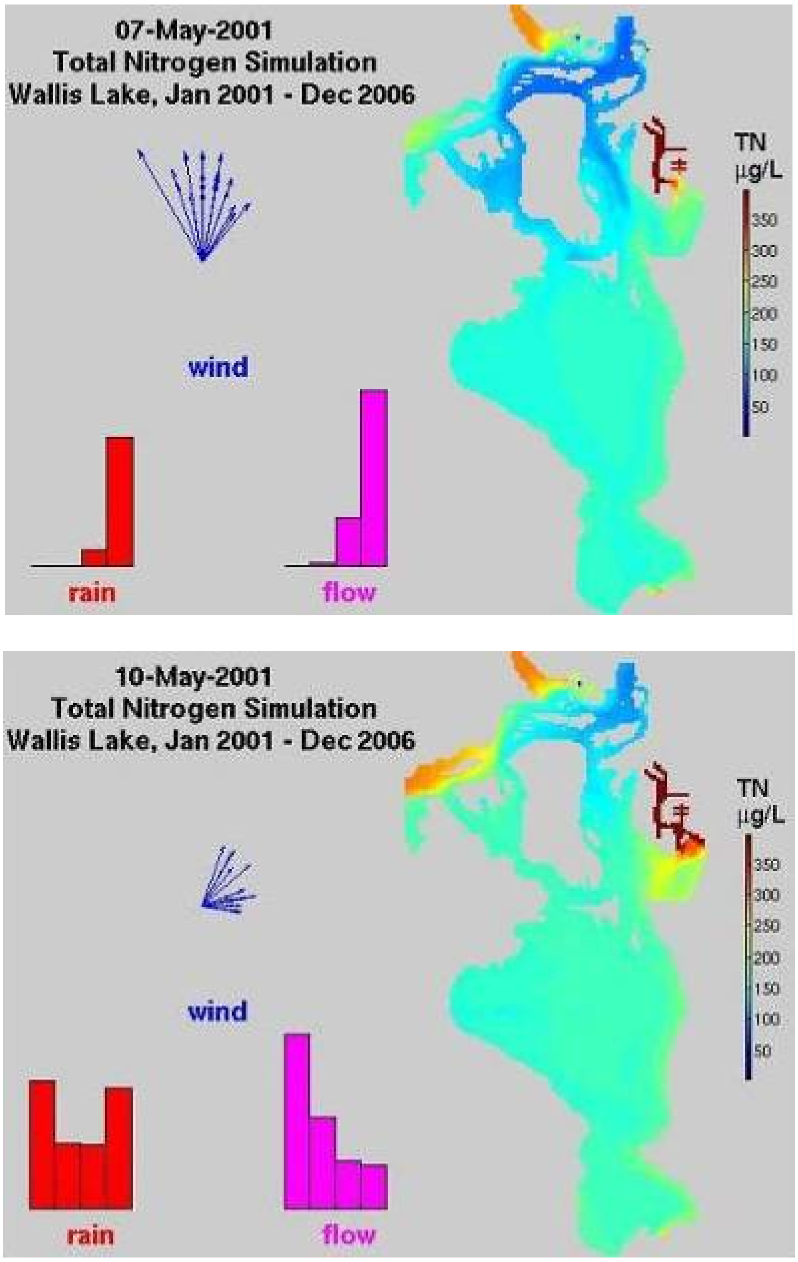
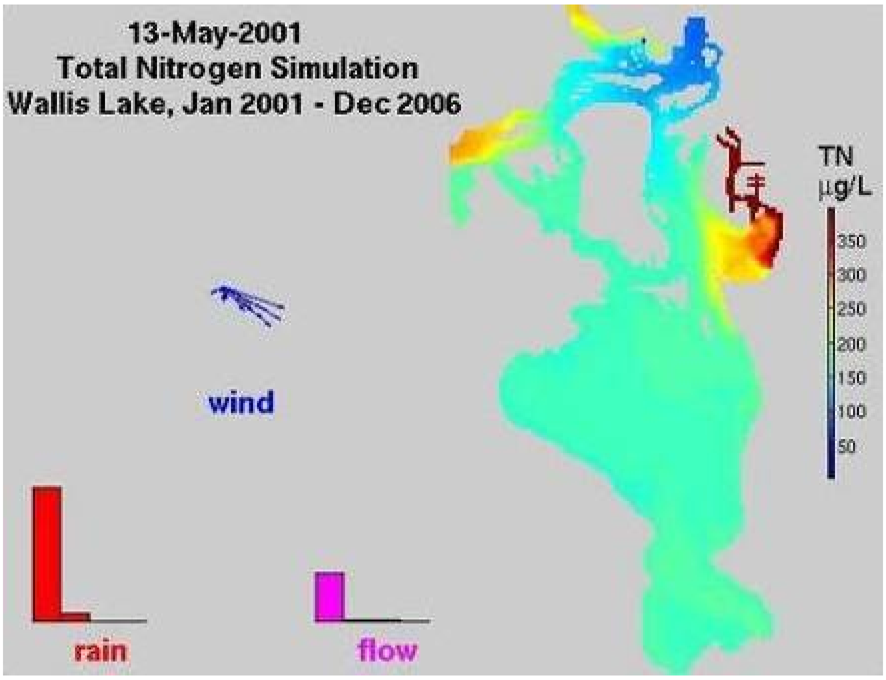


Figure 2.5.13. Simulated TN concentrations in the Wallis Lake system for 7, 10, 13, 15 and 18 May 2001. These predictions cover a period of high rainfall and flow, although by 15 May the event is over and the nitrogen that entered the lake continues to move through the estuary.



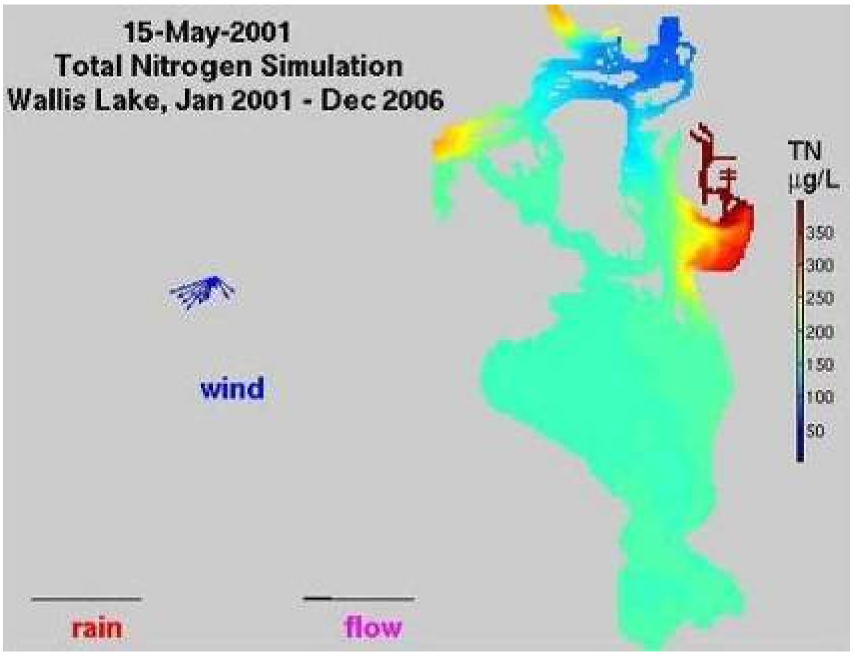


Figure 2.5.13. (cont'd)

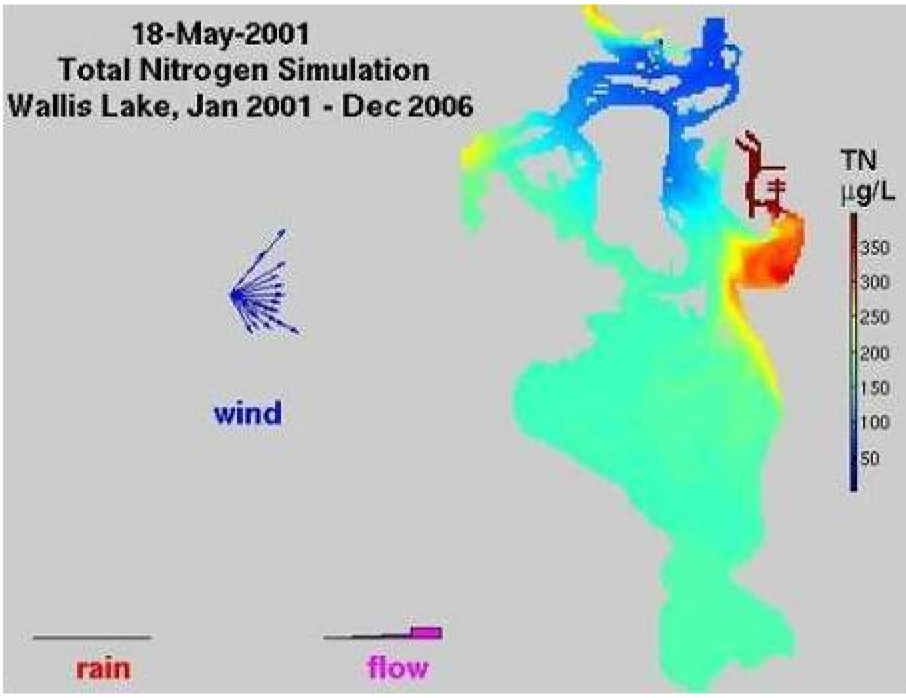


Figure 2.5.13. (cont'd)

2.5.5 Description of in-stream attenuation and remobilisation processes

There are few studies of in-stream nutrient attenuation and remobilisation processes in Australia. A description of in-stream nutrient attenuation and remobilisation processes, specific to the Great Lakes area, cannot be made without targeted experiments (e.g. nutrient uptake) and monitoring (e.g. discharge effects). This work was beyond the time and resources allocated for the CCI catchment and estuary modelling projects, although it has been recognised as a priority area for future research (Appendix 7).

2.5.6 Catchment loads and pollutant generation

Nutrient and/or sediment inputs to the hydrodynamic model come from sub-catchment inputs to the lakes, rainfall and exchange with the ocean. Estimates of the input on nitrogen from rainfall and the ocean were made from available data, and were accounted for in the estuary modelling.

As part of the CCI, models of nutrient and sediment export from rural and urban lands have been developed for the Wallis Lake catchment area. The models allow the current loads of pollutants (average annual) to be estimated for each of the sub-catchments, as well as the projected loads under a range of land use and management scenarios. A description of the seasonality of loads and the implications of this for the Plan are given in Appendix 12.

To facilitate interpretation of this plan, the catchment exports discussed in this section are grouped into the seven regions shown in Figure 2.4.1 (Section 2.4). The areas and current loads of sediment and nutrients being generated in each sub-catchment group are given in Table 2.5.8.

Table 2.5.8. Area and pollutant exports from Wallis Lake sub-catchment groups. The table shows absolute values as well as the percentage contribution of the sub-catchment to the catchment total.

Sub-catchment	Area		TN		TP		TSS	
	ha	%	kg	%	kg	%	tonnes	%
Wallamba River	44,736	38	80,339	53	7,642	59	28,325	70
Wang Wauk River	21,029	18	25,802	17	1,388	11	4,603	11
Coolongolook River	16,975	14	15,392	10	801	6	2,331	6
Wallingat River	16,359	14	11,106	7	454	3	964	2
Lower River Estuaries	10,335	9	7,044	5	1,049	8	1,503	4
Wallis Lake – southern and western sub-catchments	5,176	4	4,912	3	404	3	689	2
Wallis Lake – Forster sub-catchments	2,975	3	7,095	5	1,263	10	1,818	5
Catchment total	117,585		151,690		13,001		40,233	

This table shows that while the Wallamba River sub-catchments constitute nearly 40% of the total catchment area, they contribute half of the total catchment nitrogen exports (53%), and a higher percentage of phosphorus (59%) and sediment exports (70%). The next largest contributors are the Wang Wauk River and Coolongolook River sub-catchments. The Wallingat River sub-catchment is of a similar size to the Coolongolook River sub-catchment yet contributes much less pollutants than the Coolongolook River sub-catchment: 30% less TN, half the TP and two-thirds less TSS. The Forster sub-catchment contributes a relatively large proportion of pollutants given the area (3%), particularly TP (10%).

The relative contribution of different land use types and sources of pollutants compared to the area that take in the whole Wallis Lake catchment is shown in Figure 2.5.14. A land use can be considered to be a potential contributor to a pollutant problem if it ranks highly both in terms of absolute contribution to the catchment pollutants as well as in terms of its contribution per unit area. This allows us to distinguish between land uses that rank highly in terms of their overall contribution merely because they dominate the land use of the catchment rather than because they have elevated pollutant loads.

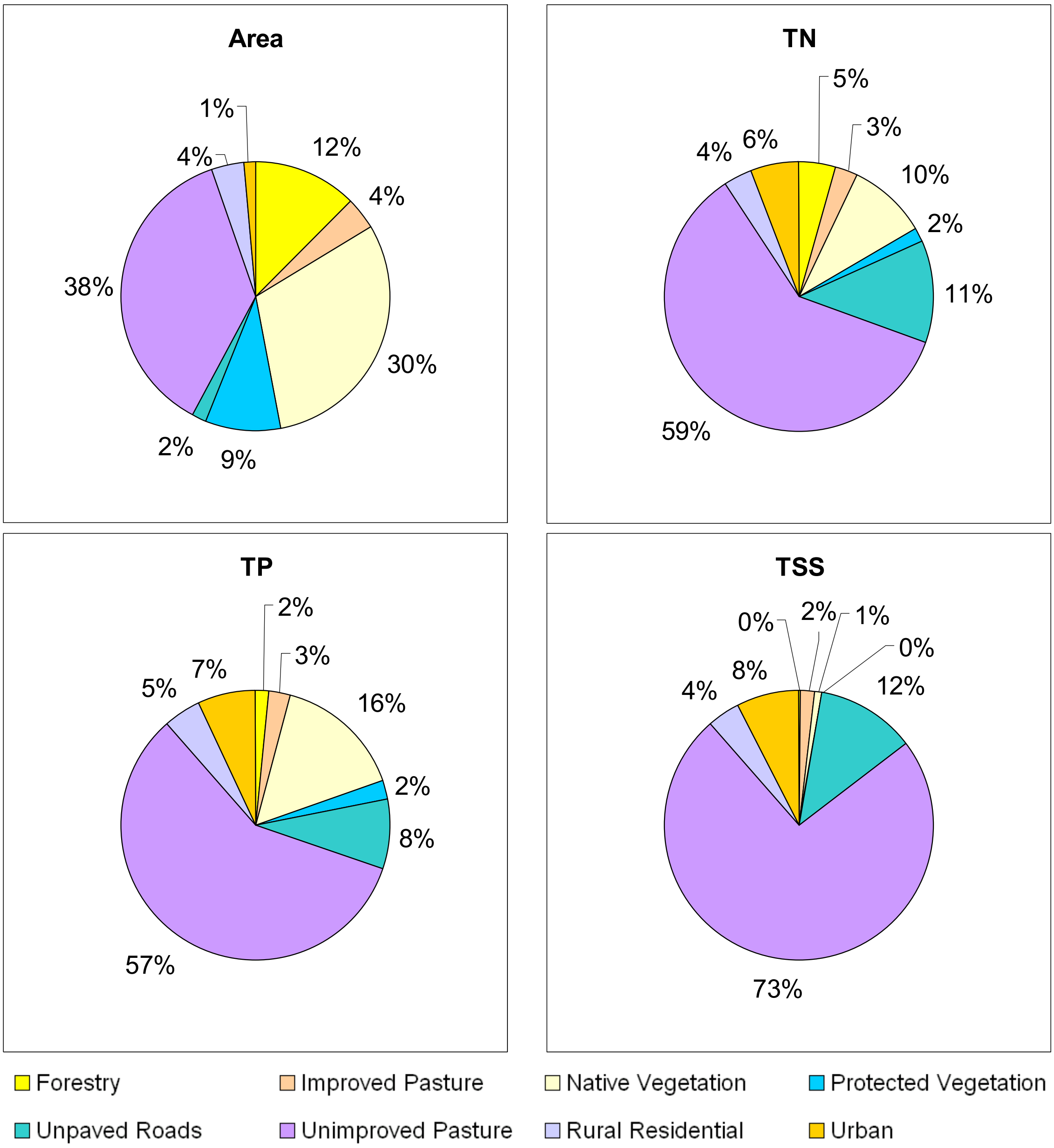


Figure 2.5.14. Relative contribution of land use activities to pollutants and area in the whole Wallis Lake catchment. For reference, these sub-catchments are in dark grey on the map. The relative contribution of different land use activities to the loads in each sub-catchment, as well as the seven sub-catchment groups, is discussed in Appendix 6. Please see Section 2.4 for a description of each land use class used in the figure.

Across the catchment, unimproved pasture is consistently a large contributor to sub-catchment exports of TN and, to a lesser degree, TP and TSS. This land use covers a major area of the catchment (~40%) and has generation rates that are generally exceeded only by unpaved roads, rural residential and urban residential land. In the more urbanised sub-catchments – the Wallis Lake sub-catchments – loads are dominated by rural and urban residential land as well as unpaved roads.

Unpaved roads do not have a large areal extent, yet contribute large amounts of pollutants to the total budget, reflecting the high generation rates assigned to this land use type in the CCI model. These generation rates were consistent with the literature for south-east Australia.

Given their areal extent, the different forest types contribute significant volumes of nutrients in many sub-catchment groups. However, generation rates obtained from the CCI modelling project for TSS are very low from forest cover, and so forests do not contribute much sediment to sub-catchment load totals, despite their area as shown by their low ranking when considering pollutants per unit area.

A discussion of the contribution of different land use activities to the loads in each sub-catchment is given in Appendix 6.

2.5.7 Summary

This section described the current condition of the Wallis Lake system including the condition of the lakes as well as current catchment loads. It also summarised the ecological condition targets that have been defined as part of the WQIP process for Wallis Lake. This has highlighted both the near-pristine condition of parts of the system, those zones that exhibit features of degraded systems as well as the threats facing the different zones in the Wallis system. Overall the following statements can be made about the Wallis system:

- The system operates as two largely non-interacting water bodies: the main part of the lake, and the rivers and entrance channels.
- Pollutants from the Wallamba, Coolongolook, Wang Wauk and Wallingat River sub-catchments are transported by the rivers into the Lower Estuary, and are flushed with the ocean or stay in the main channel to the north of Wallis Island.
- Wallis Lake is influenced primarily by its small perimeter catchment, and any pollutants that enter the lake stays in the zone. Pollutants from the urban catchments of Forster enter the Pipers Bay zone and can influence the main body of the lake.
- Upper and middle river estuaries naturally have higher turbidity and chlorophyll-a concentrations than the lower river estuaries.
- Upper Estuary – The Upper Wallamba River catchments have been significantly altered by human activities. This has resulted in elevated nutrient and sediment inputs in the Upper Estuary of the river, resulting in an ecological condition that is *Slightly to moderately disturbed*. The degree of impact is higher in the middle estuary of the river.
- Middle Estuary – The Wallamba, Coolongolook and Wang Wauk River catchments have been significantly altered by human activities. This has resulted in elevated nutrient and sediment inputs in the Middle Estuary of the rivers. The Wallamba and

Coolongolook / Wang Wauk middle estuaries both have an ecological condition that is *Slightly to moderately disturbed*, although the degree of impact is higher in the Wallamba River middle estuary.

- Lower Estuary – This zone is comprised of the lower reaches of the Wallamba, Wang Wauk and Coolongolook River estuaries, the lake entrance, and the eastern and western channels. Most aquaculture and lake-based recreation in the Wallis system occurs in this zone. Despite receiving much of the catchment input of pollutants from the four major rivers, the zone is well flushed and is in high conservation condition
- Pipers Bay – This zone is the receiving waters for the medium-density urban and light industrial developments on the eastern side of the Wallis Lake, and includes the majority of the Forster urban area. The zone, particularly Pipers Creek, represents a significantly degraded ecosystem falling into the bottom end of the range for a moderately disturbed ecosystem. Further degradation of this zone has potential implications for Wallis Lake.
- Wallis Lake – The southern end of the Wallis Lake zone is currently in a *High conservation value* or near-pristine state. It supports a wide variety of seagrass, healthy algae, brackish water plant (macrophyte) and sponge communities that are dependent on clear, clean water with very low nutrient loads. These sponge communities are, to the knowledge of DECC, unique and endemic to Wallis lake. Localised issues occur in the Coomba Bay where a large gully contributed a large volume of sediment into the waters of the bay and killed seagrass communities through burial as well as continual long-term turbidity. Wallis Lake is susceptible to any actions in the perimeter catchment that elevate nutrient and catchment exports into the lake. It can also be impacted by pollutants that move south from Pipers Bay during large flow events. Future urban development in the Wallis Lake catchment may occur in Forster and also the south-western sub-catchments that drain into Wallis Lake. Given the much higher loads per unit area contributed by urban areas than by other land uses, increases in urban area that do not have effective management controls built in are likely to lead to substantial deterioration of Wallis Lake – an area that has been identified as being near-pristine and of high ecological value – and may push this area towards a modified condition.

2.6 Wallis Lake – Setting targets for water quality management

2.6.1 Using community values to help set targets

In accordance with the *National Water Quality Management Strategy, Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) the following process shown in Figure 2.6.1 was utilised to develop water quality targets for Wallis, Smiths and Myall lakes.

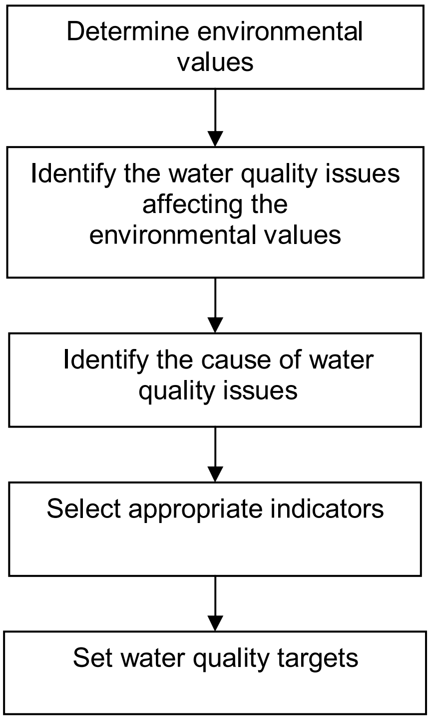


Figure 2.6.1. Process for developing water quality targets for Wallis, Smiths and Myall lakes (Source: Adapted from ANZECC & ARMCANZ 2000).

The first step in the process of identifying the environmental values, water quality issues and water quality targets for the local waterways involved checking that the existing values that had been set for the lakes by the NSW government in 1997 were still relevant. These environmental values were agreed by the community and endorsed by the State Government of NSW.

Information on the existing environmental values for Wallis Lakes (which was then divided into sub-catchment areas) and the intended process of reviewing these values with the Advisory Committee and community can be found in *Environmental Values Background Report* (Great Lakes Council 2007a).

A workshop was held with the Advisory Committee to review the existing environmental values and to make changes or additions. The results of this workshop are summarised in 'Report on environmental values by the Coastal Catchments Initiative Advisory Committee[DG40]' (Great Lakes Council 2007b).

After trialling a similar workshop (to that held with the Advisory Committee) with the Wallis Lake Estuary Management Committee, it was decided to use a simpler and more accessible method for reviewing the environmental values with the community. Thus, a 'Recall Emotion Meaning Action' method was utilised in community workshops to ascertain how community groups value and use their waterways. This method and the process used at workshops – as well as the steps taken to involve industry groups and the community in reviewing the environmental values – is described in the Engagement Strategy and summarised in the Engagement Report (Appendix 1).

The activities, uses and important aspects of the waterways suggested by the participants were combined with the values set by the Advisory Committee. The resulting environmental values for Wallis Lake are presented in Table 2.6.2.

Table 2.6.2. Environmental values and uses given by stakeholders and the community for Wallis Lake Estuary.

Aquatic eco-systems	Industry – Consump-tion	Industry – Stock	Primary recreation	Secondary recreation	Visual apprec.	Ground water	Home-stead	Industrial	Cultural	Group
✓	✓		✓	✓	✓					Existing Environmental Values (EPA 1999)
✓	✓		✓	✓	✓	✓	✓	✓	✓	Advisory Committee
✓	✓		✓	✓	✓			✓		Oyster Growers Wallis
✓	✓		✓	✓	✓	✓		✓	✓	EMC
✓	✓		✓	✓	✓				✓	Great Lakes Coastal Land mgrs network
✓	✓		✓	✓	✓				✓	Hunter – Central Rivers Aboriginal Cultural & Environmental Network (ACEN) – CMA Partnership Committee
✓	✓	*	✓	✓	✓	✓			✓	Karuah / Great Lakes Landcare, Nabiac Landcare and Dyers Crossing Landcare
✓	✓		✓	✓	✓		✓			Forster U3A
✓	✓		✓	✓	✓	✓	✓	✓	✓	**Summary of current values**

Note: Some community members said they use waterways for stock access and watering, but these comments specifically referred to areas such as Firefly creek and reaches of the Wallamba River outside of the estuary receiving waters, where targets are being developed for.[DG41]

As shown in Table 2.6.2, aquatic ecosystems were valued by the community for Wallis Lake. The *Framework for marine and estuarine water quality protection: A reference document* states that "where more than one environmental value applies to the same receiving waters, the environmental values need to be prioritised and the most stringent guideline should be used (ANZECC & ARMCANZ 2000). The most stringent guideline will in many cases also protect the other environmental values. In most cases, the water quality requirements for protection of *aquatic ecosystems* are the most stringent of all the environmental values." (Department of Environment and Heritage 2002, p. 13[DG42]).

For this reason, water quality targets were developed to protect aquatic ecosystems and, by default, to protect the other values. The ANZECC Guidelines suggest that locally relevant environmental indicators are more useful than 'single number' guidelines that are applied universally. To determine locally relevant indicators to measure the health of aquatic ecosystems, scientific assessments of the local biological community were undertaken. These assessments ascertained whether biological integrity is being maintained and determined local trigger values for the maintenance of this integrity. The locally relevant indicators determined were chlorophyll-a concentration, seagrass abundance and water clarity.

The local trigger values established were based on the ANZECC aquatic ecosystem 'levels of protection'. Aquatic ecosystems can be protected to three different levels, depending on the current ecological condition of the ecosystems:

1. High conservation value
2. Slightly to moderately disturbed
3. Highly disturbed.

Figures 2.5.5 and 2.5.6 show the current ecological condition of southern Wallis Lake, Coomba Bay, the entrance and channels, Wang Wauk and Coolongolook, Wallamba, and Pipers Creek relative to these categories. Details on these trigger values and how they were determined are outlined in Appendix 10.

Results from scientific research were used to determine the 'current' condition for each lake and potential target values for each indicator. Based on this research and the expectations of the community, the Advisory Committee selected an appropriate level of protection to aspire to and established *draft* Ecological Condition Targets for the indicators.

Possible management scenarios were tested with the DSS to ensure that targets were realistic and technically feasible. The agreed targets are documented in Section 2.6.2.

As mentioned previously, protecting aquatic ecosystems also protects many of the other values the community identified for Wallis, Smiths and Myall lakes. For example, water clarity is important for seagrass growth and also to protect the recreational benefits of visual appreciation, primary and secondary recreation, and to protect cultural values associated with natural areas.

The WQIP recognises that the chosen targets are not, alone, adequate to protect the values of human consumption (e.g. oysters). For this reason the WQIP reviews the systems that are in place to monitor and aim for targets in relation to faecal coliforms. An outline of these management systems and pollution control systems is provided in Sections 3.5 and 3.7. The WQIP also makes a number of recommendations relating to the need to maintain and improve water quality management with respect to protection of human consumption values (Section 3.7).

2.6.2 Ecological Condition Targets and catchment loads

Separate Ecological Condition Targets, and feasible chlorophyll-a and catchment load reductions, have been identified for different sections of Wallis Lake based on hydrodynamic modelling described in Section 2.5. These include:

- Wallis Lake (southern Wallis Lake and Coomba Bay)
- Pipers Bay
- Lower River Estuaries, which are comprised of the Lower Wallamba, Coolongolook and Wang Wauk River estuaries, the lake entrance, and the eastern and western channels (the Lower Estuary)
- Middle Estuaries of Wallamba, Coolongolook and Wang Wauk rivers (the Middle Estuary)
- Upper Estuary of the Wallamba River (the Upper Estuary).

Sections 2.6.2.1 to 2.6.2.5 describe the community values and aspirations for setting Ecological Condition Targets for each of these areas in Wallis Lake. Section 2.6.2.6 describes how Ecological Condition Targets were derived based on the percentage change in chlorophyll-a concentrations to reach an ecological condition of *High conservation value.* This section then considers these targets in comparison to the feasible percentage reductions in chlorophyll-a concentrations modelled with implementation of the actions in this Plan (Table 2.6.1). Section 2.6.2.7 presents feasible catchment load reductions from the Wallis Lake sub-catchments that together could meet the feasible reductions in chlorophyll-a concentrations over the seven years of the Plan.

Feasible reductions presented in Table 2.6.2 reflect the reduction in chlorophyll-a concentrations modelled in the DSS. Implementation of the remediation actions is described in Section 2.7.1. Underlying this modelled information is an expert judgement on the degree and timing of uptake of different measures, the resources required for each program, and the effectiveness of actions (see Appendix 14 for details). These predictions provide an estimate of the change that will be experienced in seven years should the Plan be implemented in its entirety.

The results in this section demonstrate the importance of protecting the lake against further deterioration. Remediation is very costly, time-consuming and is often limited in what can be achieved. Protection of areas of existing high value, such as the southern end of Wallis Lake, is very important because the costs and limitations of remediation are such that any damage to these areas is likely to be irreversible. Likewise, further deterioration of modified areas of the lake is unacceptable to the community and is likely to be very difficult to reverse.

Population pressures and land use changes in the Wallis Lake catchment mean that some level of protection and remediation is required simply to maintain the current level of water quality without any expectation of improvement, even in areas that are currently damaged.

There is a degree of natural variability in relation to catchment loads and estuary concentrations of pollutants. These targets relate to the average annual load or mean concentration calculated over a long period. The way in which the targets have been formulated takes into account some of the natural variation expected in these environments (Appendix 10).

The targets are intended as triggers for action. In this context, if they are exceeded occasionally it is not of significant concern. However, if there is a sustained trend of exceedence then there would be a need to undertake further investigation and action. There may also be the potential to establish short-term ecological condition targets to be measured subsequent to rainfall events. This approach requires further investigation and consideration for future monitoring programs (Appendix 10).

Not all of the Ecological Condition Targets proposed in this section are feasible at present, given current technology and funds available. However, they do provide an aspirational goal towards which we are moving using the actions proposed in the Plan.

2.6.2.1 Wallis Lake Ecological Condition Targets

This section describes the targets and predicted levels of feasible change for Wallis Lake (Figure 2.5.1). DECC Waters and Catchment Science note that inappropriate land use and management has the potential to destroy the unique ecological communities in the southern bays of Wallis Lake through increased inputs of sediments and nutrients. A high level of protection for the Wallis Lake catchment is essential to preserve this unique biodiversity.

The southern end of the lake should be managed to maintain its current near-pristine condition. From discussions with the community and the Advisory Committee, when setting environmental values (Section 2.6.1) it is evident that there is zero tolerance within the community for deterioration in the condition of the Wallis Lake, particularly in the southern bays. The community and Advisory Committee indicated that they would prefer as much improvement in lake condition as is financially possible, even where this does not get all areas of the lake back to *High conservation value* condition or where the lake is currently in a very good condition. This improvement was seen as necessary to provide a buffer against possible unforeseen threats and future sources of pollution that may not have been accounted for in the modelling.

Southern Wallis Lake Ecological Condition Target: No deterioration. Improvements to establish buffer.

If conditions are allowed to deteriorate, in particular if there are increased loads of sediments and nutrients entering these bays, all the symptoms of poor health that have been described for Coomba and Pipers Bay (high chlorophyll levels, turbid water, poor light penetration, loss of bottom-dwelling plants and seagrasses) will begin to occur in the southern end of Wallis Lake, and a locally unique ecosystem will be lost. Efforts should concentrate on protection actions (e.g. buffers) to reduce the risk to the lake from extreme or localised events.

The consequences of a single erosion gully close to the lake on conditions in the Coomba Bay area emphasises the scale and risk that can stem from localised catchment conditions. Even seemingly minor failings in catchment management can have large, immediate and ongoing effects on the water quality and ecology of the lakes. The community expressed serious concern about the potential for events such as this to occur again in the lake, and indicated a strong preference for preventative actions to be undertaken to reduce the risk of such occurrences.

Coomba Bay should be managed to improve its current condition to more closely resemble *High conservation value* conditions. This means that chlorophyll-a levels should be reduced. A long-term goal has been established to reduce chlorophyll-a levels back to *High conservation value* levels (i.e. 41% reduction).

Coomba Bay Ecological Condition Target: 41% reduction in chlorophyll-a concentration levels.

Predictions of feasible change were estimated for seven years [DG43]based on an assessment of physical and financial feasibility of changes in management practices. These assessments indicate that with current technology, a 2.7% reduction in chlorophyll-a is feasible.

2.6.2.2 Pipers Bay Ecological Condition Target

The Pipers Bay zone (Figure 2.5.1) should be managed to improve its current modified condition to more closely resemble *High conservation value* conditions. This means that chlorophyll-a levels should be reduced. This will also provide a measure of protection to Wallis Lake, given that in high-flow periods, pollutants flow from Pipers Bay towards the southern bays of Wallis Lake. A long-term goal has been established to reduce chlorophyll-a levels back to *High conservation value* levels (i.e. 50% reduction). Estimates of feasible changes were created for seven[DG44] years based on an assessment of physical and financial feasibility of changes in management practices.

Pipers Bay Ecological Condition Target: 50% reduction in chlorophyll-a concentration levels.

Feasible changes have been estimated at 13% and 14% reductions in chlorophyll-a, respectively. These changes are considered to be significant, and should result in a visible change in water quality and clarity.

2.6.2.3 Lower Estuary Ecological Condition Targets

Like the southern bays of Wallis Lake, the Lower Estuary (Figure 2.5.1) is in generally good condition and considered to be *High conservation value* status, despite the zone receiving much of the catchment input of pollutants from the four major rivers. This is because it is well flushed compared with other parts of the system.

The Lower Estuary is where most of the aquaculture and lake-based recreation occurs. The ecological condition of the lower estuary must not deteriorate further and should improve. From discussions with the community and Advisory Committee when setting environmental values (Section 2.6.1), it was indicated that there is no tolerance for any deterioration in the quality of this area. Also, they have a preference for actions to be undertaken to provide a buffer against possible future increases in pollutants, including from one-off events. The target is therefore to maintain and, where possible, improve on current conditions.

Lower Estuary Ecological Condition Target: No deterioration. Improvements to establish buffer.

2.6.2.4 Upper Estuary Ecological Condition Target

The upper reaches of the Wallamba River estuary (Figure 2.5.1) should be managed to improve its current modified condition to more closely resemble *High conservation value* conditions. This means that chlorophyll-a levels should be reduced. A long-term goal has been established to reduce chlorophyll-a levels back to *High conservation value* levels (i.e. 30% reduction).

Upper Estuary Ecological Condition Target: 30% reduction in chlorophyll-a concentration levels.

Estimates of the feasible level of change after seven[DG45] years, based on an assessment of physical and financial feasibility of changes in management practices, were made at a 2.7% reduction in chlorophyll-a levels.

2.6.2.5 Middle Estuary Ecological Condition Target

The mid-reaches of the Wallamba, Coolongolook and Wang Wauk River estuaries (Figure 2.5.1) should be managed to improve their current modified condition to more closely resemble *High conservation value* conditions. This means that chlorophyll-a levels should be reduced.

Wallamba River Middle Estuary Ecological Condition Target: 21% reduction in chlorophyll-a concentration levels.

A long-term goal has been established to reduce chlorophyll-a levels back to *High conservation value* levels (i.e. 21% reduction). Estimates of feasible change after seven[DG46] years based on an assessment of physical and financial feasibility of changes in management practices were made at a 2.7% reduction in chlorophyll-a, respectively.

Coolongolook / Wang Wauk rivers Middle Estuary Ecological Condition Target: 14% reduction in chlorophyll-a concentration levels. A long term goal has been established to reduce chlorophyll-a levels back to *High conservation value* levels (i.e. 14% reduction). Estimates of feasible change after seven years, based on an assessment of physical and financial feasibility of changes in management practices, were made at a 2.7% reduction in chlorophyll-a.

2.6.2.6 Feasible reductions in chlorophyll-a concentrations

Ecological Condition Targets for Wallis Lake and river estuaries are listed in Table 2.6.1. These targets are based on assumptions derived from discussions with community members and the CCI Advisory Committee, as well as modelling and analysis. Ecological Condition Targets were defined for each estuary zone by comparing monitoring data to chlorophyll-a concentrations indicative of *High conservation value*. Targets represent the percentage change required in chlorophyll-a concentrations to reach *High conservation value* (see Section 2.5.3). The monitoring data used to calculate the Ecological Condition Targets are assumed to adequately represent the average condition of the Wallis Lake water bodies.

Feasible reductions presented in Table 2.6.2 reflect the modelled reduction in chlorophyll-a concentrations achieved by implementing the modelled remediation actions described in Section 2.7.1. Underlying this information is an expert judgement on the degree and timing of uptake of different measures, the resources required for each program, and the effectiveness of actions. The Plan has been developed to guide water quality improvement actions for the next seven years. The Plan and associated modelling will be reviewed after six years and, allowing adequate time for this to occur, a revised Plan will be developed by Year 7.

Table 2.6.1. Ecological condition targets using chlorophyll-a concentrations, and estimates of feasible change for Wallis Lake estuary zones.

Wallis Lake water bodies	Ecological Condition Target	Feasible reduction in chlorophyll-a concentration (%)
Upper Estuary (Wallamba)	30% reduction in chlorophyll-a concentration	2.7
Lower Estuary	No deterioration, improvements to establish buffer	2.7
Pipers Bay	50% reduction in chlorophyll-a concentration	13.0
Middle Estuary (Wallamba) [a]	21% reduction in chlorophyll-a concentration	2.7
Middle Estuary (Coolongolook / Wang Wauk)	14% reduction in chlorophyll-a concentration	2.7
Wallis Lake (southern bays)	No deterioration, improvements to establish buffer	2.7
Wallis Lake (Coomba Bay)	41% reduction in chlorophyll-a concentration	2.7

a: Achieving the targets in the Upper Estuary should mean that targets for the Middle Estuary will be met.

2.6.2.7 Catchment loads

These Ecological Condition Targets imply reductions in catchment loads to Wallis Lake. Decision Support Systems, such as that used to develop this Plan, have been demonstrated to be accurate in terms of the direction and magnitude of impacts. However, they are not assured as predictive models in the sense of accurately predicting precise future catchment export loads or resultant estuarine concentrations. In order to limit the effect of any such inaccuracies and produce the most accurate predictions of potential changes in loads and concentrations under the plan, the magnitude and direction of change from the modelling has been used in conjunction with measured data (rather than modelled data) wherever possible to predict concentrations.

Feasible catchment load reductions for Wallis Lake are given in Table 2.6.2 (see Figure 2.4.1 for location of sub-catchments). These predicted load reductions correspond to the feasible reductions in chlorophyll-a concentrations presented in Table 2.6.1. The modelled actions are discussed in Section 2.7.1.

As identified in Section 2.5.4, the Wallamba sub-catchments have a large impact on the Upper and Middle Estuary of the Wallamba River estuary, although impacts on the Lower Estuary are partially mitigated by flushing with the ocean. These catchments have limited influence on Pipers Bay and Wallis Lake zones, which are most impacted by the Wallis

Lake perimeter catchment (the southern and western sub-catchments, and Forster sub-catchments of Wallis Lake). Variation in feasible catchment load percentage reductions across sub-catchments is further discussed in Section 2.7.1.2.

Table 2.6.2. Feasible catchment load reductions in Wallis Lake that achieve predicted change in chlorophyll-a concentrations (Table 2.6.1).

Wallis Lake sub-catchments	TN		TP		TSS	
	Current load (kg)	% load reduction	Current load (kg)	% load reduction	Current load (tonnes)	% load reduction
Wallamba River	80,339	7.6	7,642	7.6	28,325	9.6
Wang Wauk River	25,802	7.4	1,388	7.6	4,603	7.7
Coolongolook River	15,392	5.2	801	6.2	2,331	5.4
Wallingat River	11,106	3.0	454	3.0	964	7.0
Lower River Estuaries	7,044	6.1	1,049	5.3	1,503	30.1
Wallis Lake – southern and western sub-catchments	4,912	4.8	404	11.1	689	8.1
Wallis Lake – Forster sub-catchments	7,095	21.8	1,263	23.5	1,818	45.0

Note: Some community members said they use waterways for stock access and watering, but these comments specifically referred to areas such as Firefly creek and reaches of the Wallamba River, which are outside of the area where targets are being set.

2.7 Wallis Lake – Management strategies to achieve Ecological Condition Targets

The DSS developed as part of the Great Lakes CCI was used to conduct an exploratory analysis on the impact of potential rural and urban actions on nutrient and sediment exports into Wallis Lake and, as a consequence, changes in estuary condition. These changes were related to Ecological Condition Targets that were defined for each estuary zone in Section 2.6.

Section 2.7.1 describes the results from the exploratory analysis of potential management actions for the whole catchment area of Wallis Lake. Analysis of costs and feasibility of actions was then undertaken to further refine the strategies recommended in the Plan. These recommended strategies are summarised in Section 2.7.2. A benefit-cost analysis of the Wallis Lake Plan is summarised in Section 2.7.3 and detailed in Appendix 15.

2.7.1 Exploratory analysis of potential remediation and protection actions

The Wallis Lake management [pt47]strategies contain actions targeted to two specific purposes:

- to *remediate* existing areas of high pollutant loads, and thus provide reductions in catchment loads and estuary concentrations
- to *protect* areas of high conservation status that are currently providing substantial water quality benefits to the rivers and lake systems.

Protection actions are assumed in the Plan to not improve water quality, but rather protect against further decline. The old adage – that it is cheaper to protect what is left than to replace it once it is gone – has been demonstrated to be true in this project, and further emphasises the importance of protection actions as a key component of the plan. Given the costs of remediation actions and the limits to their effectiveness at improving water quality at the catchment scale, it is essential that a range of protection actions – including protecting existing buffers and vegetation, and placing limits on inappropriate developments – are undertaken to ensure that water quality does not deteriorate further in the lake. In particular, the unique values of southern Wallis Lake are at risk if significant protection is not undertaken. Damage to Coomba Bay from a single dam failure illustrates the magnitude of possible events caused by a lack of protection. However, it is often difficult to fully value the benefits of protection, as it can be difficult to estimate the damage that would be done without these actions taking place. By contrast, the effects (and benefits) of remediation actions are much easier to estimate.

Section 2.7.1.1 introduces the proposed remediation and protection actions for Wallis Lake[pt48]. The DSS modelled the proposed remediation actions, and their impact on catchment exports and estuary condition, over a seven-year period. Many of the actions identified in the Plan are designed to be implemented over more than seven years (e.g. Wetland protection and Water Sensitive Design of Greenfield sites). In these cases, the impact at seven years assumes that implementation of these actions is in progress, rather than completed. For the purposes of the benefit-cost analysis (Appendix 15), the costs and benefits of these programs were estimated over a 30-year period. Details on the programs and associated costs are outlined in Appendix 14.

Sections 2.7.1.2 and 2.7.1.3 examine the modelled impact of remediation actions on catchment exports and subsequent estuary condition. Although the effect of individual protection actions could not be modelled in the DSS, an estimate of the impact of *not* implementing *all* protection actions recommended in this Plan is provided in Figures 2.7.1 and 2.7.2. This section discusses the results of two alternative futures – full implementation of the WQIP remediation and protection actions, or no implementation of protection actions and only the existing remediation actions from current programs.

Section 2.7.1.4 discusses the cumulative costs and cost-effectiveness of the modelled remediation actions.

2.7.1.1 Description of scenarios tested

Remediation actions modelled using the DSS for rural areas of Wallis Lake catchment are shown in Tables 2.7.1 and 2.7.2. Remediation actions can be:

- *existing programs*: works currently being implemented across the catchment (e.g. sustainable grazing programs focussed on achieving groundcover management actions). This Plan models existing programs as fully implemented in both the 'No Plan' and 'WQIP' alternative futures
- *expanded programs*: actions modelled and / or recommended in this Plan that will further reduce catchment export loads into Wallis Lake beyond that in the existing programs.

In order to estimate the benefits of these possible remediation actions, several scenarios were modelled and compared using the DSS. These scenarios essentially compared implementation of these actions with the effects of current programs and the current situation.

Detailed descriptions of scenarios of existing and expanded remediation actions are provided in Appendix 14.

Table 2.7.1. Remediation actions modelled for rural areas of the Wallis Lake Catchment.

Actions	Program description
Groundcover management	Groundcover management refers to a sustainable grazing program for landholders, and is focussed on improving groundcover management on pasture lands. It involves field days and formal workshops with experts, developing information and training material on stocking rates, formal training courses such as Prograze, a dung beetle release program, and a program of on-ground works that will assist landholders to better manage their groundcover levels (including off-stream watering, solar pumps and fencing).
Nutrient management (Fertiliser)	Nutrient management is a component of a sustainable grazing program focussed on the appropriate application and storage of nutrients. It involves working with landholders to trial different types of fertilisers, formal training courses such as LANDSCAN, subsidising and promoting the use of soil tests, and providing assistance with interpretation of the tests so that the results can be integrated into the whole-farm plan. This program also supports a dung beetle program – however, it is costed in the groundcover management program. Additional actions related to the management of human and animal effluent including the upgrade of laneways and stock crossings. However, these kinds of actions were not able to be modelled.
Infrastructure (Dam) management	Infrastructure management includes the refurbishment of dams that are a water quality risk, as well as decommissioning those that are not functioning and potentially acting as a source of nutrients and sediments to the system. It involves working with landholders to repair dam structural problems, controlling stock access to the dam or providing an alternative stock water supply from the dam. It also involves landholder training, as well as training and accreditation of contractors. Additional actions related to the management of infrastructure have also been identified, including road and laneway management. However, these kinds of actions were not able to be modelled.
Riparian remediation	Riparian remediation programs include the rehabilitation of sites with active stream bank erosion. These sites are based on identified locations in existing plans, such as rivercare plans. This program includes significant in-stream repair work for bank stabilisation and fencing off the creek in the identified areas.
Unpaved road remediation	This aims to identify and seal unpaved roads in priority areas, such as creek crossings. This would also include installing and maintaining best practice sediment and erosion control features, such as mitre drains to divert road runoff into grassed areas.

Remediation actions modelled for urban areas of the Wallis Lake catchment are outlined in Table 2.7.2. Detailed descriptions of scenarios are provided in Appendix 14.

Table 2.7.2. Remediation actions modelled for urban areas in the Wallis Lake catchment.

Actions	Program description
Urban Mitigation (Water Sensitive Urban Design)	Urban mitigation includes the retrofitting of rainwater tanks supported through a program of rebates (assuming a 15% uptake of the rebate in the Pipers Creek, Pipers Bay and Big Island sub-catchments). It is recommended that the tanks are plumbed into the home to maximise the water quality benefits. It also involves an extensive program of urban retrofitting where Water Sensitive Urban Design (WSUD) systems, such as biofiltration (including trenches, raingardens and biopods), are built into the existing urban landscape to filter the urban stormwater. This program also involves education and capacity-building on maintenance and construction of WSUD devices, adoption of a development control plan that specifies best practice water-sensitive urban design, and associated staff training and capacity-building. It also includes investigating options for a nutrient offset scheme for the Pipers Creek / Pipers Bay area.
Water Sensitive Redevelopment	Water Sensitive Redevelopment involves the implementation of a development control plan that specifies best practice water-sensitive urban design (including biofiltration and rainwater tanks) on all redevelopments. The program of redevelopment has been estimated based on existing redevelopment rates.

Protection actions considered for the Wallis Lake catchment are shown in Table 2.7.3. The individual impacts of not implementing these actions could not be modelled with the DSS. It is assumed that these actions all contribute to the avoidance of future deterioration. In order to estimate the effects of these ‘protection’ activities scenarios under the ‘No Plan’ situation, an estimate was made of the deterioration that would occur without recommended levels of protection being undertaken. It is recommended that these assumptions are reviewed as part of the seven-year review of the Plan and new estimates are made of the scale of protection necessary to avoid deterioration in water quality.

Table 2.7.3. Protection actions considered for the Wallis Lake catchment. These actions were not modelled.

Actions	Program description
Wetland protection	Wetland protection involves the acquisition of healthy but threatened wetlands, and undertaking management and / or rehabilitation as required (e.g. fencing off the wetland, establishing property vegetation plans, management plans, reinstating natural hydrology in acid sulfate-affected landscapes). The program also involves assisting landholders to protect natural wetlands, with advice, training and on-ground works to control stock access. More generally, the program involves partnerships with the community, including raising the profile of wetlands and their role in providing environmental services, as well as encouraging participation in management and restoration.

Actions	Program description
Riparian protection	The riparian protection program involves fencing and / or stock exclusion for areas of remnant riparian revegetation, including off-stream watering and some planting where vegetation requires rehabilitation. It also involves establishing property vegetation plans in areas not suitable for fencing (e.g. high slope areas).
Water Sensitive Development of Greenfield sites	Establish and implement LEP / DCP provisions on Greenfield development sites in the Wallis lake catchment to enforce 'no net increase' in pollutants relative to the existing land use (agricultural and forest land use classifications). This program also involves establishing heads of consideration for voluntary planning agreements with developers. [4]
Water Sensitive Urban Design protection	WSUD protection is an education and capacity-building program on water-sensitive urban design and management of urban land. It involves workshops, field days and demonstration sites with stakeholders including the general community, business, students, and [DG49]building and development industries. It involves updating plans, strategies and design guidelines (such as road guidelines), as well as resourcing a general sediment and erosion control audit and training program.[DG50]
Foreshore and riparian management in urban areas	Foreshore and riparian management in urban areas involves improving foreshore areas around Wallis and Smiths lakes through establishing site-specific management plans, education and engagement of residents surrounding foreshore areas to reduce the impact of their behaviours, and increased enforcement of environmental legislation in these areas[pt51]
Best management of unpaved roads	Best management of unpaved roads includes construction of mitre drains to divert road runoff into grassed areas, and sealing and diverting runoff away from streams particularly in the vicinity of creek crossings[DG52]. This program also includes developing and undertaking training and auditing of contractors and council staff specific to road construction to ensure best management practices are applied.
Improved pollution control systems / management systems	Improved management and pollution control systems involves reviewing how water quality management, both within and between organisations, is approached. It focuses on establishing checking and review loops in key areas, such as compliance with conditions of consent, and sediment and erosion control, The program also highlights the need to embed water quality improvement actions in organisational plans to ensure the WQIP is implemented. It highlights the need to review a range of existing systems such as the fee structure for on-site sewage management, and recommends exploring alternative ways to formalise the response to complex pollution cases and strengthen cross-agency relationships and delegation.
Improved management of lake use activities	Improved management of lake use activities involves reviewing stormwater management plans to clarify the outcomes required to protect the environment and oyster growing areas in relation to SEPP 62, and oyster grower monitoring programs to identify synergies with ecological monitoring programs. The program also involves establishing memoranda of understanding with key groups of lake users and investigating other management options, such as closing boat ramps during high-flow events and establishing markers to protect seagrass beds.

4 The modelling examines the operational phase of Greenfield developments, and therefore does not account for construction phase impacts. However, these are likely to be confined to sediment with only minimal impact on nutrients. Sediment impacts are very much dependent on current erosion and sediment control programs being fully implemented within the GLC region. Further analysis on the potential impacts of not implementing the sediment and erosion control policy should be considered.

In this exploratory analysis, two alternative futures are considered:

- No Plan – no implementation of protection actions and only implementation of existing remediation actions
- WQIP – implementation of all protection actions and implementation of expanded remediation actions.

A trajectory of impacts over seven years is used to demonstrate the benefits of implementing protection and expanded remediation actions as part of the WQIP, compared with the current ‘No Plan’ condition as above. Many of the actions identified in the Plan are designed to be implemented over more than seven years (e.g. Wetland protection and Water Sensitive Design of Greenfield sites) – in these cases, the impact at seven years assumes that implementation of these actions is in progress, rather than completed. [pt53]

Table 2.7.4. Scenario trajectories with (WQIP) and without (No Plan) the implementation of the Water Quality Improvement Plan for the Wallis Lake catchment. Existing programs refer to the full implementation of remediation actions planned and commence prior to the development of this Plan. Expanded programs were developed for this Plan to further reduce nutrient and sediment inputs into the Wallis Lakes system, and are remediation actions. Both types of programs were modelled in this Plan. Protection actions were not modelled in this Plan.

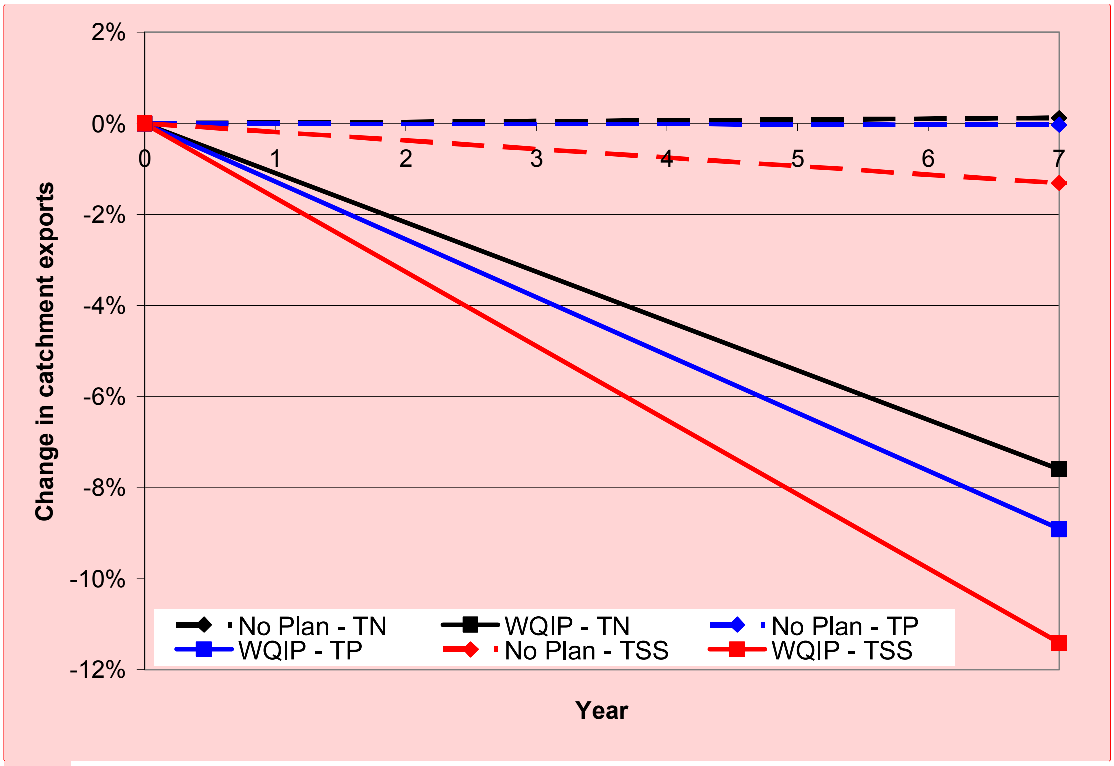
Management action	Year 0	Year 7	
		No Plan	WQIP
Remediation actions			
Nutrient management (Fertiliser)	Existing situation	Existing programs	Expanded programs
Groundcover management	Existing situation	Existing programs	Expanded programs
Infrastructure (Dam) management	Existing situation	Existing programs	Expanded programs
Riparian remediation	Existing level	Existing level	Seven years of works
Unpaved road remediation	Existing situation	No works	Seven years remediation
Urban Mitigation [a] (Water Sensitive Urban Design)	Existing situation	None	Full mitigation
Water Sensitive Redevelopment	Existing situation	Seven years redevelopment (unmitigated)	Seven years redevelopment (mitigated)
Protection actions			
Riparian protection	Existing situation	Loss of healthy riparian veg	No loss of healthy riparian vegetation
Wetland protection	Existing situation	Loss of healthy wetlands	No loss of healthy wetlands
Water Sensitive Development of Greenfield sites	Existing situation	Seven years of development without controls	Seven years of development with controls
Water Sensitive Urban Design protection	Existing situation	Seven years without protection	Seven years with protection
Best management of unpaved roads	Existing situation	Seven years without improved systems	Seven years with improved systems
Improved pollution control systems / management systems	Existing situation	Seven years without improved systems	Seven years with improved systems
Improved management of lake use activities	Existing situation	Seven years without improved systems	Seven years with improved systems
Riparian protection	Existing situation	Loss of healthy riparian vegetation	No loss of healthy riparian vegetation

a: Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

2.7.1.2 Catchment exports

The percentage change in TN, TP and TSS loads for the entire Wallis Lake catchment in the ‘No Plan’ and ‘WQIP’ alternative futures, as defined in Table 2.7.4, is shown in Figure 2.7.1. The ‘No Plan’ scenario incorporates a level of deterioration in the catchment that reflects a worsening of conditions if no protection actions or expanded remediation actions are taken over a seven-year trajectory. This estimate of deterioration is based on an extrapolation of past degradation, given model estimates of 'historic' loads and the rate at which these have increased in the past. Full implementation of the protection actions is assumed to prevent any deterioration in the current condition of the Wallis Lake catchment and estuary.

For TN, this deterioration is not halted by fully implementing existing rural programs. The effectiveness of these existing remediation programs is higher for TP and TSS and, consequently, more TP and TSS is captured than TN by implementing the existing remediation actions. Minor benefits are seen (<2% change in catchment exports). Full implementation of the protection and expanded remediation actions in the WQIP reduces catchment exports from current levels by 7.7% (TN), 9.2% (TP) and 11.6% (TSS).



[DG54]

Figure 2.7.1. Percentage change in Wallis Lake catchment exports of TN, TP and TSS both with (WQIP) and without (No Plan) implementation of the Water Quality Improvement Plan.

Percentage load reductions under the WQIP scenario vary across sub-catchment groups, which largely reflects differences in land use (Table 2.7.5). In the urban sub-catchments of Forster, significant (>20%) reductions in TN and TP are predicted, along with large reductions in TSS (45%). The Wallingat River sub-catchment, and the southern and western sub-catchments of Wallis Lake, have a high proportion of forest land and thus there is less potential for large reductions in the export from these catchments. That said, both sub-catchments have a predicted decrease in TSS loads exceeding 10%. TP is predicted to decrease by ~14% in the southern and western sub-catchments of Wallis Lake.

Table 2.7.5. Percentage change in loads from the modelled Wallis Lake sub-catchment groups achieved after seven years implementation of the WQIP (assumption of all protection actions preventing further deterioration and modelled impacts of expanded remediation actions).

[pt55]**Sub-catchment group**	**% at seven years**			**% of total catchment change in load**		
	TN	**TP**	**TSS**	**TN**	**TP**	**TSS**
Wallamba River	-7.7	-7.6	-9.7	53.0	60.0	72.0
Wang Wauk River	-7.4	-7.6	-7.7	17.0	11.0	12.0
Coolongolook River	-5.2	-6.2	-5.4	10.0	6.0	6.0
Wallingat River	-3.0	-3.0	-7.0	8.0	4.0	3.0
Lower Estuary	-6.1	-5.3	-30.1	5.0	8.0	3.0
Wallis – southern / western sub-catchments	-3.9	-11.1	-8.1	3.0	3.0	2.0
Wallis – Forster sub-catchments	-21.8	-23.5	-45.0	4.0	8.0	3.0

Figures 2.7.2 to 2.7.9 demonstrate the relative effectiveness of the modelled expanded remediation actions on pollutant exports for the whole Wallis Lake catchment, as well as the seven sub-catchment groups shown in Figure 2.4.1. Across all sub-catchment groups, expanded groundcover programs have the greatest impact on exports from largely rural sub-catchments, and mitigation (WSUD devices) is highly effective at reducing exports in the urban sub-catchments. However, there is considerable variation in the relative effectiveness of other actions between sub-catchment groups and constituents (TN, TP and TSS).

The modelled actions target agricultural, rural residential and urban residential lands, which comprise 47% of the area, and contribute 72% of the nutrients and 80% of the TSS loads from the whole Wallis Lake catchment. Unpaved roads were specifically targeted for the Wallamba River sub-catchment group. This means that the bulk of the pollutants sourced from the catchment will be mitigated by the modelled remediation actions. Some of the 'non-targeted' pollutants will be 'background' levels sourced from relatively unmodified land uses (e.g. protected vegetation), although there is still scope to develop further remedial actions on review of the Plan. Section 2.7.1 identified actions that were modelled as well as those that could not be modelled for specific reasons (e.g. data or model limitations, perceived to be minor importance, not in CCI focus area). It is likely that further reductions in catchment loads could be made by addressing other remedial actions that are not modelled in this Plan, such as implementation of best management practices for unpaved roads.

A summary of the relative land use contributions to sub-catchment pollutant loads is given in Appendix 6. The major contributors of pollutants in the Wallamba River, Wang Wauk and Coolongolook River sub-catchment groups that could be targeted by remedial works are agricultural lands with smaller contributions from urban and residential lands. Unpaved roads contribute a considerable proportion of loads in the Wang Wauk and Coolongolook River sub-catchments, and Wallingat and the south-western sub-catchments of Wallis Lake. The major contributions of pollutant in the Lower Estuary and Forster sub-catchment groups that could be targeted by remedial works are urban and rural residential lands, with lesser contributions from agricultural lands.

Agricultural, rural residential and urban residential lands are well targeted in this Plan for all the Wallis Lake sub-catchment groups. Road remediation actions were applied only to the Wallamba River sub-catchment group, and this treatment substantially reduced TSS loads (4% reduction) from the sub-catchment group.[5,6] To further protect Wallis Lake and the Lower River Estuary – and improve conditions in the river estuaries, Coomba Bay and Pipers Bay – additional reductions in catchment loads could be achieved by undertaking actions relating to unpaved roads, especially in identified ‘hot spots’ adjacent to the lake or drainage / creek lines. Additional improvements may be achieved in all sub-catchment groups by implementing best management practices on roads. As outlined in the Action Plan for Rural Road Management (Section 3.3.3), a key area for future investigation should be the mapping of the location and extent of road erosion sites, and undertaking risk analysis in each sub-catchment (Section 3.3.3).

5 Road remediation was identified as an issue by the Advisory Committee throughout the CCI project. Limitations in data suitable for the development of the rural water quality model (AnnAGNPS) meant that this model, and therefore the DSS, were limited to coarse assessments of sediment and nutrients sourced from roads. The AnnAGNPS and DSS are not capable of modeling, for example, the impacts of best management practices within the time frame of the development of the Plan. Implementing these would be expected to decrease sediment and nutrient exports from roads, which would have beneficial impacts on ecological condition of the whole Wallis Lake system, and more pronounced impacts on the creeks and rivers that receive runoff from roads.

6 The Advisory Committee identified the Wallamba River sub-catchment group as of importance with respect to erosion from unpaved roads. The decision was made to model the road remediation actions only in the Wallamba River sub-catchment group. Given this scenario definition, the remediation of unpaved roads has a negligible modelled impact on the whole Wallis Lake catchment loads (<2%). Implementing road remediation actions across the whole Wallis Lake catchment would have beneficial impacts through further reductions in sediment exports from roads (although at a substantial monetary cost). In sub-catchment groups where unpaved roads dominate sediment loads (e.g. the Wallis Lake sub-catchment), remediation of roads should be considered when implementing the WQIP.

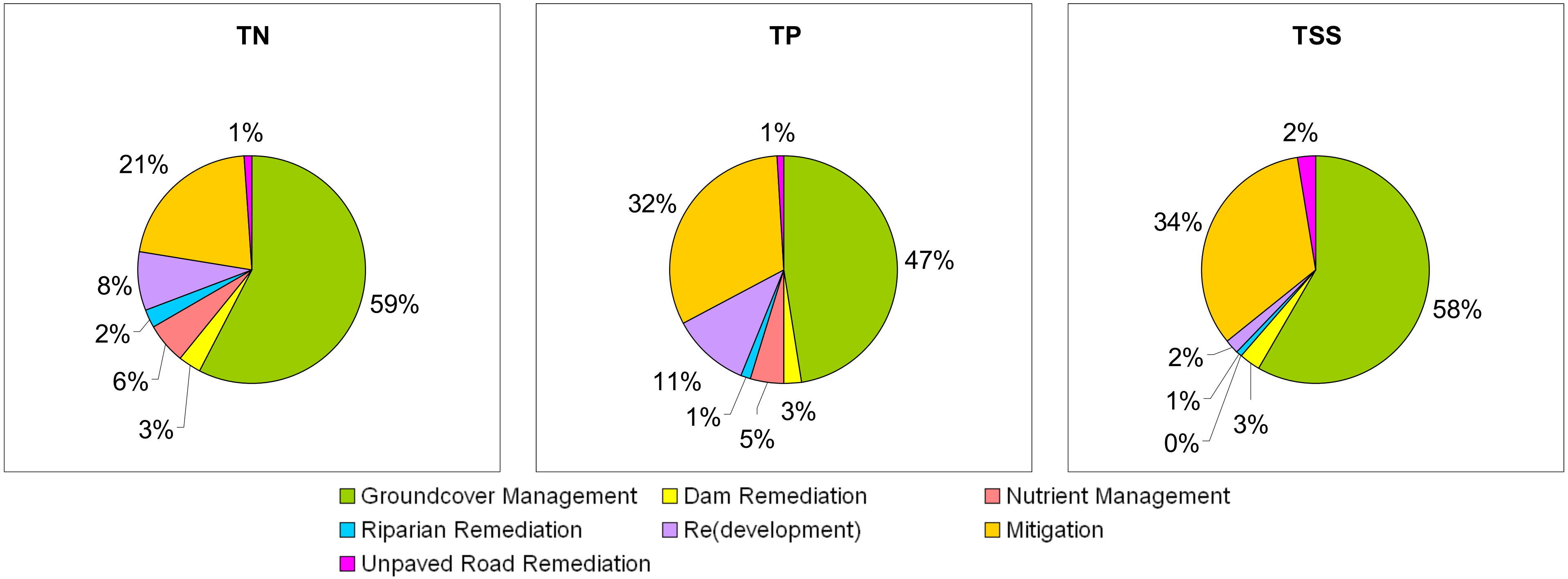


Figure 2.7.2. Relative modelled impact of expanded remediation actions for the whole Wallis Lake catchment with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

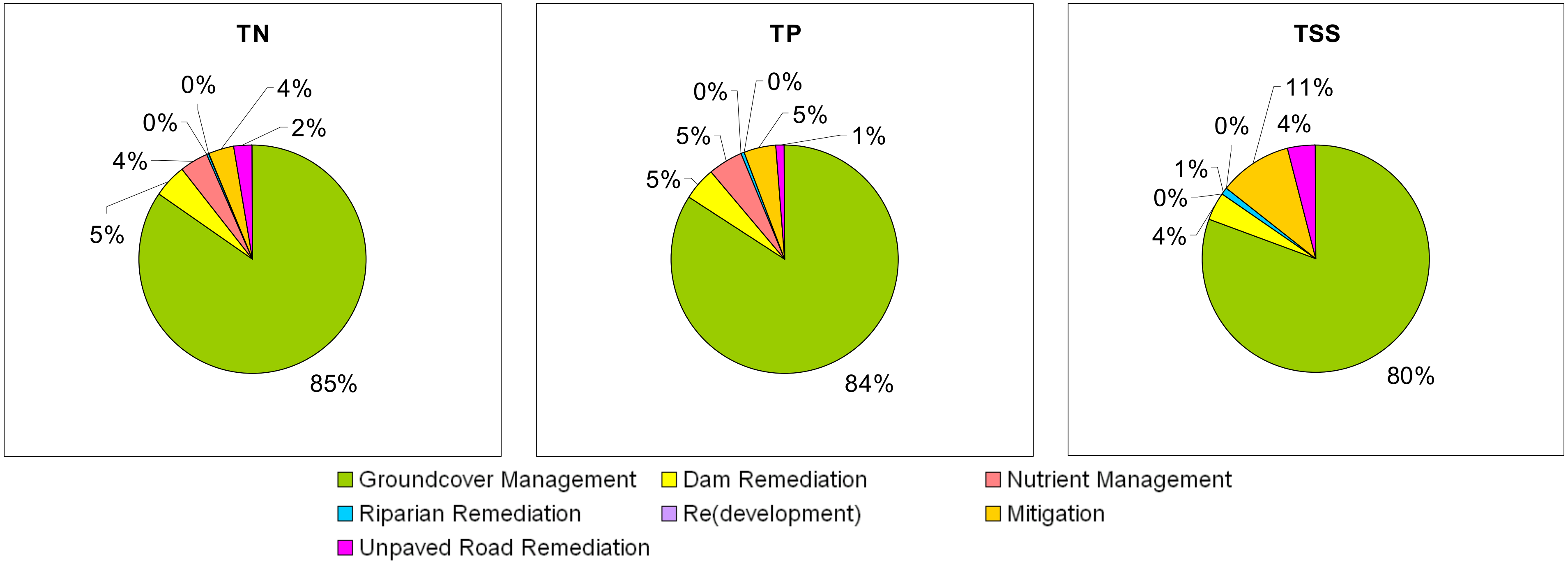


Figure 2.7.3. Relative modelled impact of expanded remediation actions for the Wallamba River sub-catchment of the Wallis Lake system, with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

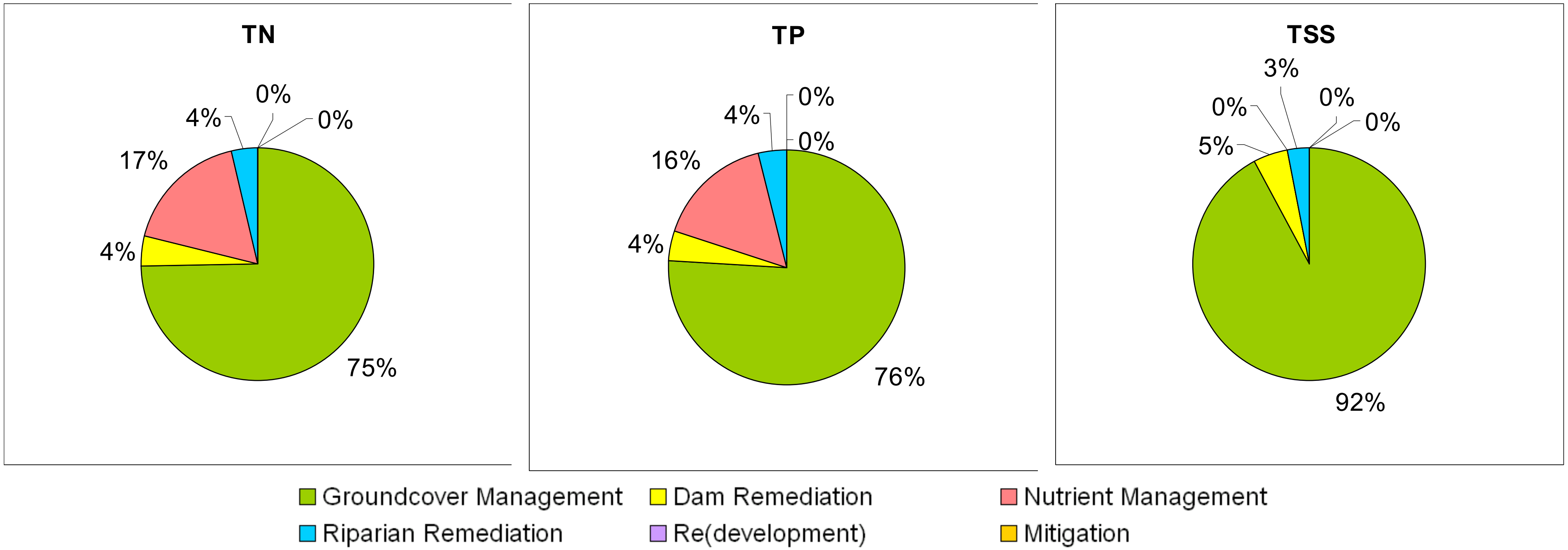


Figure 2.7.4. Relative modelled impact of expanded remediation actions for the Wang Wauk River sub-catchment of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

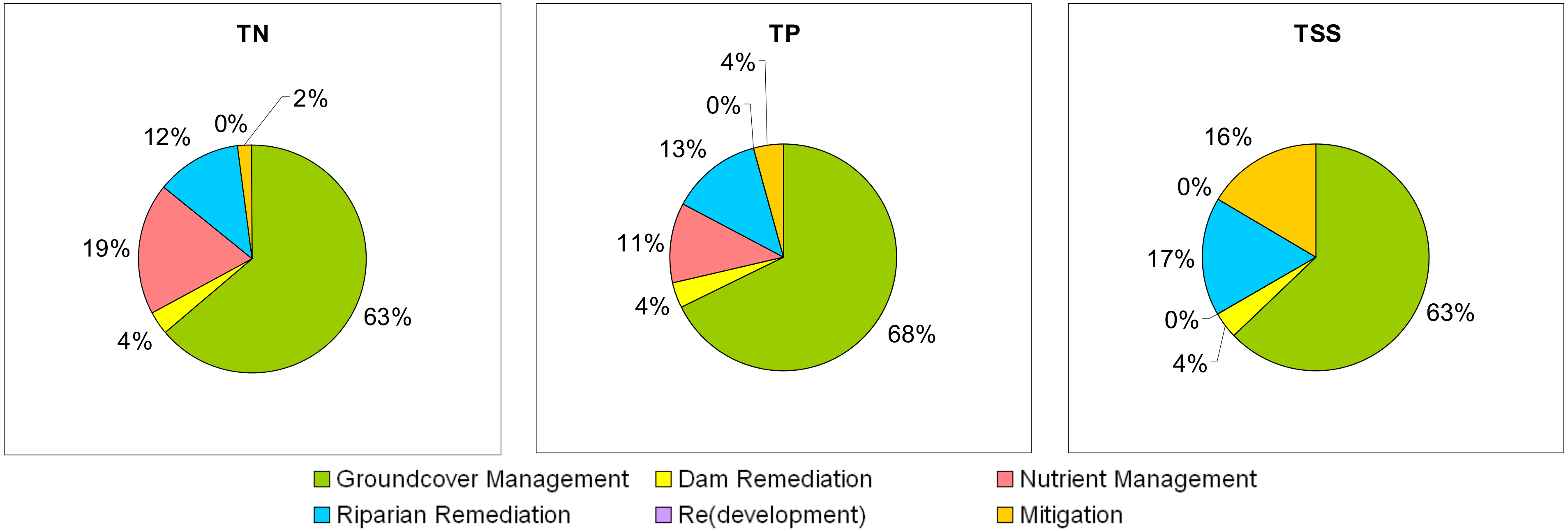


Figure 2.7.5. Relative modelled impact of expanded remediation actions for the Coolongolook River sub-catchment of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

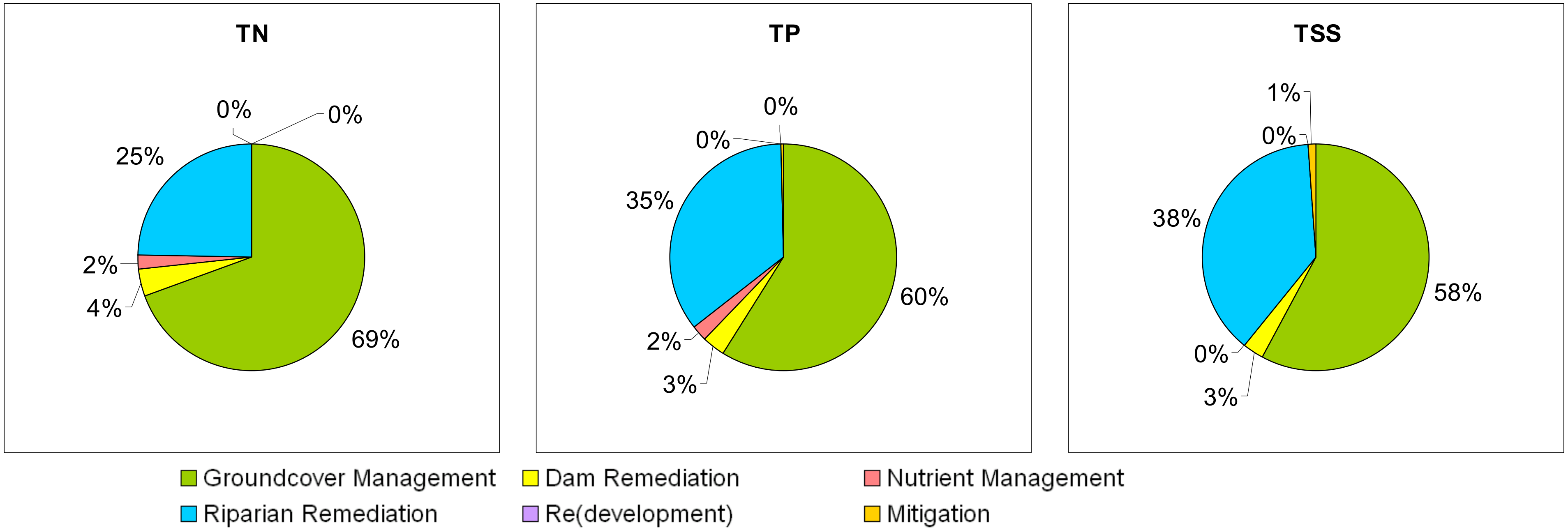


Figure 2.7.6. Relative modelled impact of expanded remediation actions for the Wallingat River sub-catchment of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

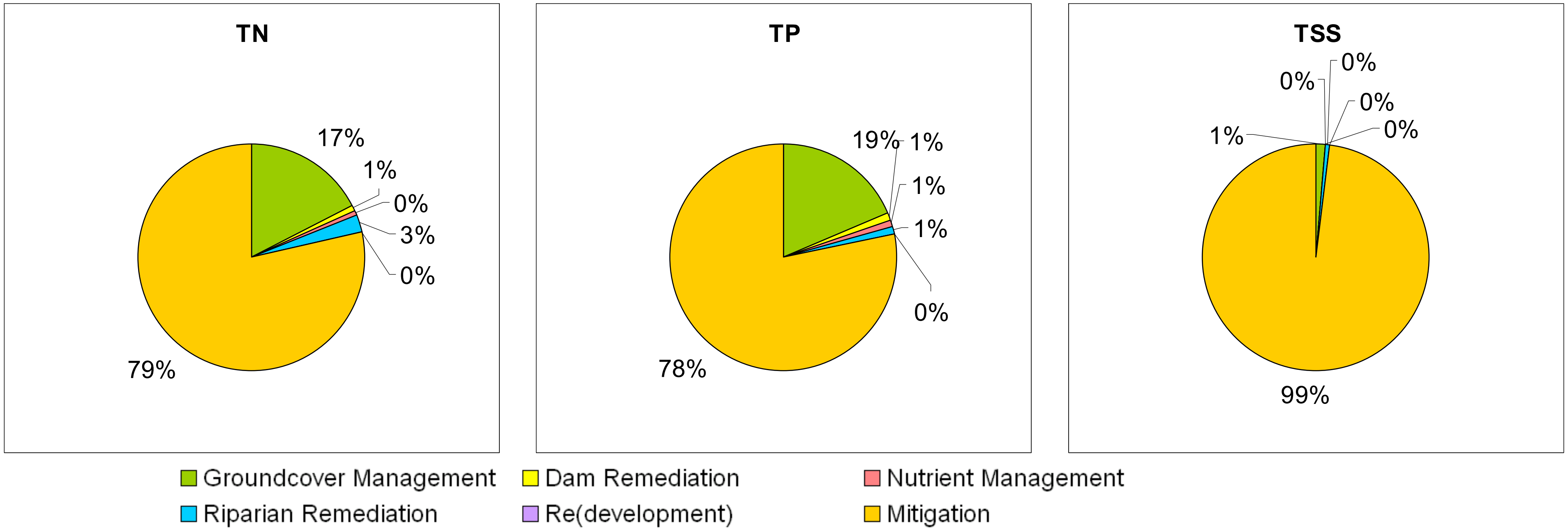


Figure 2.7.7. Relative modelled impact of expanded remediation actions for the Lower Estuary sub-catchment of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

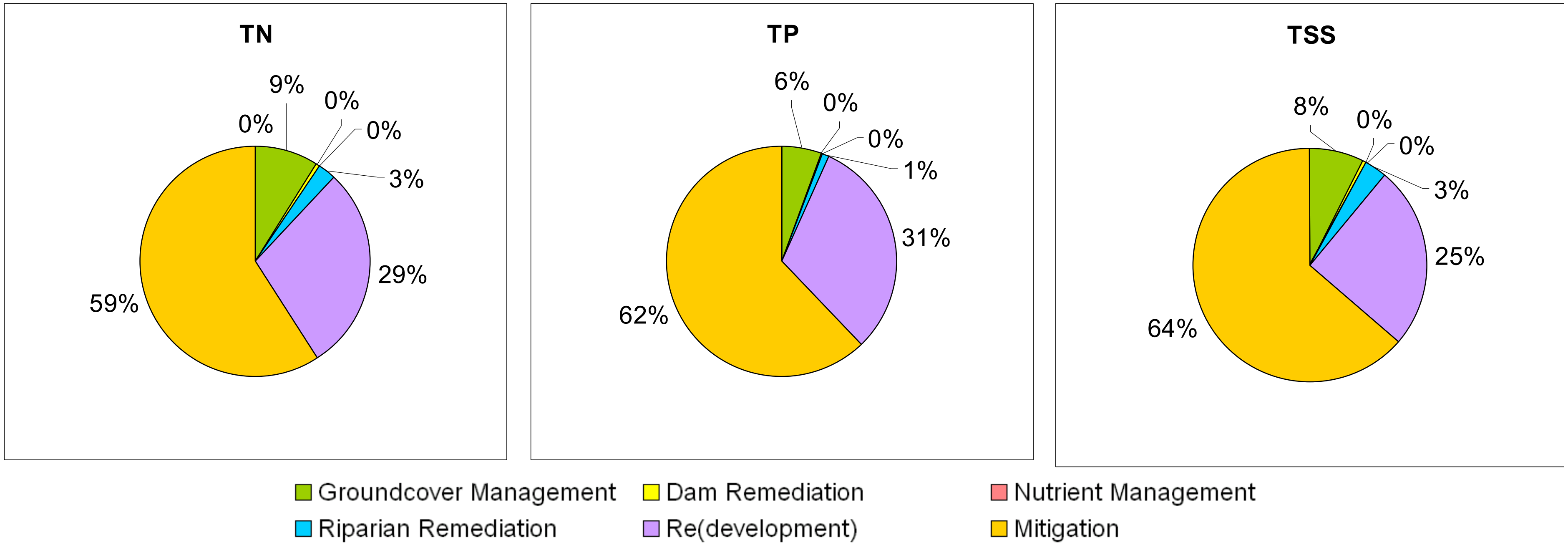


Figure 2.7.8. Relative modelled impact of expanded remediation actions for the Wallis Lake (southern and western) sub-catchment of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

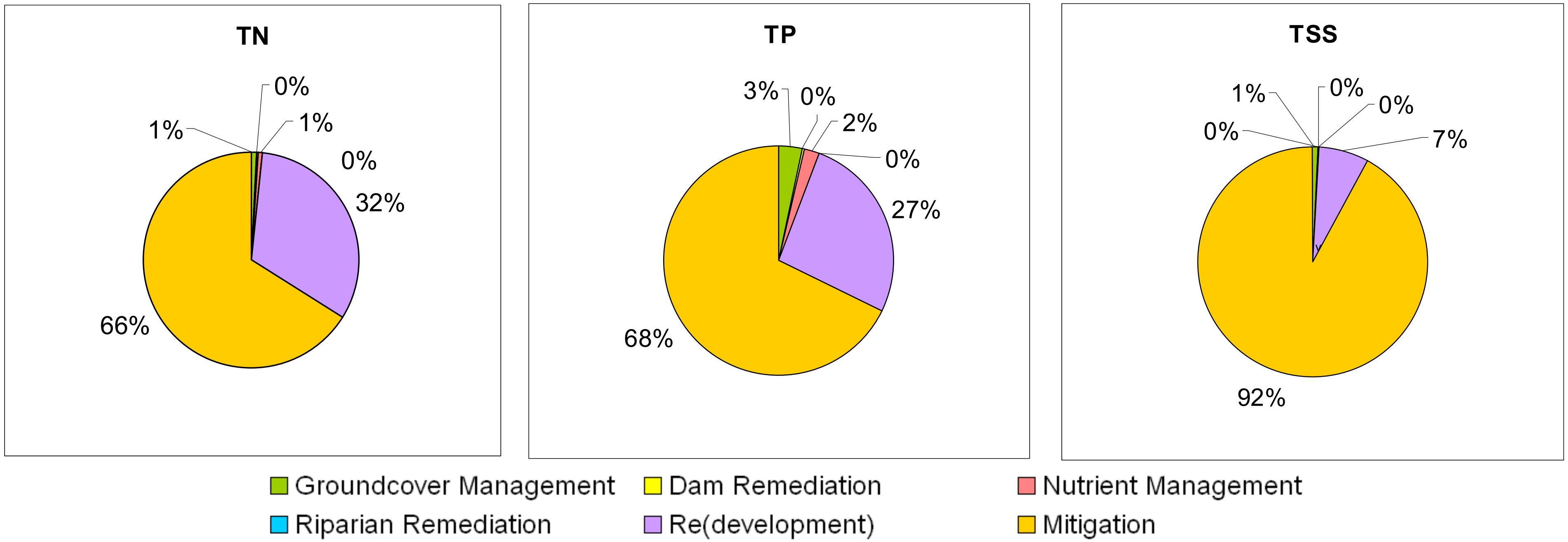


Figure 2.7.9. Relative modelled impact of expanded remediation actions for the Wallis Lake (Forster) sub-catchment groups of the Wallis Lake system with implementation of the WQIP. Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

2.7.1.3 Estuary condition

The percentage reductions in chlorophyll-a and TSS concentrations in Wallis Lake with implementation of the WQIP are shown in Figures 2.7.10 to 2.7.14.

Substantial reductions in chlorophyll-a concentrations are achieved in the Pipers Bay region of the lake with full implementation of the WQIP (all protection actions and expanded remediation actions). Averaged across each zone, chlorophyll-a concentrations are reduced by approximately 13% for Pipers Bay, and 3% for Wallis Lake, Lower, Upper and Middle Estuary zones (Figure 2.7.12). Within each zone, the 'worst' areas show further improvements – in Pipers Bay there was a 26% improvement, and for the Lower Estuary a 7% improvement.

Reductions in TSS concentrations in response to the remediation actions were larger than predicted for chlorophyll-a. Averaged across each zone, TSS concentrations are reduced by approximately 33% for Pipers Bay and 17% for the Wallis Lake, Lower, Upper and Middle Estuary zones (Figures 2.7.10 to 2.7.14.). The 'worst' areas within the Pipers Bay zone – near Forster Keys – show improvements of about 45%.

Although substantial, these changes do not reach the Ecological Condition Target of 50% reduction in chlorophyll-a concentrations identified for Pipers Bay. While these changes do not fully achieve long-term targets for the lake zones, they are an important step in moving towards these outcomes. Importantly under the Plan, the protection actions and expanded remediation actions would result in no further decline in lake condition, and all lakes and rivers would improve in condition to varying degrees. Advice from DECC indicates that the estimated 'feasible changes' in water quality would lead to changes in condition in these areas of the lake that would be substantial enough to be visible.

In summary, given the magnitude of the changes predicted with full implementation of the WQIP, we would expect to see much clearer water in the upper and mid reaches of Wallamba River, with reduced risk of algal blooms (Figure 2.7.10). In Pipers Creek, we would expect to see a considerable reduction in the risk of macroalgal blooms, as well as the frequency and severity of the blooms (particularly in the vicinity of Forster Keys). The reduction in chlorophyll-a and TSS concentrations in Pipers Creek (Figure 2.7.12) would result in significant visible improvements in water clarity, which would have benefits for seagrass and other flora in the zone. For areas already identified as *High conservation value* (Lower Estuary and Wallis Lake), the improvements in ecological condition in these other zones would create a buffer to protect the ecology of the lakes into the future, and we would therefore not expect to observe changes to the current condition in these areas.

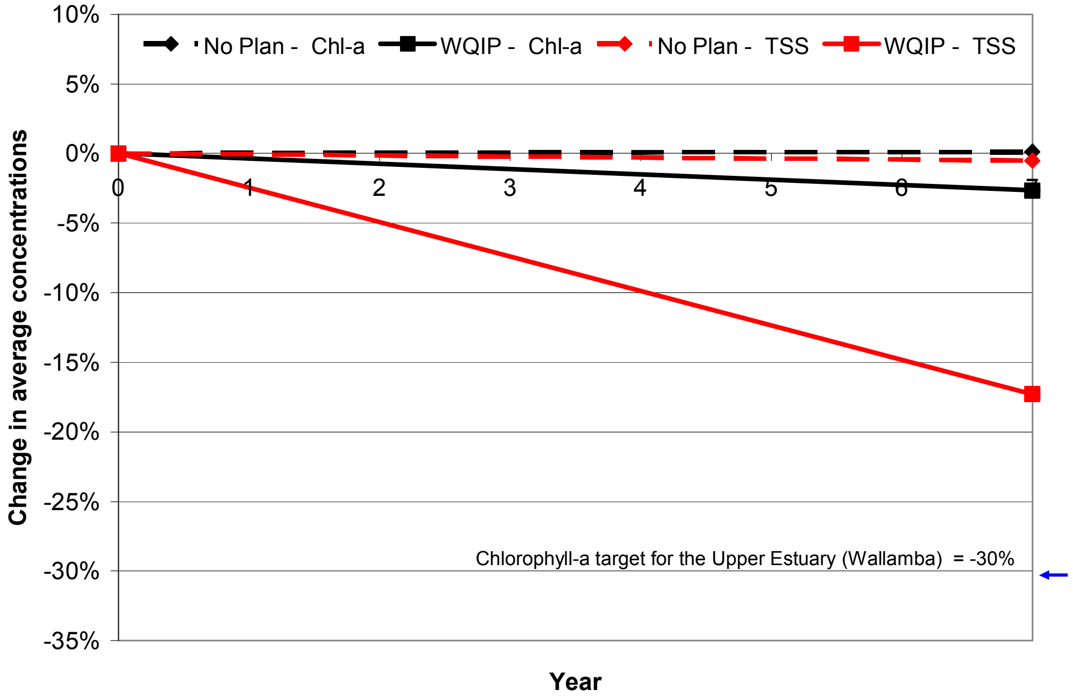


Figure 2.7.10. Percentage change in chlorophyll-a achieved in the Upper Estuary of Wallamba River in the Wallis Lake system. A negative value indicates an improvement in conditions in the water body.

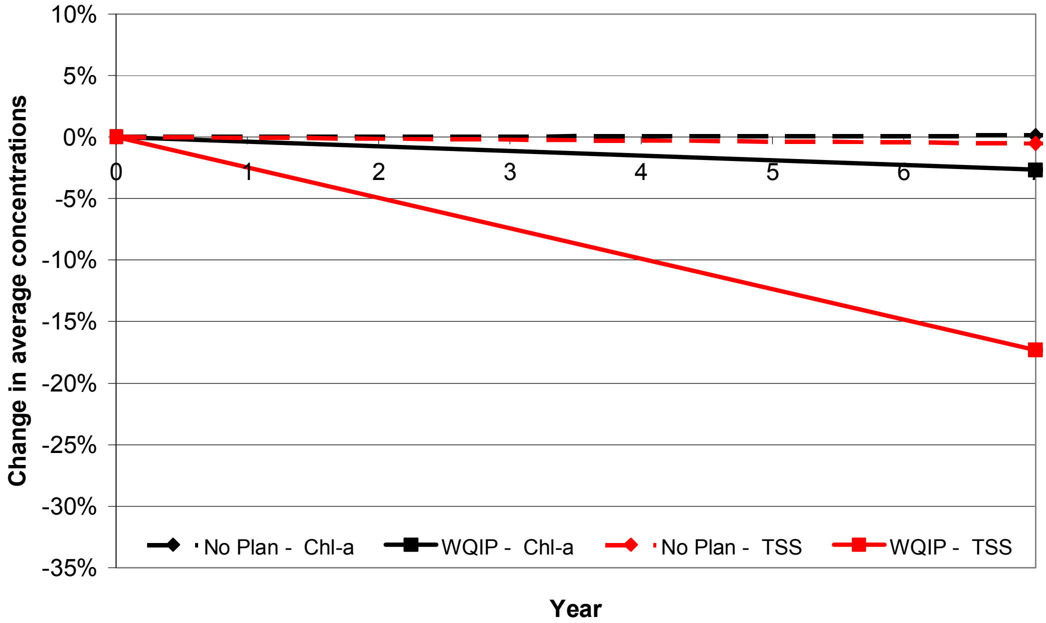


Figure 2.7.11. Percentage change in chlorophyll-a achieved in the Lower Estuary of the Wallis Lake system. A negative value indicates an improvement in conditions in the water body.

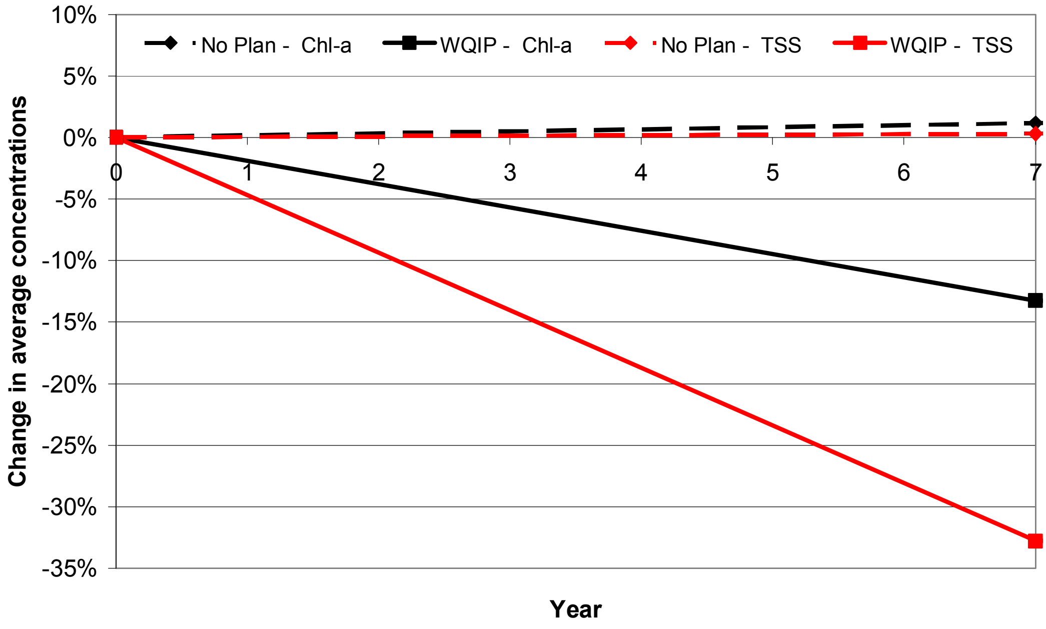


Figure 2.7.12. Percentage change in chlorophyll-a achieved in Pipers Bay of the Wallis Lake system. A negative value indicates an improvement in conditions in the water body.

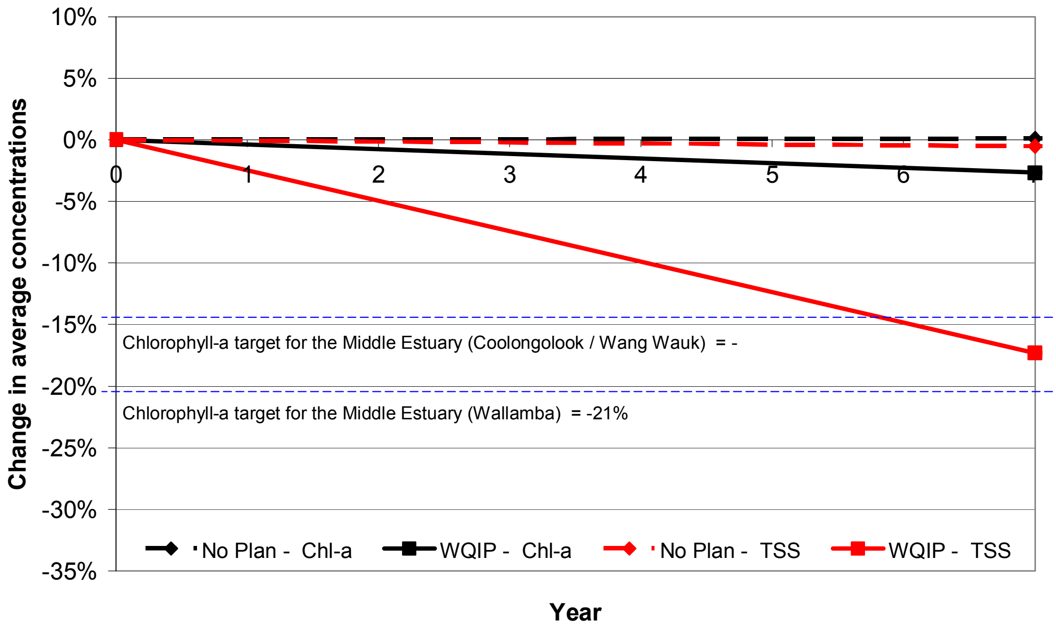


Figure 2.7.13. Percentage change in chlorophyll-a achieved in the Middle Estuary of the Wallamba, Coolongolook and Wang Wauk rivers in Wallis Lake. A negative value indicates an improvement in conditions in the water body.[pt56]

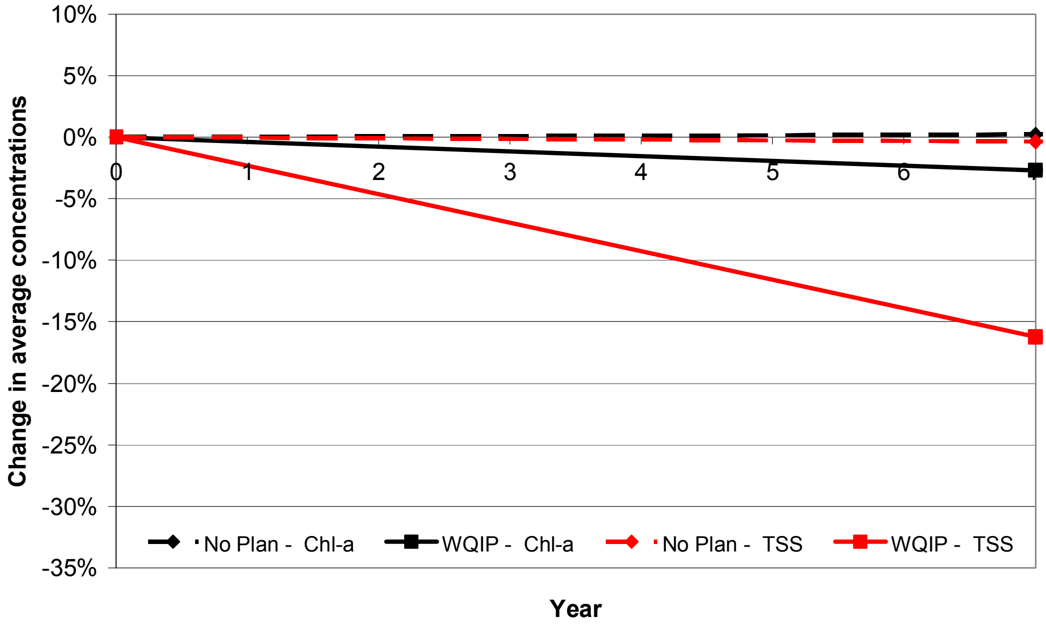


Figure 2.7.14. Percentage change in chlorophyll-a achieved in Wallis Lake. A negative value indicates an improvement in conditions in the water body.

2.7.1.4 Costs of modelled remediation actions

The cumulative costs of implementing and maintaining the modelled expanded remediation actions across the Wallis Lake catchment over a seven-year trajectory are shown in Figure 2.7.15. Details of the assumptions used to define these figures are provided in Appendix 14. Unpaved road remediation, dam remediation and removal actions followed by groundcover management are the most expensive overall options. Riparian 'hot spot' remediation is the cheapest option. This reflects the relatively few riparian hot spots identified in the Wallis Lake catchment and not the cost-effectiveness of the riparian remediation action. The expense of the groundcover management and dam remediation actions reflect the need for ongoing program costs towards protection actions over the period of this Plan (see Appendix 14).

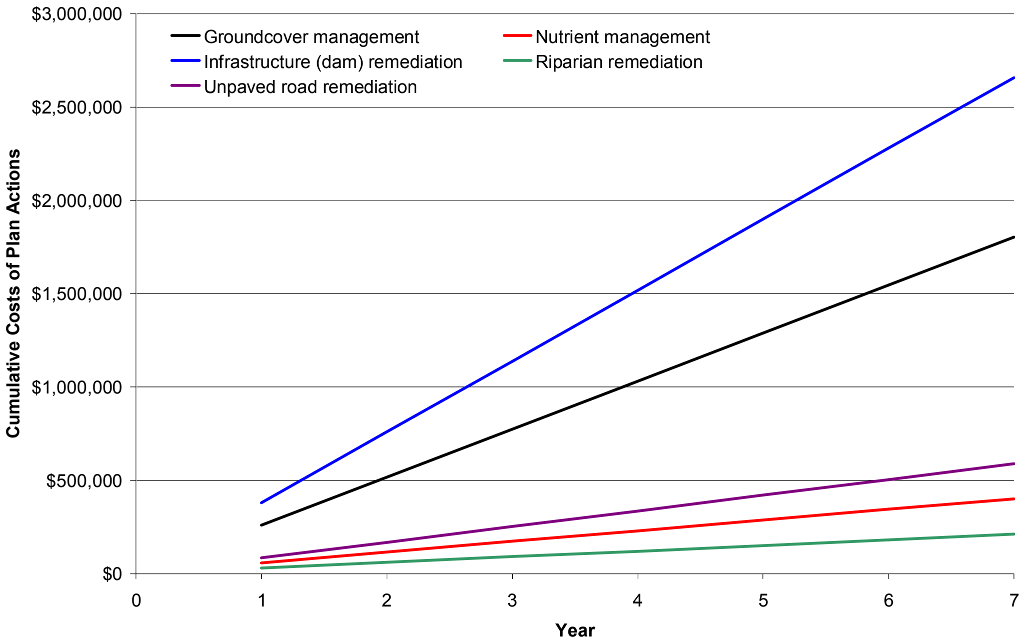


Figure 2.7.15. Cumulative costs of modelled rural remediation actions in the Wallis Lake catchment.

Figure 2.7.15 does not demonstrate the cost effectiveness of the modelled actions. The cost per unit of load controlled by each action in Table 2.7.6 illustrates the relative effectiveness of each action given their cost. This table shows that while the total cost of groundcover programs is relatively high, its effectiveness in terms of reducing catchment pollutant loads is higher than for any other rural remediation program. Infrastructure (Dam) management and unpaved road remediation are the least cost-effective options, with very high costs per unit pollutant reduced, even though unpaved roads are a major contributor of pollutants to the lake. This is because of the very high cost of the remediation actions considered in this scenario.

Table 2.7.6. Cost ($) per unit of load controlled by modelled rural remediation actions applied across the Wallis Lake catchment. A unit is 1 kg for TN and TP, and 1 tonne for TSS.

	Groundcover management	Infrastructure (Dam) management	Nutrient management (Fertiliser)	Riparian remediation	Unpaved road remediation
TN	$265	$7,685	$580	$911	$5,100
TP	$3,317	$76,565	$6,938	$18,149	$50,817
TSS	$678	$19,316	n/a	$4,579	$6,410

n/a = not applicable.

Dams have limited cost-effectiveness, as they have a large cost to implement and maintain. Also, dams do not show significant impacts at the catchment scale or in the estuary. However, this does not account for the potential risks of dam failure as was seen in Coomba Bay. While this action is seen as a remediation action, it is also having a protective effect against impacts such as those seen as the result of a dam failure in Coomba Bay (where 25 ha of seagrass was smothered by a single dam failure).

This analysis does not account for the improvements that the full implementation of WQIP protection and expanded remediation actions generated in the rivers and creeks. Previous studies have shown the importance of healthy riparian vegetation, and limiting sediment and nutrient inputs to creeks and rivers for maintaining stream water quality, habitats and fish communities in associated aquatic ecosystems (Growns, Pollard & Gehrke 1998; Pusey & Arthington 2003; Wang, Lyons & Kanehl 2002). The value of these improvements was estimated as part of a benefit-cost analysis undertaken by Gillespie Economics (see Appendix 15). Section 2.7.3 summarises the results of the benefit-cost analysis for the Wallis Lake Plan.

The cumulative costs of urban remediation actions are shown in Figure 2.7.16. This figure shows that redevelopment is the most expensive option, far outpacing both mitigation (urban retrofitting program) and rainwater tanks. Rainwater tanks costs more than groundcover management but less than dam remediation. Mitigation costs less than both these options but more than other rural remediation actions.

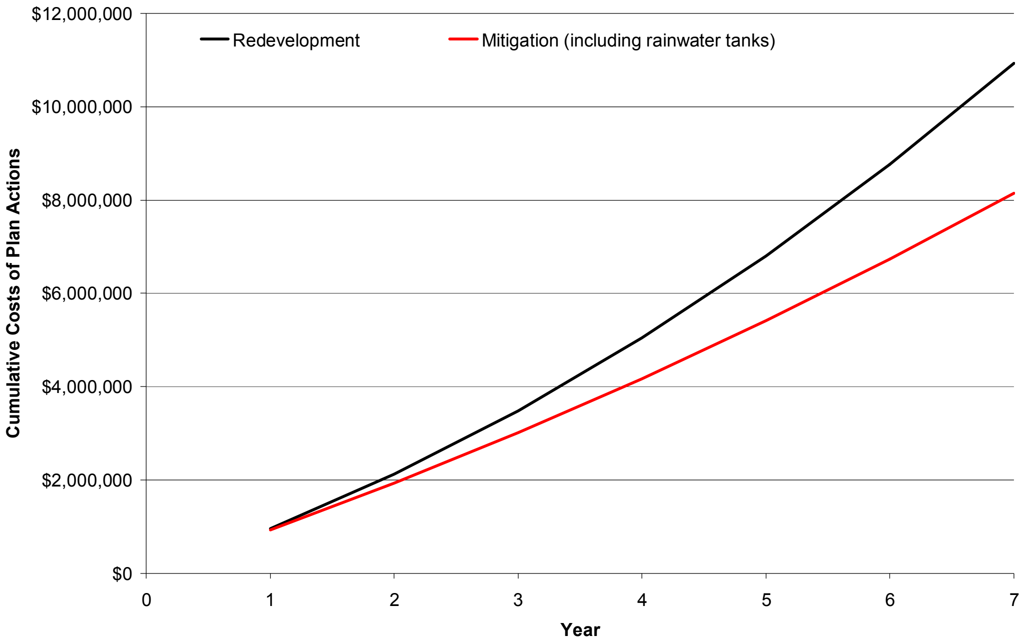


Figure 2.7.16. Cumulative costs of urban remediation actions in the Wallis Lake catchment.

Table 2.7.7 shows the costs of urban remediation actions per unit of pollutant reduced (per kg for nutrients, and per tonne for sediment). This table shows that the costs of mitigation are relatively low per unit of pollutant reduced. By contrast, the costs of redevelopment are relatively high.

Table 2.7.7. Cost ($) per unit of load controlled by urban actions applied across the Wallis Lake catchment. A unit is 1 kg for TN and TP, and 1 tonne for TSS.

	Redevelopment	Urban Mitigation (Water Sensitive Urban Design)[pt57] [a]
TN	$11,852	$3,362
TP	$85,880	$21,983
TSS	$119,161	$5,220

a: Mitigation refers to both retrofitting of existing urban areas through implementation of WSUD devices and adoption of rainwater tanks.

In summary, these results show the effectiveness of urban actions at improving water quality and ecological condition in the lake. These actions induce changes in catchment loads contributing to areas of the lake currently under significant stress such as Pipers Bay, or in need of substantial protection such as southern Wallis Lake, where there is significant potential for catchment loads to affect water quality (as demonstrated by the scenario results).

Note that the costs analysed above consider only those remediation actions that were modelled using the DSS. For actions that were not modelled, costs and benefits of implementing the actions are summarised in Section 2.7.3.

2.7.2 Summary of recommended programs for protection, remediation and management support of Wallis Lake

A brief description of the programs recommended as part of this plan for protection, remediation and management support of the Wallis Lake catchment are given in Table 2.7.8. Management support actions are those recommended to support the implementation of protection and remediation actions in the Wallis Lake Plan, and include: adaptive management strategies, ecological monitoring and future investigations, and extension for the Farm Scale Action Plan. Management support actions do not lead themselves to having their impacts estimated using biophysical models and so have not been modelled. Their costs are included to establish a comprehensive budget for the Water Quality Improvement Plan.

The resources required and activities undertaken as part of these remediation, protection and management support programs are also summarised in Table 2.7.8. Full details of assumptions behind these recommendations are given in Appendix 14 and more detail on the farm-scale actions that underpin the programs described are outlined in Section 3.3.

Note that it is recommended that the rural programs described below should be considered in the 'whole farm approach' described in Section 3.3 and not implemented in isolation.

Table 2.7.8. Summary of recommended programs in the Wallis Lake catchment: Protection, remediation and management support.

Program	Program description	Resources	Details
Remediation activities – modelled using DSS			
Groundcover management	Groundcover management refers to a sustainable grazing program for landholders, and is focussed on improving groundcover management on pasture lands. It involves field days and formal workshops with experts, developing information and training material on stocking rates, formal training courses such as Prograze, a dung beetle release program, and a program of on-ground works that will assist landholders to better manage their groundcover levels (including off-stream watering, solar pumps and fencing).	• 1.5 x Catchment officer providing one-to-one advice and extension activities • Landholder training courses • Field days • Workshops • Dung beetle release • Provision of off-stream water and fencing	Section 3.3.2, Appendix 14
Nutrient management (Fertiliser)	Nutrient management is a component of a sustainable grazing program focussed on the appropriate application and storage of nutrients. It involves working with landholders to trial different types of fertilisers, formal training courses such as LANDSCAN, subsidising and promoting the use of soil tests, and providing assistance with interpretation of the tests so that the results can be integrated into a whole-farm plan. This program also supports a dung beetle program – however, it is costed in the groundcover management program. Additional actions related to the management of human and animal effluent include the upgrade of laneways and stock crossings. However, these kinds of actions were not able to be modelled.	• 0.33 x Catchment Officer providing one-to-one advice and extension activities • Landholder training courses • Soil tests	Section 3.3.2, Appendix 14
Infrastructure (Dam) management	Infrastructure management includes the refurbishment of dams that are a water quality risk as well as decommissioning those that are not functioning, and potentially acting as a source of nutrients and sediments to the system. It involves working with landholders to repair dam structural problems, controlling stock access to the dam or providing an alternative stock water supply from the dam. It also involves landholder training, as well as training and accreditation of contractors. Additional actions relating to the management of infrastructure have also been identified, including road and laneway management. However, these kinds of actions were not able to be modelled.	• 0.75 x Catchment Officer providing one-to-one advice and extension activities • 0.375 x Technical Officer • Workshops • On-ground works (dam repair or decommissioning)	Section 3.3.2, Appendix 14

Program	Program description	Resources	Details
Riparian remediation	Riparian remediation programs include the rehabilitation of sites with active stream bank erosion. These sites are based on identified locations in existing plans, such as rivercare plans. This program includes significant in-stream repair work for bank stabilisation and fencing off the creek in the identified areas.	• 0.24 x Catchment Officer providing one-to-one advice and extension activities • Fencing, replanting, engineering works as appropriate • Provision of off-stream water	Section 3.3.2, Appendix 14
Urban Mitigation (Water Sensitive Urban Design)	Urban mitigation includes the retrofitting of rainwater tanks supported through a program of rebates. It is recommended that the tanks are plumbed into the home to maximise the water quality benefits. For Wallis Lake, a predicted 15% uptake of rebates over a seven-year period was tested for the Pipers Creek, Pipers Bay and Big Island sub-catchments. It also involves an extensive program of urban retrofitting where Water Sensitive Urban Design (WSUD) systems, such as biofiltration (including trenches, raingardens and biopods), are built into the existing urban landscape to filter the urban stormwater. This program also involves education and capacity-building on maintenance and construction of WSUD devices, adoption of a development control plan that specifies best practice Water Sensitive Urban Design, and associated staff training and capacity-building. It also includes investigating options for a nutrient offset scheme for the Pipers Creek / Pipers Bay area.	• Staff time (various amounts depending on year of program) to deliver capacity-building and auditing programs to implement DCP • Cost of retrofitting water tanks	Section 3.4.2, Appendix 14
Water Sensitive Redevelopment	Water Sensitive Redevelopment involves the implementation of a development control plan that specifies best practice Water Sensitive Urban Design (including biofiltration and rainwater tanks) on all redevelopments. The program of redevelopment has been estimated based on existing redevelopment rates.	• Costs of new WSUD devices based on predicted redevelopment rates and cost of maintenance	Section 3.4.2, Appendix 14
Protection activities – estimate of combined effect of protection programs estimated based on past degradation. No split of impacts between actions was able to be provided. This was not modelled using the DSS.			
Wetland protection	Wetland protection involves the acquisition of healthy but threatened wetlands, and undertaking management and / or rehabilitation as required (e.g. fencing off the wetland, establishing property vegetation plans, management plans, reinstating natural hydrology in acid sulfate-affected landscapes). The program also involves assisting landholders to protect natural wetlands with advice, training and on-ground works to control stock access. More generally, the program involves partnerships with the communty, including raising the profile of wetlands and their role in providing environmental services as well as encouraging participation in management and restoration.	• 0.2 x Council staff to manage program for 10 years • Acquisition of 2,618 ha of wetlands • Fencing as required (estimated 24 km) • Property Vegetation Plan for 146 ha of wetlands	Appendix 14

Program	Program description	Resources	Details
Riparian protection	The riparian protection program involves fencing and / or stock exclusion for areas of remnant riparian revegetation, including off-stream watering and some planting where vegetation requires rehabilitation. It also involves establishing property vegetation plans in areas not suitable for fencing (e.g. high-slope areas).	• 0.5 x Catchment Officer to manage program • Protection of 720 km of remnant riparian vegetation • Fencing and Property Vegetation Plan as appropriate (estimate 70:30) • Provision of off-stream water	Section 3.3.2, Appendix 14
Water Sensitive Development of Greenfield sites	Water Sensitive Development of Greenfield sites involves establishing and implementing LEP / DCP provisions on Greenfield development sites in the Wallis Lake catchment. This will involve enforcing 'no net increase' in pollutants relative to the existing land use (agricultural and forest land use classifications). This program also involves establishing heads of consideration for voluntary planning agreements with developers.	• Acquisition and annual maintenance costs for WSUD devices • Staff and consultant time to implement programs	Section 3.4.2, Appendix 14
Water Sensitive Urban Design protection	WSUD protection is an education and capacity-building program on Water Sensitive Urban Design and management of urban land. It involves workshops, field days and demonstration sites with stakeholders including the general community, business, building and development industries. It involves updating plans, strategies and design guidelines (such as road guidelines), as well as resourcing a sediment and erosion control audit and training program.	• Council staff to deliver education and capacity-building programs, including training and audits	Section 3.4.2, Appendix 14
Foreshore and riparian management in urban areas	Foreshore and riparian management in urban areas involves improving foreshore areas around Wallis and Smiths lakes through establishing site-specific management plans, education and engagement of residents surrounding foreshore areas to reduce the impact of their behaviours, and increased enforcement of environmental legislation in these areas.	• Council staff to develop management plans and undertake community engagement	Section 3.4.2, Appendix 14
Best management of unpaved roads ~	Best management of unpaved roads includes construction of mitre drains to divert road runoff into grassed areas, and sealing and diverting runoff away from streams particularly in the vicinity of creek crossings. The program involves mapping the location and extent of road erosion sites, and undertaking risk analysis in each sub-catchment to prioritise roads for rehabilitation or closure. A program of training and auditing of contractors and council staff specific to road construction to ensure best management practices are applied will also be undertaken as part of this action.	• Staff and consultant time for training and education program • Note this program does not cover the cost of undertaking best practice, as they are covered with routine road maintenance	Section 3.3.3

Program	Program description	Resources	Details
Protect sea sponge beds	To facilitate the protection of the unique sea sponges in Wallis Lake, this program involves identifying and mapping the location of sea sponges, and developing and implementing an action plan and case for formal protection. This program also involves engaging with the community and key stakeholders, such as professional fishers, to establish support for protection as well as establishing appropriate community monitoring programs.	• Staff and consultant time • Field days • Workshops	Appendix 14
Improved management of lake use activities	Improved management of lake use activities involves reviewing stormwater management plans to clarify the outcomes required to protect the environment and oyster growing areas in relation to SEPP 62, and oyster grower monitoring programs to identify synergies with ecological monitoring programs. The program also involves establishing memoranda of understanding with key groups of lake users, and investigating other management options such as closing boat ramps during high-flow events and establishing markers to protect seagrass beds.	• Staff and consultant time • On-ground works	Section 3.5.2, Appendix 14
Improved pollution control systems / management systems	Improved management and pollution control systems involves reviewing how water quality management, both within and between organisations, is approached. It focuses on establishing checking and review loops in key areas, such as compliance with conditions of consent, and sediment and erosion control. The program also highlights the need to embed water quality improvement actions in organisational plans to ensure the WQIP is implemented. It highlights the need to review a range of existing systems such as the fee structure for on-site sewage management, and recommends exploring alternative ways to formalise the response to complex pollution cases and strengthen cross-agency relationships and delegation.	• Council and state government agency staff time • Costs of development of GIS-based data base	Section 3.7, Appendix 14
Management support actions – not modelled			
Adaptive Management Strategy / Ecological monitoring program	The Adaptive Management Strategy underpins the implementation of the WQIP. It highlights the ecological, political and social uncertainties surrounding the WQIP, and identifies ways to track these and make informed management decisions during plan implementation. The ecological monitoring program outlined in the strategy involves the collection of data on ecological indicators such as chlorophyll-a,water clarity, habitat assessments on river reaches and fish sampling. The strategy also recommends a public reporting regime for the WQIP.	• 0.05 x Council staff to do the reporting and collating for the WQIP • Specialist assistance for establishing the WQIP monitoring program – Staff time • Equipment hire	Section 3.9, Appendix 30

Program	Program description	Resources	Details
Future investigation relating to the Farm Scale Action Plan[DG58]	Specific areas for future investigation that relate to improving farm management practices are undertaken through this program. Areas for investigation include riparian management, wetland management, groundcover management, farm infrastructure management, nutrient management and ways to encourage uptake of improved management practices. The findings from this research are applicable across all three catchments (Wallis, Smiths and Myall lakes).	• Researcher and specialist time	Section 3.3.2

~ Due to the high cost of road remediation and the negligible modelled impact on the whole Wallis Lake catchment loads (<1%), road remediation has not been recommended for Wallis Lake. Under best management practice of unsealed roads, further research to identify hot spot areas is required. In sub-catchments where unpaved roads dominate as a source of sediment loads, remediation of roads should be considered when implementing the WQIP.

Responsibilities for implementing these programs are detailed in Section 3 of the Water Quality Improvement Plan.

Total costs over seven years of the Plan for protection, remediation and management support actions are summarised in Table 2.7.9. These costs assume that all of the actions identified in the Plan are in the process of being fully implemented. Many of the actions identified in the Plan are designed to be implemented over more than seven years (e.g. Wetland protection and Water Sensitive Development of Greenfield sites). In these cases, the impact at seven years assumes that implementation of these actions is in progress, rather than completed.

Table 2.7.9. Summary of total costs at seven years of remediation, protection and management support actions in the Wallis Lake catchment as recommended by the Plan.

Action	Cost at seven years
Remediation actions	
Groundcover management	$2,005,000
Nutrient management (Fertiliser)	$400,000
Infrastructure (Dam) management	$2,660,000
Riparian remediation	$375,000
Urban Mitigation (Water Sensitive Urban Design)	$4,570,000
Water Sensitive Redevelopment	$10,035,000
Rainwater tanks	$2,125,000
Protection actions	
Wetland protection	$9,945,000
Riparian protection	$2,605,000
Water Sensitive Development of Greenfield sites	$17,750,000
Water Sensitive Urban Design protection	$285,000[pt59]
Foreshore and riparian management in urban areas	$121,000
Best management of unpaved roads [7]	$147,000[pt60]
Protect sea sponge beds	$535,000
Improved management of lake use activities	$382,000
Improved pollution control systems / management systems	$60,000
Management support actions	
Adaptive Management Strategy / Ecological monitoring	$240,000
Future investigation relating to the Farm Scale Action Plan	$561[pt61],000
Total	**$54,801,000**

This table shows that protection actions (riparian protection and wetland protection) are expected to cost more than most rural remediation actions (not dam management). Redevelopment costs are by far the most expensive in the Plan. The Plan for the Wallis Lake costs in total approximately $53 million over seven years.

7 The costs specified for the best management of unpaved roads covers the cost of establishing a new auditing and training program, and identifying areas for rehabilitation. The actual cost of rehabilitation has not been costed here. Neither has the cost of implementing best practice management, as it is assumed that best practice should currently be undertaken. The cost does not include the ongoing maintenance of roads to best practice standards but focuses on ensuring those standards are implemented.

Refer to Section 2.7.1.3 to see the ecological condition and load reductions achieved for full implementation of these expanded remediation actions and all protection actions.

2.7.3. *Summary of benefit-cost analysis results for Wallis Lake Plan*

Gillespie Economics conducted a benefit-cost analysis for the Wallis Lake management actions. To undertake this type of analysis it was necessary to cost the implementation of the plan over a 30-year period. While the plan does not present the 30-year figures, this section is intended to provide indicative benefit-cost for future implementation. This section summarises the results of this analysis. Table 2.7.10 lists the potential costs and benefits identified in the analysis of the implementation of the Wallis Lake Plan.[8] Full details of the assumptions made and methods used for estimates of the benefit-cost results presented here can be found in Appendix 15. The actual costs associated with the identified programs are detailed in Appendix 14.

Table 2.7.10. Costs and benefits for the Wallis Lake management actions[pt62]**.**

Costs	Benefits
Direct program costs	***Direct program benefits***
• Nutrient management	• Improvements in estuary health
• Infrastructure (Dam) management	• Improvements in river health
• Groundcover management	• Increased native vegetation conservation
• Riparian remediation	• Increased wetland conservation
• Water Sensitive Development of Greenfield sites	• Benefits to oyster growers
• Riparian protection	• Benefits to commercial recreation
• Wetland protection	• Benefits to commercial fishers
• Water Sensitive Redevelopment	• Benefits to non-market recreation
• Urban Mitigation (Water Sensitive Urban Design)	• Benefits to urban amenity
• Protect sea sponge beds	
• Water Sensitive Urban Design protection	
• Improved management of lake use activities	
• Improved pollution control systems / management systems	
• Adaptive Management Strategy / Ecological monitoring	
• Future investigation relating to the Farm Scale Action Plan	
• Rainwater tanks	

8 Protection actions for unpaved roads were not included as part of the benefit-cost analysis.

Indirect program costs	***Indirect program benefits***
• Opportunity costs of riparian revegetation and protection	• Reduced fertiliser costs and increased productivity of agricultural land
• Costs of alternative water supplies where dams are eliminated	• Increased agricultural productivity where dams are eliminated

Two decision criteria for assessing the economic desirability of a project to society were considered in this analysis:

- *Net present value*: the sum of the discounted benefits less the sum of the discounted costs. A positive net present value indicates that it would be desirable from an economic perspective for society to allocate resources to the project, because the community as a whole would obtain net benefits from the project
- *Benefit-cost ratio*: the sum of discounted benefits divided by the sum of discounted costs. A benefit-cost ratio greater than 1 indicates that the investment is economically efficient and hence desirable from an economic perspective.

Calculations of both net present value and benefit-cost ratio indicate that the Plan is economically efficient and desirable from a community perspective (Appendix 15). Table 2.7.11 shows that the total benefit-cost ratio for implementation of the Wallis Lake management actions is 1.4. Benefit-cost ratios above 1 are considered to be positive.

As described in Section 2.7.1.3 the modelling undertaken to develop this WQIP has focussed on the ecological response of the estuary in relation to changes in catchment loads. Recognising that there is a suite of benefits that cannot be accounted for in this approach (including the improvements that occur on individual river reaches), economic analysis of individual management actions was undertaken to partially account for this limitation. The benefit-cost ratios for individual actions in the Wallis Lake Plan are shown in Table 2.7.11.

Table 2.7.11. Wallis Lake WQIP benefit-cost ratio of individual actions.

Program	**Benefit-cost ratio**
Remediation actions	
Groundcover management	2.8
Nutrient management (Fertiliser)	1.8
Infrastructure (Dam) management	0.1
Riparian remediation	23.4
Urban Mitigation (Water Sensitive Urban Design) + Rainwater tanks	4.2
Water Sensitive Redevelopment	0.1

Program	Benefit-cost ratio
Protection actions	
Wetland protection	2.2
Riparian protection	7.9
Water Sensitive Development of Greenfield sites	0.4
Water Sensitive Urban Design protection	0.4
Foreshore and riparian management in urban areas	*
Best management of unpaved roads [9]	*
Protect sea sponge beds	*
Improved management of lake use activities	*
Improved pollution control systems / management systems	*
Management support actions	
Adaptive Management Strategy / Ecological monitoring	*
Future investigation relating to the Farm Scale Action Plan	*
Total	**1.35**

* The benefit-cost ratio was not able to be calculated for these programs. Refer to Appendix 15 for further information.
[pt63]

This data facilitates consideration of which action is providing the greatest return on investment, as represented by the benefit-cost ratio. Allocation of benefits to each individual action in the WQIP was achieved by estimating the contribution that each action makes to general water quality improvement in the estuary, and allocating benefits associated with water quality improvement, accordingly. Non-water quality benefits – including vegetation conservation, wetland benefits and changes to river health – were also allocated to the relevant WQIP action.

The analysis indicates that the majority of Wallis Lake management actions provide a positive return on investment (Table 2.7.11). Riparian protection and riparian remediation provide the greatest return on investment largely because of benefits not associated with the estuary. This return on investment is more than just water quality benefits, and includes benefits such as conservation and river health. While this analysis has shown that actions including water-sensitive urban design protection, redevelopment and dam remediation have costs that exceed benefits, these actions should not be discounted as a result of the study. A very coarse analysis was undertaken of the water quality benefits associated with protection actions, which may have biased the results for these actions, resulting in a low benefit-cost ratio. While dam rehabilitation did not produce a high benefit-cost ratio, it was still

9 The costs specified for the best management of unpaved roads covers the cost of establishing a new auditing and training program, and identifying areas for rehabilitation. The actual cost of rehabilitation has not been costed here. Neither has the cost of implementing best practice management, as it is assumed that best practice should currently be undertaken. The cost does not include the ongoing maintenance of roads to best practice standards but focuses on ensuring those standards are implemented.

considered an important risk minimisation action given the impacts recorded from a dam failure at Coomba Bay (Appendix 11). These types of low-probability, high-impact events were not able to be accurately accounted for in the modelling, so the benefits of avoiding these types of impacts are also likely to have been underestimated. It is recommended that a more comprehensive analysis of these actions be undertaken in the future to estimate the benefits associated with these types of actions.