Average Year Results	Junction 1	Junction 2	Junction 3	Total	Pollutant load kg/ha/yr	Ave daily concen. mg/L
Total Nitrogen (kg/yr)	596	2730	1420	**4746**	**14.03**	**1.14**
Gross Pollutants (Kg/yr)	39.1	680	202	**921.1**	**2.72**	**n/a**

The wetlands reduce annual TSS loads by 66 %, TP loads by 34 % and TN loads by 8%. Gross pollutants are greatly reduced by around 98%, however the other pollutants still exceeded the requirements of Council as shown below in Table 3.18.

Table 3-18: Comparison of wetland case performance against TSC WQO

Pollutant	Wetland Outflow (kg/ ha)	TSC WQO (kg/ ha)	Exceedance factor
Total Suspended Solids	342.7	300	1.1
Total Phosphorous	1.66	1.65	1.0
Total Nitrogen	14.03	13	1.1

The results indicate that wetlands alone will provide a good level of treatment, however additional measures to form a stormwater treatment train will be required to provide sufficient removal of stormwater pollutants.

The wetlands have been sized using the TSC guidelines. A review by Dr Graham Jenkins indicated that the inlet zone of the wetland sized using the guidelines are reasonably large. In MUSIC, the open water zone or sedimentation basin of a constructed wetland is modelled as an inlet pond. Typically, the aim of the sedimentation basin is to capture sediment particles approximately 125 µm in size during a three month ARI design storm. The settling velocity of a particle of this size is approximately 0.012 m/s. The surface area of the wetlands can be calculated by dividing the design flow by the settling velocity, which in this case would indicate much smaller inlet ponds than calculated using the TSC guidelines. The larger inlet ponds may be used to mitigate the increase in peak flows resulting from urbanisation. Overflow weirs could be designed to allow flows greater than the wetland capacity to be bypassed with inlet pipes discharging the design storm through the wetland. The required sizes of detention basins have been estimated in section 3.4.4. Buffers will be required around the wetlands for maintenance and should be allowed for in any preliminary planning. The inlet ponds have been modelled as per the TSC guidelines with their characteristics provided below in Table 3.19.

Table 3-19 Wetland sizes

	Inlet Pond		Macrophyte Zone		
Sub-catchment	Surface Area (ha)	Volume (m3)	Surface Area (ha)	Extended Detention depth (m)	Permanent Pool Volume (m3)
1	1.2	18525	1.2	0.5	8645
2	5.1	75700	5.1	0.5	35350
3	2.2	32625	2.2	0.5	15225

3.4.3.7 Mitigation option 2 – WSUD

The use of water sensitive urban design philosophies of vegetated swales and bio-retention trenches was adopted for the second case. It was assumed that all allotments would fall to a vegetated swale that discharged to a bio-retention trench. The adopted parameters for both treatment measures were estimated as there is no current lot layout to calculate the actual treatment train lengths. It was assumed that the roads would run generally parallel with the contours rather than across them.

The adopted parameters are provided below in Table 3.20. It is suggested that these criteria together with Tweed Shire Council's development guidelines (DCP16 Subdivision Manual - Section 4.2.3 Stormwater runoff, drainage, waterways and flooding; Development Design Specification D5 Stormwater Drainage Design; and Development Design Specification D7 Stormwater Quality) be adopted for future development.

Table 3-20: Grassed swale and bio-retention design parameters

Design Parameter - Grassed Swale		Design Parameters Bio-retention trench	
Length (m)	continuous	Length (m)	70m per ha
Slope (%)	2	Slope (%)	Flat
Base width (m)	1.5	Base width (m)	1.5
Depth (m)	0.5	Extended Detention Depth (m)	0.5
Vegetation height (mm)	100	Filter Depth (m)	1
Side slopes (1 in x)	4	Side slopes (1 in x)	4

The MUSIC model assumes that the treatment measures are in series downstream of the source nodes, however vegetated swales and bio-retention trenches are usually distributed throughout the catchment receiving distributed flows rather than a plug flow. An Excel spreadsheet for a small 1 ha catchment consisting of 10 allotments (1 ha in area allowing for road reserve and open space) was produced that allowed for individual allotment flows to enter a 200 m long swale fronting each allotment. The model cumulated flow from each individual block and calculated the various detention times each allotment flow would receive. The model showed that flow from the upper allotment would receive a detention time of over nine minutes, the middle allotment over five minutes, and the final allotment runoff would only travel in the swale for over one minute for the three month ARI flow. Overall, the runoff from all 10 allotments would receive good treatment with an average treatment time of over five minutes. As MUSIC models swales at the end of the catchment, not throughout the catchment, the equivalent swale configuration at the end of the 10 allotments was estimated using a similar Excel spreadsheet. The model showed that a swale length of 80 m would provide just over five minutes of retention time for the entire flow. This methodology was then adopted for all vegetated swales within the MUSIC model as it was assumed that the retention time is the main parameter of swale pollutant removal.

The scale of the catchments in the MUSIC model is much greater than 1 ha, therefore the scale of the swale had to be increased as the catchment area increased. As flow depth, velocity and retention time are the key parameters for swales, it was assumed that a doubling in catchment area would require a doubling in base width of the swale to approximate a more realistic flow depth, rather than doubling the length of the swale. Similar Excel spreadsheets were used to verify this assumption and a peer review by Dr Graham A Jenkins confirmed that this approach, while not 100 % correct (as the response is not linear), was the best approach to model a distributed swale network for large catchments.

The bio-filtration treatment processes are dependant on filter depth, filter media, surface area and extended detention depth. The surface area was therefore scaled up from the 1 ha catchment model which assumed a base width of 1.5 m for a length of 80 m. It was assumed that sand would be used as the filter media with an equivalent particle size of 0.7 mm and a saturated hydraulic conductivity of 360 mm/hr.

The MUSIC model was used to evaluate the expected performance of the vegetated swales and bio-retention systems and the results of the modelling are provided below in Table 3.21.

Table 3-21: Developed Mitigated Case WSUD – Pollutant Loads and Annual Flow

Average Year Results	Junction 1	Junction 2	Junction 3	Total	Pollutant load kg/ha/yr	Ave daily concen. mg/L
Flow (ML/yr)	429	2230	993	**3652**	n/a	n/a
Total Suspended Solids (kg/yr)	11900	59000	27000	**97900**	**289.5**	**2.9**
Total Phosphorous (kg/yr)	38.3	194	90.2	**322.5**	**0.95**	**0.03**
Total Nitrogen (kg/yr)	229	1360	626	**2215**	**6.55**	**0.30**
Gross Pollutants (Kg/yr)	0	0	0	**0**	**0.00**	n/a

The results assume that swales will be continuous throughout the model and that they will have a grade of 2 %. Any deviation from this will result in different pollutant removal efficiencies.

The MUSIC model results indicate that the WSUD treatment measures adopted will meet TSC's required annual pollutant guidelines. TSS is reduced by 71% from the developed unmitigated case, while TP and TN are reduced by 62% and 57% respectively. The model indicates that gross pollutants are completely removed by the treatment system. Pollutants could be reduced further by lengthening vegetated swales and increasing the surface area and depth of bio-retention, however the steep nature of the site will limit the effective length of both measures. The adopted lengths have been estimated by preparing a possible lot layout for one of the sub-catchments and estimating appropriate lengths.

3.4.3.8 Mitigation Option 3 – WSUD including rainwater tanks

Rainwater tanks were added to the WSUD case to observe their impact on pollutant loads. The MUSIC model does not include the option of adding rainwater tanks, however they were simulated by adding the MUSIC pond treatments. It was assumed that each allotment would have a 7.5 kL tank approximately 2 m high. The tanks were assumed to have a low flow bypass of 1l/s to allow for the bypass of first flush. Once the tanks are full, any excess water will overtop the storage and be directed towards the swales and bio-retention trenches. Recent studies by the Gold Coast City Council have indicated that the average water use per allotment is 693 L/ET.day (Gold Coast Water, 2003). The same study concluded that rainwater could be used to supplement between 30 % (external use only) to 90 % (all water use except kitchen use). This study has assumed that 75 % of daily household water demand could be supplied by rainwater, if available. The break-up of this is provided in the table below.

Table 3-22: Household water use

House hold use	% of total household use	Daily Water volume (litres)	Volume Adopted for Rainwater demand (litres)
Kitchen	10	69	0
Bathrooms	15	104	0
Laundry	15	104	104
Hot water	15	104	104
Toilets	15	104	104
External	30	208	208
TOTAL	**100**	**693**	**520**

It should be noted although the goal is to use rainwater for 75% of the daily household water supply, rainfall patterns and tank sizing may limit the available supply to much less than 75%.

It was assumed that each allotment had a daily demand of 520 L from the rainwater tanks and that each allotment has a roof area of 300 m^2. An additional source node was created to represent the roof area and typical roof pollutant loads were adopted by research from Duncan 1999. The TSC urban source node was amended to account for the loss of roof area with both the runoff and pollutant characteristics being amended. A check of both runoff volumes and the pollutant characteristics was undertaken to ensure that the separated source nodes produce the same characteristics as the TSC urban source node. The results of the MUSIC model are provided below.

Table 3-23: Developed Mitigated Case WSUD with rainwater tanks – Pollutant Loads and Annual Flow

Average Year Results	Junction 1	Junction 2	Junction 3	Total	Pollutant load	Ave daily concen.
					kg/ha/yr	mg/L
Flow (ML/yr)	420	2110	938	**3468**	**n/a**	**n/a**
Total Suspended Solids (kg/yr)	11700	57200	26100	**95000**	**280.9**	**2.9**
Total Phosphorous (kg/yr)	37.4	187	86.8	**311.2**	**0.92**	**0.03**
Total Nitrogen (kg/yr)	221	1300	598	**2119**	**6.27**	**0.30**
Gross Pollutants (Kg/yr)	0	0	0	**0**	**0.00**	**n/a**

The MUSIC model results indicate that the WSUD incorporating rainwater tanks will provide a small improvement to water quality. TSS is reduced by 72% from the developed unmitigated case, while TP and TN are reduced by 64% and 59% respectively. It would be expected that the addition of rainwater tanks would provide a greater benefit than a reduction of just 15% in annual flow volumes. This may be due to the rainfall pattern from the adopted average year which consists of large rainfall events dispersed throughout the year. A long term daily balance could be undertaken to analyse the change in flow conditions over a much longer period to determine if a greater supply of water from rainwater tanks is possible.

The rainwater tanks will also provide the benefit of reducing the demand on potable supplies. The Gold Coast City Council has estimated that domestic potable water demand could be reduced by up to 50% after the adoption of suitably sized rainwater tanks (Gold Coast Water, 2003). Measures should be in place to ensure that the maximum volume of rainwater is captured and stored for household use. The ability to capture the maximum possible roof area, installing large enough tanks to store water between dry periods, location of tanks (surface or buried tanks), and the ability to pump water to various areas of the house should be investigated to optimise rainwater tank performance. Manufacturers of rainwater tanks and pump systems should be consulted to provide guidance on the practical applications of suitable systems.

3.4.3.9 Mitigation option 4 – Treatment Train Approach

The MUSIC model indicates that an approach adopting grassed swales and biofiltration measures can reduce pollutants sufficiently to meet the TSC annual pollutant load requirements. This option was based on the criteria that grassed swales and biofiltration would be suitable for the entire site, based on an initial review of a potential lot layout. Best practice suggests that a treatment train approach would be appropriate to enhance further pollutant removal and provide a "redundancy" should a particular measure fail. The WSUD case with rainwater tanks was amended to include the wetlands previously modelled to provide a treatment train for the catchment. The design criteria discussed previously for each individual measure was adopted for this case. The results of the MUSIC model are provided below in Table 3.24.

Table 3-24: Developed Mitigated Case Treatment Train (Wetlands, WSUD with rainwater tanks) – Pollutant Loads and Annual Flow

Average Year Results	Junction 1	Junction 2	Junction 3	Total	Pollutant load	Ave daily concen.
					kg/ha/yr	mg/L
Flow (ML/yr)	395	2010	895	**3300**	**n/a**	**n/a**
Total Suspended Solids (kg/yr)	9280	49200	21300	**79780**	**235.9**	**5.8**
Total Phosphorous (kg/yr)	55.8	286	128	**469.8**	**1.39**	**0.08**
Total Nitrogen (kg/yr)	423	2180	1090	**3693**	**10.92**	**0.96**
Gross Pollutants (Kg/yr)	0	0	0	**0**	**0.00**	**n/a**

The MUSIC model results indicate that the treatment train approach provides the greatest level of TSS reduction of 77% from the developed unmitigated case. TP and TN reductions are still in-line with the requirements of TSC, however the addition of the wetlands provides a slight increase in both from Option 3. This increase is due to the MUSIC model default parameter of C* which equates to the minimum concentration that can be discharged by the treatment device, such as a wetland. Any increase in wetland size, detention time etc will not provide any reduction of pollutants below this level.

A review of site constraints has indicated that the available area for each wetland is around 50% of the area required for wetlands as per the TSC design guidelines. The inlet pond has therefore been reduced to the size suggested by Dr Jenkins which is based on the settling velocity of a sediment particles approximately 125 µm in size during a three month ARI design storm.

A separate MUSIC model was constructed with the following inlet pond volumes provided below:

- Wetland 1 – 434 m^3;
- Wetland 2 – 1000 m^3; and
- Wetland 3 – 563 m^3.

The results of the MUSIC model are provided below.

Table 3-25: Smaller Inlet pond wetlands – pollutant loads and annual flow

Average Year Results	Junction 1	Junction 2	Junction 3	Total	Pollutant load	Ave daily concen.
					kg/ha/yr	mg/L
Flow (ML/yr)	395	2010	895	**3300**	**n/a**	**n/a**
Total Suspended Solids (kg/yr)	8060	40900	18500	**67460**	**199.5**	**5.6**
Total Phosphorous (kg/yr)	42.6	219	99.1	**360.7**	**1.07**	**0.08**
Total Nitrogen (kg/yr)	321	1690	870	**2881**	**8.52**	**0.95**
Gross Pollutants (Kg/yr)	0	0	0	**0**	**0.00**	

The results indicate that the wetlands with smaller inlet ponds provide better treatment than the larger ponds with a reduction of annual TSS loads by 80 %, TP loads by 58 % and TN loads by 44%. This may indicate that the larger pond surface areas are redundant and do not contribute to any greater removal of stormwater pollutants.

It is recommended that the mitigation option 4, the treatment train approach, be adopted for the Tweed Area E development. The adoption of a range of best practice stormwater treatment measures that includes wetlands will provide additional water quality treatment should site constraints prevent any section of the system from performing to expectations. The addition of wetlands and rainwater tanks will provide additional benefits such as the attenuation of more frequent events and assist in limiting the impact of increased levels of imperviousness through the new development.

3.4.3.10 Cost estimate

Cost estimates for the three water quality infrastructure cases are provided in Table 3.26 below. The three cases investigated include:

- wetlands;
- grass swales and bio retention; and
- grass swales, bio retention and rainwater tanks.

The cost of the wetlands is high as the inlet ponds surfaces areas are large, as discussed previously.

Table 3-26: Cost estimate summary

	Capital Cost	Maintenance Cost per year
	Wetlands	
Catchment 1 – 49ha	$735,000	$15,000
Catchment 2 – 202ha	$3,030,000	$60,000
Catchment 3 – 87ha	$1,305,000	$26,000
Total – Option 1	**$5,070,000**	**$101,000**
	Grass Swales & Bio Retention	
Grass Swales	$1,010,000	$45,000
Bio-retention	$945,000	$60,000
Total – Option 2	**$1,955,000**	**$105,000**
	Grass Swales & Bio Retention & Rainwater Tanks	
Grass Swales	$1,010,000	$45,000
Bio-retention	$945,000	$60,000
Rainwater Tanks	$8,400,000	$300,000
Total – Option 3	**$10,355,000**	**$405,000**
	Treatment Train using all measures	
Grass Swales	$1,010,000	$45,000
Bio-retention	$945,000	$60,000
Rainwater Tanks	$8,400,000	$300,000
Wetlands	$5,070,000	$100,000
Total – Option 4	**$15,425,000**	**$505,000**
	($7,025,000 not incl. rain tanks)	**($205,000 not incl. rain tanks)**

Wetland costs are based on $15,000/ha of catchment area reporting to the wetland.

Grass swale costs are based on $46/m, with 65 m of swale allowed for per hectare.

Bio-retention costs are based on $80/m, with 35 m of bio-retention swale allowed for per hectare. Bio-retention costs also allow for a grass swale on top of each bio-retention trench.

Rainwater tank costs allow for one tank per allotment, assuming 10 allotments per hectare. Rainwater tanks are based on $3000 per 7.5 kL tank and pump.

Maintenance costs are based on the following:

- wetlands systems $6000/ha of wetland/year;
- rainwater tanks and gross pollutant traps 3% of the capital per year;
- swales $3/m/year; and
- bio-retention $5/m/year.

No additional allowance has been made for asset replacement after a predetermined time.

3.4.3.11 Additional Pollutants

The WQO's identified in the EPA interim guidelines include parameters for the protection of aquatic ecosystems, shellfish production and recreational activities. These values include parameters such as faecal coliforms, pH, turbidity and dissolved oxygen. The MUSIC program was used to identify the water quality impacts from catchment development and evaluate the performance of potential stormwater quality treatment measures. The default MUSIC pollutants do not include these parameters; however they could be modelled if sufficient statistical data existed. Discussions with TSC officers have indicated that this data is currently not available. PB has reviewed research undertaken by the CRC for Catchment Hydrology to identify the likely concentrations of these additional pollutants from a typical urban catchment in order to assess their likely impact on downstream water quality.

Table 3.27 highlights the expected concentration and the required concentration to protect the desired value as presented in the NSW EPA interim guidelines. Where different environmental values have objectives for the same pollutant, the more stringent criteria has been identified, eg. the water quality objectives for primary contact recreation have been adopted over those for secondary contact recreation.

Table 3-27: Additional water quality objectives

Indicator	WQO	Expected Pollutant value	Environmental Value
Chlorophyll-a	1-10µg/L		**Aquatic ecosystem**
Dissolved Oxygen	>6mg/L or 80-90 % saturation over a 24 hour period		**Aquatic ecosystem**
pH	5.0-9.0	6.8	**Aquatic ecosystem, Primary contact recreation**
Chemical contaminants	Free from chemicals or pollutants that are either toxic to humans, animals, plants and other organisms or irritating to the skin or mucus membranes		**Aquatic ecosystem, Primary contact recreation.**
	Refer to ANZECC (1992) guidelines for chemical contaminants and tainting substances.		**Aquatic Foods (cooked)**
Surface films and debris	Oils and petrochemical films should not be noticeable as a visible film nor detected by odour. Free from floating debris and litter.		**Primary contact recreation, Visual Amenity**
Faecal coliforms	Median over bathing season < 150 faecal coliforms per 100mL, with 4 out of 5 samples < 600/100mL	25,000/100ml	**Primary contact recreation**
	Median bacterial concentration < 14MPN/100mL; 10 % of samples > 43 MPN/100mL NSW SQAP medial faecal coliform level of 14 faecal coliforms/100mL		**Aquatic Foods (cooked)**
Turbidity	Approximately 5 NTU	70 NTU	**Aquatic Ecosystems, Primary contact**

Indicator	WQO	Expected Pollutant value	Environmental Value
			recreation
Algae and blue green algae	No guidelines for aquatic foods, however limit blue green algae which may contain toxins Primary contact recreation < 15 000 cells/mL	Dependant on Nutrient bioavailability	**Aquatic Foods (cooked), Primary contact recreation**
Enterococci	<35 /100mL		**Primary contact recreation**
Protozoans	Pathogenic free-living protozoans should be absent		**Primary contact recreation**
Temperature	15-35 deg C < 2 deg increase		**Primary contact recreation, Aquatic ecosystems**
Visual clarity and colour	< 20% reduction in visual clarity Waters deeper than 50% euphotic depth – depth should not change by more than 10%. Waters shallower than 50% of euphotic depth max reduction in light at the sediment bed should not exceed 20% < 10 point change on Munsell Scale <50% change in natural reflectance		**Aquatic ecosystems, Visual Amenity**
Nuisance organisms	Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae, sewage fungus and leeches should not be present in unsightly amounts		**Visual Amenity**
Salinity	<1500 uS/cm		**Aquatic ecosystems**

The following is a summary of each physico-chemical indicator for the environmental values significant to Tweed Area E:

- primary recreation;
- secondary recreation;
- visual amenity;
- aquatic ecosystems; and
- aquatic foods (shell fish).

Primary recreational contact relates to activities such as swimming, bathing and other direct water-contact sports and the water quality objectives require that the water should be sufficiently free from faecal contamination, pathogenic organisms and other hazards such as poor visibility or toxic chemicals to protect the health and safety of the user.

Secondary contact activities such as boating and fishing relate to usage where there is less body contact with the water and need to incorporate excessive growth of algae and other plants, and floating or submerged debris which could injure skiers or damage boating vessels.

Aquatic ecosystems comprise the plant, animal and microbial communities that live in water and the physical environment and climate regime with which they interact. The guidelines required to protect aquatic ecosystems are often the most stringent, and specifically in this case because of the downstream shellfish culture and harvesting.

Surface waters used for visual recreational use (no-contact activity) should not be altered in any way that reduces their ability to support aesthetically valuable flora and fauna. Visual amenity is directly related to each of the above environmental values and can be improved by protecting the ecosystems and improving stormwater quality management (EPA interim guidelines).

Turbidity

Turbidity is a pollutant that impacts primary recreation and aquatic ecosystems environmental values. The turbidity of water is caused by the presence of suspended particulate and colloidal matter consisting of suspended clay, silt, phytoplankton and detritus. Turbidity depends mostly on particle size, composition and particle concentration and the main source is usually from fine particulates, 0.125 mm and below (Fletcher et al, 2003).

Impacts

Water clarity is a major determinant of the condition and productivity of an aquatic system, and of the quality of water for primary recreation. Increased turbidity can change an ecosystem significantly, reducing the light available for photosynthesis.

Turbidity caused by suspended sediment can smother benthic organisms and habitats, and cause mechanical and abrasive impairment to the gills of fish and crustaceans. Suspended sediment also transports contaminants (particulate nutrients, metals and other potential toxicants), promotes the growth of pathogens and waterborne diseases, makes marine pests difficult to detect and can lead to dissolved oxygen depletion in the water column if it is caused by particulate organic matter.

Potential Sources

Tweed Area E is primarily a residential development and the main source of suspended particulate matter is from diffuse land runoff due to soil erosion in the upstream catchment. Suspended particulate matter could arise from point sources such as sewage outfalls and stormwater drains.

Management Practices

Useful structural stormwater treatment measures for turbidity are given below:

- grass swales;
- sand filters;
- porous pavements; and
- constructed wetlands.

These appropriate treatment measures are able to retain particles down to 0.45 μm (NSW EPA, 1997) which is expected to reduce turbidity levels. Optimum structural treatment methods include filters and porous pavements because they target the smaller particle sizes (GCCC, 2002). Constraints to sand filter treatment performance includes hydraulic head loss limitation and high sediment input, similarly constraints for porous pavements include, steep catchment slopes, high water tables, shallow bedrock and land availability.

Managing the construction and operational phases of the development at the source is a positive option to assist in reaching guideline turbidity values. Source management options include:

- Minimising stormwater runoff across construction sites and areas of roadwork to prevent sediment washing downstream.
- Provision of a buffer zone with a mixture of native plants to filter runoff from disturbed slopes, trapping pollutants and stabilizing gully banks, preventing bank erosion. These plants will also provide a natural riparian ecosystem.
- community education to encourage increased planting and maintenance of native vegetation on properties and including information about the importance of buffer zones and riparian vegetation along creeks.

Appendix F shows the pollutant reduction efficiencies for a range of structural stormwater management practices.

Algal Blooms

The environmental values that are directly affected by algal blooms are cooked shellfish and primary recreation. Algal blooms occur naturally with phytoplankton or micro-algae providing food for aquatic organisms. Harmful algal species are usually naturally occurring algae that reach high enough concentrations to be a nuisance. Harmful algal blooms can be divided into three groups:

1. group one (some cyanobacteria, diatoms and macroalgae) – when these species occur in dense blooms, they can cause fish and invertebrate kills as dissolved oxygen is consumed when the bloom decomposes;
2. group two (toxic cyanobacteria and dinoflagellates) – harmful algal species that produce potent toxins and can cause illness or death in grazers which may impact species further up the food chain due to the effects of bioaccumulation; and
3. group three (some diatoms, dinoflagellates and raphidophytes) – species that are not toxic, but that have physical attributes such as spines which can irritate and damage gills and tissues of fish.

Impacts

Harmful algal species can be composed of species that are toxic and irritate the skin of humans (public health nuisances) or be toxic to fish and other aquatic life. Blooms give rise to large fluctuations in water column dissolved oxygen concentrations and pH, and only species with broad dissolved oxygen and pH tolerances can survive. In addition, when the microalgae decay it releases waste products and bioavailable nitrogen, produces offensive odours and consumes large amounts of dissolved oxygen. Aquaculture production can be severely impacted by the presence of algal blooms, both from direct mortality of fish and shellfish due to reduced dissolved oxygen availability and the potential bioaccumulation of toxins if filter feeding organisms are being grown.

Potential Sources

Blooms are most common if warm, calm and stratified conditions occur after rainfall events in waterbodies and estuaries that are subject to elevated nutrient loads. If nutrient loads within the Tweed Area E development are high and there are no natural systems in place for dilution, then algal blooms could occur.

Management Practices

PB developed a water quality pollutant export model to generate pollutant loads and event mean concentrations for Total Phosphorus and Total Nitrogen. The structural stormwater treatment measures proposed to assist in the mitigation of high nutrient levels were:

- wetlands;
- at source vegetated swales and bio-retention trenches; and
- rainwater tanks together with at source vegetated swales and bio-retention trenches.

Because of the direct relation to nutrient loading, algal blooms are not expected to be a problem for the Tweed Area E development if the above measures are implemented and successful in mitigating high nutrient loads.

Further management options for high nutrient loading include source measures such as reducing stormwater runoff and rehabilitating riparian zones to assimilate nutrients (Cranmer et al, 2001). Some possible alternatives to structural treatment measures are given below:

- encourage properties to use native vegetation along creeks and elsewhere on private property to naturally filter organic material;
- educate and encourage residents to adopt stormwater wise management practices to reduce nutrient generation at the source;
- rehabilitate riparian zones to act as a natural trap for sediments and nutrients; and
- encourage residents to control animal wastes and fertilizer use through education via pamphlets and signs in parks and other recreational areas.

Dissolved Oxygen

Measures of dissolved oxygen (DO) refer to the amount of oxygen contained in water, and define the living conditions for oxygen-requiring (aerobic) aquatic organisms. DO concentrations reflect equilibrium between oxygen-producing processes (e.g. photosynthesis) and oxygen consuming processes (e.g. aerobic respiration, nitrification). The dissolved oxygen concentration in a waterbody is highly dependant on temperature, salinity, biological activity (microbial, primary production) and rate of transfer from the atmosphere.

Impacts

Low DO concentrations can result in adverse effects on many aquatic organisms (e.g. fish, invertebrates and microorganisms) which depend upon oxygen for their efficient functioning. Most aquatic organisms require oxygen in specified concentration ranges for respiration and efficient metabolism, and DO concentration changes to above or below this range can have adverse physiological effects. Even short-lived anoxic conditions (DO concentrations near zero) or hypoxic conditions (DO concentrations < 2.0 mg/L) can cause major kills of aquatic organisms (AGGA et al 2003). Exposure to low oxygen concentrations can have an immune suppression effect on fish which can elevate their susceptibility to diseases for several years. Moreover, the toxicity of many toxicants (lead, zinc, copper, cyanide, ammonia, hydrogen sulfide and pentachlophenol) can double when DO is reduced from 10 to 5 mg/L (NSW EPA, 2003). If dissolved oxygen becomes depleted in bottom waters (or sediment), nitrification, and therefore denitrification, may be terminated, and nutrients may be released from the sediment to the water column which can give rise to or support algal blooms.

Potential Sources

Dissolved oxygen levels are primarily dictated by nutrient levels in the water. Nutrient enrichment stimulates plant and algal growth (and algal blooms as discussed previously) and often results in a mass influx of particulate organic matter to the sediments (eutrophication). The decomposition of this organic matter by aerobic microorganisms leads to a rapid acceleration of oxygen consumption, and potential depletion of oxygen in bottom waters. Increased human activity will be the main source of nutrient loads in Tweed Area E in addition to eroded soils and aquaculture. In Australia, nitrogen and phosphorus export in waterways increases with the extent of catchment cleared.

Management Practices

The amount of dissolved oxygen is related primarily to the discharge of nutrients into the Tweed Area E waterways. As described in the suggested management practices of algal blooms, low dissolved oxygen should not be an issue for the development if nutrient loads are successfully managed as water quality modelling demonstrated. Structural stormwater treatment measures have been recommended to help mitigate high nutrient loading and indirectly mitigate both algal bloom and dissolved oxygen pollutants.

At source management options such as community education on stormwater management and riparian habitat rehabilitation as described for both nutrient loading and algal blooms will be effective in mitigating dissolved oxygen problems.

Chlorophyll a

Chlorophyll a (chl a) is a physico-chemical indicator for aquatic ecosystem health. Chlorophyll a is a green pigment found in plants. It absorbs sunlight and converts it to sugar during photosynthesis. Chl a in the water indicates that plants, algae or cyanobacteria are actually growing and that appropriate management action should be taken to identify the species. Chl a can be used as a non-specific indicator of the trophic status (level of pollution) of a water body.

Impacts

High chlorophyll concentrations can lead to excessive water column productivity and contribute to high amounts of easily decomposed organic matter to the sediments. Photosynthetic production and subsequent decomposition of algal biomass can increase the diurnal amplitude of water column pH and dissolved oxygen fluctuations, and in some cases may lead to anoxic and hypoxic events. The above changes can translate into an overall reduction in animal and plant species diversity.

Potential Sources

Chlorophyll a concentrations can be an alternative indicator of nutrient pollution. It is natural for chlorophyll a levels to fluctuate over time. Chlorophyll a concentrations are often higher after rainfall, particularly if the rain has flushed nutrients into the water. Higher chl a levels are common during the summer months when water temperatures and light levels are high because these conditions lead to greater phytoplankton numbers. Nutrient loading into the waterways will directly affect the chlorophyll a levels. Changes to systems which decrease (e.g. construction of canal estates) or increase (e.g. breakwaters, training water, and dredging) flushing rates influence chlorophyll a concentrations because flushing dilutes nutrients and moves them away from plants, making them less available. Conversely, slow moving or stagnant waters let nutrients increase and cell numbers grow.

Management Practices

The management strategies that have been recommended for nutrient loading in the Tweed Area E development will assist in mitigating chlorophyll a levels. Investigation of construction practices in the residential area is needed to ensure that the aquatic ecosystem and flushing system of the waterway is not adversely affected.

Faecal Coliforms

Faecal coliforms are indicators of disturbance to environmental values such as shellfish and primary recreation and are used as an indicator of faecal contamination of water. Faecal coliforms are bacteria and are a subset of total coliforms, and are more closely associated with faecal contamination. Escherichia coli (E. coli) is a member of this group, and is specifically of faecal origin (Duncan, 1999). Faecal coliforms are used to indicate the presence of viruses in the aquatic food and ecosystems because the viruses of concern to human health are derived mainly from sewage, E. coli and other faecal coliforms.

Impacts

Primary Recreation – faecal coliform is an indicator for detection of pathogens in fresh and marine waters. There is a long international experience of disease outbreaks associated with bathing areas contaminated with pathogens such as salmonellae, shigellae, enteropathogenic Escherichia coli and infectious hepatitis (ANZECC, 2000). Generally, the most common types of diseases that have been associated with swimming areas are eye, ear, nose and throat infections, skin diseases and gastrointestinal disorders.

Shellfish (cooked) – there are a number of biological contaminants which can affect human consumers of aquatic foods, including bacteria, viruses, parasites and micro-algae. Filter-feeding shellfish (bivalves) can concentrate these potential contaminants to levels higher than that in the water source. Shellfish are considered to be a higher risk for consumers of aquatic foods (ANZECC, 2000).

Potential Sources

Faecal coliform counts from residential areas are typically ten times as large as those from other types of high urban land use (Duncan, 1999). Possible causes include:

- sewer overflows — to release to land any sewage flow blockages resulting from pump failure and other disturbances; and
- household pets and native animals — faecal contamination around parklands and lakes, runoff into waterbodies.

Management Practices

Useful structural stormwater treatment measures to prevent contamination from faecal coliforms are given below:

- filter strips;
- grass swales;
- sand filters;
- infiltration trench/basin;
- porous pavements;
- extended detention basin; and
- constructed wetlands.

Porous pavements, filter strips, grass swales and constructed wetlands are the optimum treatment methods (BCC, 2000), however site constraints must be considered before adopting any structural treatment measure.

Preventing faecal coliforms at the source is a positive option to assist in reaching guideline values. Source management options include:

- encouragement of responsible pet ownership, e.g. doggie bags for pet faeces located at walkways and parks; and
- signs highlighting regulations and fines signs for pet walkways, parks and lakes to dispose correctly of domestic animal faeces.

Appendix F shows the pollutant reduction efficiencies for the faecal coliform management practices.

Salinity

Salinity or electrical conductivity are measures of the total concentration of inorganic ions (salts) in estuarine and marine waters, with ocean waters having a salinity around 35 parts per thousand (ppt) (AGGA et al, 2003). EC is used to measure the total ion concentration in fresh and brackish waters. Measures of salinity can indicate whether the chemical nature of aquatic ecosystems is being altered and provides a warning of the potential loss of native biota.

Impacts

Most aquatic organisms function optimally within a narrow range of salinity. Salinity changes may affect aquatic organisms in two ways:

- direct toxicity through physiological changes (particularly osmoregulation) – both increases and decreases in salinity can have adverse effects; and
- indirectly by modifying the species composition of the ecosystem and affecting species that provide food or refuge.

While freshwater biota are most vulnerable to increased salinity, marine and estuarine biota are equally susceptible to decreased salinity. The development of salinity guidelines is complicated because of the uncertainty of whether discharges of either highly saline water or freshwater is likely to substantially change the existing (or desired) salinity regime in the system. Trigger values for naturally saline wetlands or streams, and similarly for systems with naturally very low salinity, must be derived only after adequate scientific data are available for the particular ecosystem. Site specific evaluations using biological indicators may be necessary in these cases, especially where the natural variability is small.

Potential Sources

Salinity levels fluctuate with the penetration of tidal flows and with mixing of fresh water and marine water by wind and currents. Decreased freshwater inflows, due to the diversion of rivers and streams into impoundments such as weirs or wetlands, lead to the dissipation of salinity gradients and extended periods of elevated salinity in natural wetlands adjacent to the Broadwater. Conversely large incursions of stormwater runoff can severely depress normal salinity levels in inshore areas (ANZECC, 2000). The salinity levels of the existing wetlands is controlled by the existing amount of freshwater runoff from rain events from the upstream catchments and the tidal flushing from Trutes Bay which is limited by existing flood gates.

Management Practices

The most effective option to help alleviate the adverse effects of salinity is to minimise disruption to the natural flow regime of the water system (DNRE et al, 1998). Some specific management options are:

- minimise stormwater runoff and increase of water reuse within the development;
- minimise use of weirs and dams that will prevent natural flow through the system;
- investigate the impacts that wetlands have on the flow regime;
- awareness of upstream and downstream engineering works that could affect salinity; and
- conduct site specific evaluations using biological indicators and develop rigorous experimental modelling to create trigger values for normal ecosystem salinity.

Temperature

Aquatic ecosystem functioning is very closely regulated by temperature. Biota, and physical and chemical processes like oxygen solubility and hydrophobic interactions are sensitive to temperature changes (ANZECC, 2000). Water temperature regulates ecosystem functioning both directly through physiological effects on organisms, and indirectly, as a consequence of habitat loss.

Impact

Unnatural changes in water temperature impact indirectly upon biota through loss of supporting habitat, by changing the solubility of oxygen and calcium carbonate in water, or by influencing the extent to which metal contaminants and other toxicants are assimilated by physiological processes. Temperature is probably the most important factor influencing viral persistence in estuarine environments (AGGA et al, 2003). Water temperature influences the density, conductivity, pH, partial pressure of Carbon Dioxide and the saturation states of minerals of seawater. Water temperature also impacts the conversion of dissolved oxygen measurements to % saturation values.

Potential Sources

The main causes for water temperature change in the Tweed Area E development will be changes in the amount of freshwater flow and the extent of to which freshwater is mixed with marine water by winds and tides. There should be no major discharge sources of either hot or cooling water from municipal or industrial effluent in the Tweed Area E.

Management Practices

Temperature changes are very strongly mediated by hydraulic mixing, e.g. river flow, tidal mixing or wind-driven mixing in lakes and waterbodies (ANZECC, 2000). A well mixed waterbody will not stratify and will be buffered to some extent from the effects of thermal pollution. The two main management options to prevent thermal stratification are artificial aeration and managing water diversions such that streams and gullies continue to flow.

Artificial aeration is not expected to be required for the Tweed Area E residential development. Managing water diversions to maintain natural flow regimes as shown above (salinity) is recommended to help achieve a stable temperature distribution.

pH

pH is a measure of the acidity or alkalinity of water on a log scale from 0 (extremely acidic) through 7 (neutral) to 14 (extremely alkaline). The NSW EPA interim guidelines for pH are 5-9. The expected pollutant concentration for Tweed Area E is 6.8 (NSW EPA, 2003). The pH of the water bodies within the area and runoff generated from the catchment is not expected to cause significant problems to the environmental values of the area. A monitoring program that includes measurements of pH will determine if levels stay within guideline values.

Oil and Grease (including petrochemicals)

Oil and grease is a composite of possibly thousands of organic chemicals with different properties and toxicities (Duncan, 1999), as components of liquid and gaseous fuels, petroleum hydrocarbons are amongst the most widely processed and distributed chemical products in the world (ANZECC, 2000).

Impacts

The presence of oil and petrochemicals makes water aesthetically unattractive. They can form deposits on shorelines, and bottom sediments that are detectable by sight and odour. Some organic compounds can be absorbed directly from the water through the skin, making these substances even more undesirable in recreational areas (ANZECC, 2000).

The lighter oil fractions (kerosene, petrol, benzene, toluene and xylene) are much more toxic to fish than the heavy fractions (heavy paraffins and tars). Fish species can differ significantly in their sensitivity to these compounds.

In general, oils of animal or vegetable origin are chemically non-toxic to aquatic life, although they can taint the flesh of food species, coat gills reducing oxygen uptake, increase BOD levels and increase maintenance of water treatment equipment.

Potential Sources

Primary sources in surface waters include runoff from roads, car parking areas and discharges from areas using oil. Sources of oil and grease include food processing and preparation, operation and maintenance of vehicles and machinery, and natural compounds leached from vegetation and plant litter.

Management Practices

Useful structural stormwater treatment measures for oil and grease are given below:

- oil and grit separators;
- sand filters;
- infiltration trench/basin;
- porous pavements; and
- constructed wetlands.

These appropriate treatment measures are able to help mitigate oil and grease in the water system. The optimum treatment methods from those available are sand filters and constructed wetlands.

Preventing the pollutant at the source is a positive option to assist in reaching guideline oil and grease values. Source management options include:

- encouragement and education of responsible resident disposals — all oil from the house disposed of correctly;
- minimise food disposals from restaurants and food industries in the residential area; and
- providing car parking areas with suitable oil collection systems such as oil and grit separators.

Appendix F shows the pollutant reduction efficiencies for the oil and grease management practices.

Litter

Litter includes paper, plastic, glass, metal and other packaging materials.

Impacts

The impacts of litter are primarily aesthetic, but also pose a risk to aquatic ecosystems by preventing plant growth and entrapping animals. Litter may not indicate the degree to which the water is affected by chemicals, nutrients and bacteria but is often seen by the community as a sign of poor water quality. The poor visual appearance of the water system can perpetuate a depressing image, reduce the environmental and recreational facility of the river and set a poor example for people and actually encourage more littering (AGGA, 2003).

Potential Sources

Litter is generally associated with human activities that result in waste generation. Litter can be deposited in the catchment in a number of ways such as deliberate pollution or overflows from rubbish bins. Once litter is on the ground it can easily be transported by storm runoff into stormwater systems and washed into local gullies and creeks.

Management Practices

Useful structural stormwater treatment measures for litter are given below:

- in ground gross pollutant traps (GPTs);
- open GPTs;
- water quality ponds;
- filter strips;
- litter and trash racks;
- litter booms;
- downwardly inclined screens; and
- constructed wetlands.

These appropriate treatment measures are able to help mitigate litter problems in the water system. The optimum treatment methods from those available are in-ground GPTs, open GPTs water quality ponds and constructed wetlands (BCC, 2000).

Managing litter generation at the source is a major beneficial option to assist in preventing litter problems. Source management options include:

- Installation of rubbish bins throughout the Tweed Area E development area, particularly recreational areas such as parks and shops.
- Street sweeping – is a widely used practice to reduce the amount of street borne pollutants entering the stormwater system (DNRE et al, 1998). Coordination and integration between street cleaning and other maintenance activities is essential to maximise the benefits of street cleaning.
- Encouragement and education of responsible resident disposals — all litter from the residential area should be disposed of correctly.

Appendix F shows the pollutant reduction efficiencies for the litter management practices.

Chemical Contaminants

Chemical contaminants may be categorised into three broad groups (ANZECC, 2000).

- ***Inorganic chemicals (mostly heavy metals):*** These are a potential problem for human health, particularly in the case of bivalve molluscs where bioaccumulation increases the concentrations of toxicants. The rate of accumulation is species specific and depends on the mechanism of absorption and tissue distribution.
- ***Organic chemicals (pesticides and herbicides):*** This broad group includes synthetic compounds which through either bioaccumulation or residue concentrations are potentially toxic to human consumers of contaminated aquatic foods.
- ***Radionuclides (radioactive elements):*** Any man-made or natural element that emits radiation and that may cause cancer after many years of exposure through drinking water.

Impacts

Waters containing chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreation. In general, there are two kinds of human exposure in swimming areas: contact with the waterbody and ingestion of the water. Many pesticides are broken down into harmless products by microorganisms.

Potential Sources

Heavy metals in the residential area will mainly be sourced from roads, roofs, cars and paints. These will usually enter waterways via runoff. Pesticides and fertilisers enter water from land by aerial drift, runoff or leaching into groundwater.

Management Practices

Useful structural stormwater treatment measures for chemical contaminants are given below:

- constructed wetlands;
- grass swales;
- sand filters;
- infiltration trench/basin; and
- porous pavements.

These appropriate treatment measures are able to help mitigate chemical contamination problems in the water system. The optimum treatment methods from those available are constructed wetlands, infiltration trenches and basins and porous pavement (BCC, 2000).