Te Awanui Harbour

Literature review of scientific reports

Bay of Plenty Regional Council
Environmental Publication 2014/13

5 Quay Street
PO Box 364
Whakatāne 3158
NEW ZEALAND

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Part 1: Summary of Environmental Health

1.1 Te Awanui Tauranga Harbour and Catchment Environmental Monitoring

Monitoring of key parameters of ecological health of Tauranga Harbour and Catchments has occurred since the early 1990's as part of the Natural Environment Regional Monitoring Network (NERMN) Programme (see Figure 1). Results from this monitoring enables analysis of trend information to show whether the health of the harbour and catchments is decreasing, improving or stable. The following is a summary of recent trend information from the NERMN Programme. Much of this monitoring information will be published as part of our regional focused reporting of estuaries and rivers.

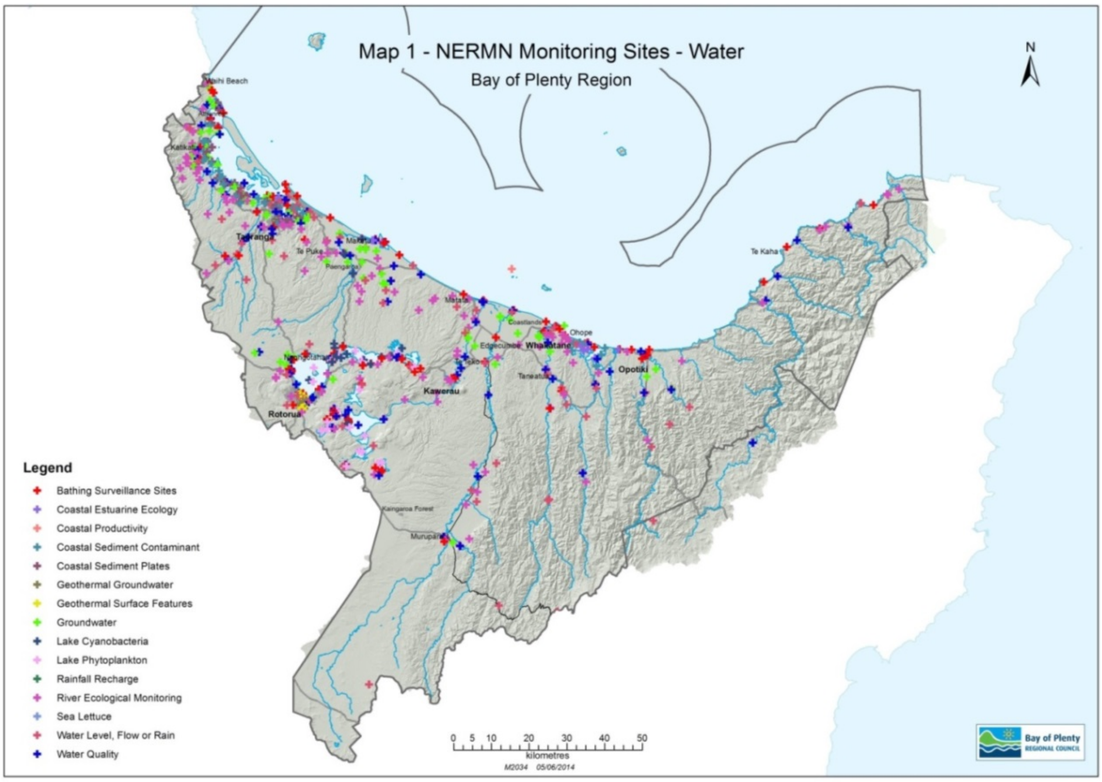


Figure 1 Map of NERMN monitoring sites throughout the Bay of Plenty region. Showing over 1,000 locations where environmental monitoring information is collected.

1.2 Water quality

Water quality information is collected from 10 swimming water quality sites, 19 stream water quality sites and 13 harbour water quality sites, across Tauranga Harbour and Catchments. This information is used to derive trends in water quality and compare against national standards such as the National Objectives Framework (NOF) for freshwater. The National Policy Statement (NPS) for Freshwater Management which set national values for freshwater to protect human health for recreation and ecosystem health. The NOF defines thresholds for numeric attributes, ranked into four bands (A-D) which define water quality and effectively set Natural Bottom Lines. Below summarises water quality trends and compares Tauranga Harbour water quality against the NOF banding.

1.2.1 Tauranga Harbour – estuarine water quality

Several trends have been observed in water quality data collected from Tauranga Harbour. The most consistent trend is a decrease in total phosphorus concentrations at five of the ten sites in the southern harbour, and a decrease in dissolved phosphorus at three sites in the northern harbour. Sites at Kauri Point and Maungatapu had the highest median total phosphorous concentrations, but these are below the established Water Quality Guideline levels.

Three northern harbour sites showed increases in chlorophyll-a concentrations which is an indicator of phytoplankton production. Pahoia, in the upper reaches of the southern harbour, has the highest median chlorophyll-a concentrations followed closely by its northern counterpart, Kauri Point. Spring-summer concentrations of dissolved phosphorus are lowest at these sites indicating that this nutrient may limit potential phytoplankton and macro-algae (seaweed) production.

The highest average suspended solids and turbidity values occurred at Pahoia, Otumoetai and Te Puna, with maximum values highest at Pahoia, Te Puna and Ōmokoroa. While maximum turbidity results have been above the recognised Water Quality Guideline (ANZECC) (10 NTU) at five of the 13 sites in the harbour, three quarters of the data is below this level for all sites. This shows that overall water clarity is good.

1.2.2 Stream and river water quality

The water quality from suspended sediment, clarity, nitrogen, phosphorus and faecal contamination from 19 sites in Tauranga Harbour tributary streams has been largely stable or improving over the last decade. A small number of sites are showing increases in dissolved reactive phosphorus (DRP), total phosphorus (TP) and nitrate-nitrogen. Of note is a significant deterioration (since 2004) in DRP and TP in the Omanawa River, most probably related to land use changes to large areas of land in the upper part of that catchment during the monitoring period. However, the indicator bacteria (*E.coli)* has displayed an improving trend in the Omanawa River.

1.2.3 Recreational water quality

When compared with the Microbiological Water Quality Guidelines, faecal indicator results show that the microbiological water quality of Tauranga Harbour is generally good. Elevated results exceeding safe recreational limits occasionally occur, and are often associated with rainfall or contamination events such as sewage overflows. Increasing trends in Tauranga Harbour are at sites in close proximity to the Wairoa River, the largest freshwater inflow.

The swimming water quality of streams flowing into the Tauranga Harbour was variable with Kaiate Stream and the Wairoa River at McLarens Falls having the highest exceedances (see Figure 2). No median values were over the Orange/Alert Mode, indicating that on average, all rivers over the 2014/2015 season where suitable for swimming.

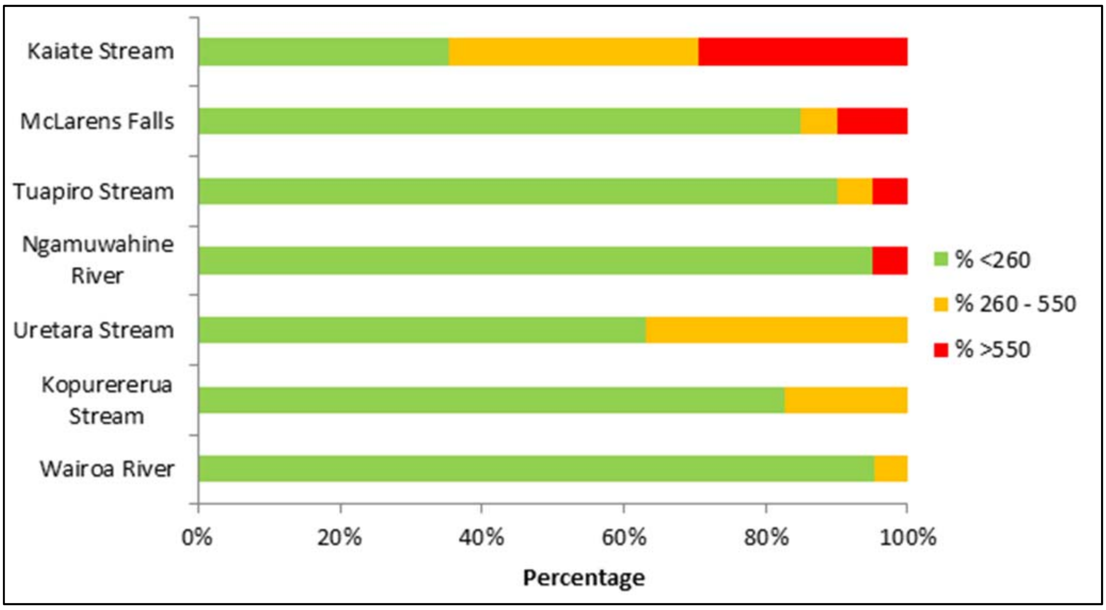


Figure 2 *River and stream E.coli levels compared against each of the modes in the NZ Microbiological Water Quality Guidelines (MfE/MoH 2003), 2014/2015 bathing season. The system uses the colours green (safe mode, 'surveillance'), orange (cautionary mode, 'alert') and red (unsafe mode, 'action') to denote the level of risk to users.*

1.2.4 National Objective Framework (NOF) comparison

Below is a summary of water quality data in comparison to the NOF bands.

- No sites are currently below the National Bottom Line, or indeed in the 'C' Band, for nitrate, ammonia or *E.coli* (for secondary contact recreation).
- Four sites have fallen into the "C" Band for *E.coli*, secondary contact recreation (e.g. boating), in previous years (Table 3).
- Summer surveillance *E.coli* monitoring (weekly or bi-weekly monitoring over the summer period) all sites fail to meet the Minimum Acceptable State (MAS) for primary contact recreation (e.g. bathing, swimming) (Table 4).

1.2.5 Rivers and streams - Tauranga Harbour

Table 1 NOF banding for Nitrate (annual median) and ten-year trends (2004-2013) in rivers and streams. NT = No trend, ⇩ = Meaningful decrease, ⬂ = Significant decrease, ⇧ = Meaningful increase. ⬀= Significant increase.

Site by WMA	2009	2010	2011	2012	2013	Ten-year trend
Tauranga Harbour						
Aongatete River @ SH 2		A	A		A	NT
Kopurererua @ SH 2	A	A	A	A	A	NT
Kopurererua @ SH 29	A	A	A	A	B	NT
Ngamuwahine @ Old Bridge		A	A		A	NT
Omanawa @ SH 29	B	B	B	B	B	⇩
Rocky @ Mangatawa	A	A	A		A	NT
Te Mania @ SH 2	A	A	A	A	A	NT
Te Rereatukahia @ SH 2		A	A		A	NT
Tuapiro @ Surtees Road		A	A		A	NT
Uretara at Henry Road Ford		A			A	NT
Waiau @ Road Ford		A	A		A	NT
Waimapu @ 100 m d/s of SH 29	A	A	A	A	A	NT
Waimapu @ Pukemapui Road		A	A		A	NT
Waipapa @ Old Bridge		A	A		A	NT
Wairoa at SH 2 Bridge	A	A	A	A	A	NT
Wairoa d/s of Ruahihi		A	A		A	NT
Waitao @ Spenser's Farm		A	A	A	A	NT
Waitekohe @ SH 2		A	A		A	NT

Table 2 *NOF banding (annual median) and 10 year Trend, for Ammonia in rivers and streams. NT = No trend, ⇩ = Meaningful decrease, ⬂ = Significant decrease, ⇧ = Meaningful increase. ⬀= Significant increase. (Median and maximum data have been adjusted to relative pH=8).*

Site by WMA	2009		2010		2011		2012		2013		Ten-year trend
	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	
Tauranga Harbour											
Aongatete River @ SH 2			A	A	A	A			A	A	NT
Kopurererua @ SH 2	A	B	A	B	A	B	A	B	A	B	NT
Kopurererua @ SH 29	A	A	A	A	A	B	A	A	A	A	NT
Ngamuwahine @ Old Bridge			A	A	A	A			A	A	NT
Omanawa @ SH 29	A	A	A	A	A	A	A	A	A	A	⇧
Rocky @ Mangatawa	B	B	B	B	B	B			B	B	NT
Te Mania @ SH 2	A	B	A	A	A	A	A	A	A	A	⇧
Te Rereatukahia @ SH 2			A	A	A	A			A	A	NT
Tuapiro @ Surtees Road			A	A	A	A			A	A	NT
Uretara at Henry Road Ford			A	A	A	A			A	A	NT
Waiau @ Road Ford			A	A	A	A			A	A	NT
Waimapu @ 100 m d/s of SH 29	A	A	A	A	A	A	A	A	A	A	NT
Waimapu @ Pukemapui Road			A	A	A	A			A	A	NT
Waipapa @ Old Bridge			A	A	A	A			A	A	NT
Wairoa at SH 2 Bridge	A	A	A	A	A	A	A	A	A	A	NT

Table 3 NOF banding for Human Health for Secondary Contact Recreation, E.coli (annual median) in rivers and streams.

Site by WMA	2009	2010	2011	2012	2013
Tauranga Harbour					
Aongatete River @ SH 2		A	A		A
Kopurererua @ SH 2	A	A	B	A	A
Kopurererua @ SH 29	A	A	C	A	A
Ngamuwahine @ Old Bridge		A	A		A
Omanawa @ SH 29	A	A	B	A	A
Rocky @ Mangatawa	A	A	A		A
Te Mania @ SH 2	A	A	B	A	A
Te Rereatukahia @ SH 2					A
Tuapiro @ Surtees Road		A			A
Uretara at Henry Road Ford					A
Waiau @ Road Ford					A
Waimapu @ 100 m d/s of SH 29	B	A	C	B	B
Waimapu @ Pukemapui Road		A	B		A
Waipapa @ Old Bridge		A			A
Wairoa at SH 2 Bridge	A	A	C	A	A
Wairoa d/s of Ruahihi		A	B		A
Waitao @ Spenser's Farm		C	B	B	A
Waitekohe @ SH 2					A

Table 4 *NOF banding for Human Health for Primary Contact Recreation, E.coli (95th percentile), 2009-2013 in rivers and streams (>MAS = above minimum acceptable state) and ten-year trend. NT = No trend, ↓ = Meaningful decrease, ↑ = Meaningful increase.*

Site	95th Percentile *E.coli*	NOF	Ten-year trend
Te Mania @ SH 2	1,076	>MAS	NT
Wairoa at SH 2 Bridge	1,450	>MAS	NT
Waimapu @ 100 m d/s of SH 29	1,520	>MAS	NT
Te Rereatukahia @ SH 2	1,542	>MAS	NT
Rocky @ Mangatawa	1,575	>MAS	NT
Tuapiro @ Surtees Road	1,633	>MAS	NT
Kopurererua @ SH 29	1,750	>MAS	NT
Waiau @ Road Ford	1,940	>MAS	NT
Wairoa d/s of Ruahihi	1,960	>MAS	NT
Ngamuwahine @ Old Bridge	2,020	>MAS	NT
Aongatete River @ SH 2	2,204	>MAS	NT
Kopurererua @ SH 2	2,310	>MAS	NT
Waipapa @ Old Bridge	2,385	>MAS	NT
Waitao @ Spenser's Farm	2,545	>MAS	NT
Uretara at Henry Road Ford	2,896	>MAS	NT
Waimapu @ Pukemapui Road	3,353	>MAS	NT
Omanawa @ SH 29	830	>MAS	↑

1.2.6 Groundwater and geothermal resources

Work as part of the NERMN Programme has enabled a model to be constructed to visualise the groundwater systems of the Tauranga area, using data from BOPRC Wells Database. This conceptual model was completed in 2009, since this time more information has been collected to better inform the model. The existing model is now being upgraded with the revised version of the groundwater system mapping becoming available in September 2015.

The 2009 conceptual model was used in 2013 as a base to develop a numeric model of the Tauranga Geothermal Groundwater System. This model was constructed to provide direction for environmental monitoring and management of the warm water resource (geothermal groundwater >30°C and <70°C). The numeric model (based on the data available to 2013) suggested that some areas of the Geothermal Groundwater System could cool in a matter of decades if the volume of take (allocation) was not better managed. This initiated a work programme in compliance and consents to better target which bores required consent for groundwater takes. And a programme through science and planning to understand the temperature profiles and gradients over the system and how best to allocate geothermal groundwater to sustain the resource temperatures. This work is progressing with completion expected in 2016.

The Geothermal Groundwater NERMN Programme identifies areas around the harbour where the water levels are in decline. This suggests a risk of saltwater intrusion into these areas due to its proximity to the coast. The geothermal groundwater discharges to the sea off Tauranga. A water level drop due to takes from the Geothermal Groundwater System can provide a vehicle for saltwater to contaminate the freshwater resource of the Tauranga Harbour. To date, saltwater intrusion monitoring has only been installed along Papamoa Beach, but not in the northern areas of the harbour.

1.2.7 River and stream ecology

Sampling of stream invertebrates and fish has occurred in the harbour catchment at 33 sites. Stream invertebrates consist of aquatic insects, snails, worms and shrimp. Stream invertebrates are sensitive to changes in water quality with different types of invertebrates found in waterways that can indicate its overall health. Health is measured by using the Macro-invertebrate Community Index (MCI).

Of the streams sampled in the Tauranga Harbour Catchment 17 of these streams drain catchments dominated by pastoral land use, 14 streams drain catchments dominated by native bush, and only two streams drain urban catchments. Of the 33 streams examined, none were rated as ‘poor’ when assessed by the Macro-invertebrate Community Index (MCI), with most streams (17) being assessed as ‘good’ (see Figure 3).

Trends observed in stream ecological health indicates that in 16 streams with over eight years data, ecological health is relatively stable. Work is currently being conducted to study freshwater fish populations during low flow stream conditions during summer.

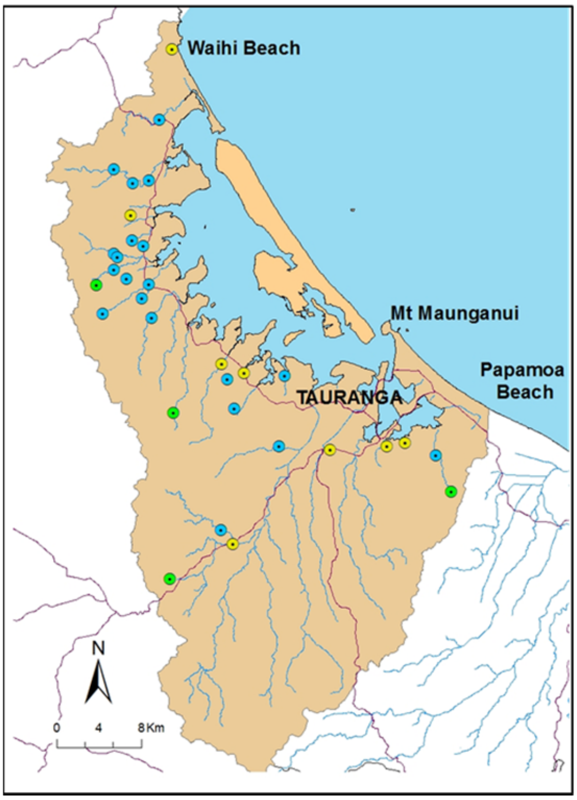


Figure 3 Map of the Tauranga Harbour Catchment area showing the location of the study streams, colour coded by their calculated MCI water quality code (green = excellent, blue = good, yellow = fair, red = poor).

1.2.8 Harbour ecology

The ecological health of the Harbour is measured through multiple parameters such as, benthic macrofauna (crabs, worms, snails etc.), seagrass extent, sedimentation accumulation rates, sediment contamination (heavy metals, oils) mangrove cover, shellfish beds monitoring and sea lettuce abundance. Tauranga Harbour has a diverse range of habitats and species that inhabit it. Overall estuarine health is stable, with decreasing ecological health trends observed in the upper estuaries mainly due to increased sediment inflows from erosion in the catchments, and nutrients into the harbour.

Monitoring of the seagrass beds has shown significant historic declines in extent, particularly in the upper sub estuaries. Since the 1950's to 2011 seagrass cover has decreased from around 40,437 ha to 2,735 ha. Meaning that in the harbour we have lost over 61% of our historic seagrass beds, with the greatest decrease observed in the northern harbour. The good news is that preliminary analysis of seagrass cover in the southern harbour indicates that from 1996 to 2001 seagrass beds have stabilised, with a slight increase in total cover.

Surveys of shellfish distribution and abundance have shown a similar decline in the upper estuaries. This can be linked to increased sediment and nutrient input. In the lower more exposed eastern harbour areas, seagrass and shellfish beds have shown much less change.

Monitoring of sub-surface macrofauna has shown a similar trend to seagrass with declining habitat quality in the western sub-estuaries. No significant changes have been found in the lower eastern open harbour areas since the 1990's.

Mapping of the extent of mangroves in the harbour indicates that canopy cover of mangroves has increased significantly from just over 200 ha in the 1940's to 811 ha in 2011 (see Figure 4). Mangrove expansion in the harbour is a natural response to increased sedimentation, nutrients and less frequent frosts.

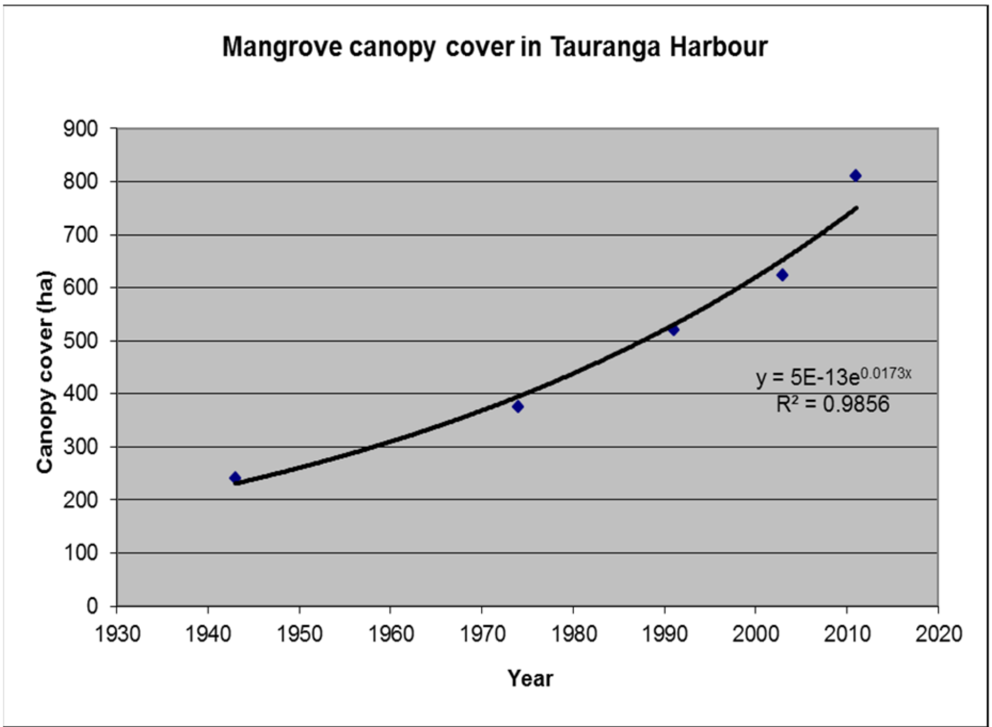


Figure 4 Mangrove canopy cover hectares (ha) in Tauranga Harbour from 1943 to 2011.

Monitoring of sea lettuce abundance occurs at a number of sites across the harbour. Monitoring since 1993 shows the abundance of sea lettuce is highly variable with a strong correlation between blooms of sea lettuce and El Nino and La Nina events (see Figure 5). Large blooms of sea lettuce have been recorded during El Nino years compared to smaller blooms during neutral years. Research is currently being conducted to better understand the drivers of sea lettuce growth in the harbour through PhD research conducted with the University of Waikato.

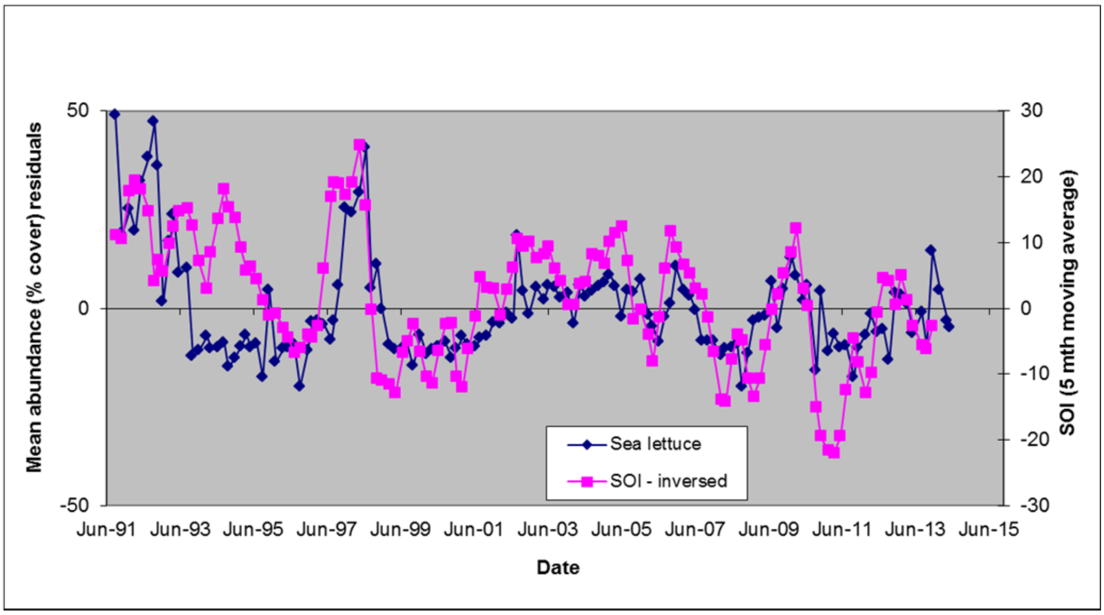


Figure 5 *Mean sea lettuce abundance as percent cover averaged across seasons and sites from Tauranga Harbour versus Southern Oscillation Index (SOI) for El Nino and La Nina conditions.*

1.2.9 Sedimentation trends

Estuaries are very sensitive to sediment and contaminants inputs which enter via rivers, streams and storm water drains. Contaminants such as heavy metals, Polycyclic Aromatic Hydrocarbons (PAH), pesticides and nutrients can have negative impacts on harbour ecological health.

In Tauranga Harbour, contaminant levels in sediments tend to be low and meet ANZECC guidelines for the protection of marine life. For much of the harbour, metals and PAHs are near natural background levels but increase substantially in industrial areas and new commercial development, particularly in close vicinity to storm water outlets. Monitoring from 2003 has shown no significant trends in contaminant levels although one site at Fraser Cove in Waimapu Estuary may be trending up for metals. A likely cause of the increasing levels at Fraser Cove is stormwater from commercial and industrial premises in the Courtney Road Drain Catchment. The Pollution Prevention Team is targeting this area in the industrial pollution prevention audits.

Impacts from high sedimentation rates in the harbour are caused mainly by high loads of fine clay and silt fractions which settle in more sheltered sub-estuaries. Since the times of first land clearance, sediments in sheltered areas have become muddier causing a decline in health of harbour ecology. In the open areas of Tauranga Harbour, high wave and current energy keeps the sediments in a healthy sandy state, and no significant change has occurred at monitored sites since the 1990's. Additional monitoring of both the sediment mud content and the Sediment Accumulation Rates (SAR) has been setup at 60 sites across the harbour to provide more accurate trend analysis (see Figure 6).

Figure 6 Sediment Accumulation Rate (SAR) monitoring plate installation in Wainui Estuary. Note the thick soft mud anoxic muds a clear sign of high erosion rates from the surrounding catchment.

1.2.10 Other indicators of harbour health

Other observations of Tauranga Harbour that can indicate its state of health include the extent and condition of its wetlands, the state of its bird populations and fisheries resources.

Extent of freshwater wetlands was estimated to have reduced from 3,002 ha in 1,840 to 469 ha in 1991 which is an 84% loss. Saltwater wetlands increased from 1,576 ha to 1,840 ha, or by 16% over the same period, due to increase of mangroves. Human modification in terms of the harbour area reclaimed, dredged or impacted by the building of causeways and seawalls can have impacts on harbour health. Up to 1991 it is estimated that 693 ha of saltmarsh was destroyed by reclamation.

Part 2: Tauranga Harbour water quality

Overall the water quality of the Tauranga Harbour is good with most sites displaying values of bacteria e.g. enterococci, pollutants and contaminants e.g. heavy metals and polycyclic aromatic hydrocarbons (PAH's) which comply with the recommended guidelines (Scholes, 2010). However, there are localised areas of reduced water quality in areas of the harbour, particularly in sheltered estuaries, and in the vicinity of urban development, and after periods of heavy rainfall (Bay of Plenty Regional Council, 2014).

2.1 Swimming water quality

Bacterial contamination typically originates from faecal bacteria and can come from a wide range of sources in a catchment (Sinner *et al.* 2011). Wastewater treatment plants, on-site wastewater treatment systems (e.g. septic tanks), leaky sewage infrastructure, livestock agriculture, avian populations, marine vessels, and meat processing plants contribute to faecal contamination, therefore distinguishing the main source of contamination in a catchment can be problematic (Scholes and McIntosh, 2009). A precautionary approach is taken to health risk with indicators tending to reflect the poorest water quality measured at a site rather than the average water quality.

2.1.1 Marine/River Bathing Guideline Values: Surveillance, alert and action levels

The Marine/River Bathing Guidelines are categorized into three modes; Green/Surveillance, Orange/Alert and Red/Action to denote the level of risk and management response for the site (Table 5). The guidelines are precautionary and are based on keeping illness risks associated with recreational water use to less than about 2%. Results from 2013/2014 recreational waters surveillance indicate that most sites in the Tauranga Harbour are generally suitable for bathing. Only one estuarine site of twelve (Pahoia end of beach) reached the Red Action Mode (MfE, 2003; Scholes, 2014). The Red Action Mode for marine sites is reached when two consecutive samples greater than 280 enterococci/100 ml are observed, this prioritises the site for further investigation/action (Table 5). Pahoia end of beach had 90^{th} percentiles over the Red/Action Mode in the 2013/2014 bathing season (e.g. the 280 enterococci/100 ml guideline was exceeded 10% of the time). Analysis was also undertaken on the percentage of samples which exceeded the Red/Action Guideline over the last five years (2009-2014). Athenree and Otumoetai were the only two sites with 95^{th} percentiles over the Red/Action Mode for the 2009-2014 testing period (Scholes, 2014). It was predicted that these sites were affected by inflow from nearby rivers. Waiau Stream enters the harbour near Athenree, whereas Otumoetai is influenced by the Wairoa River, and in periods of flooding these rivers may cause elevated bacterial levels. The Otumoetai Site can also be influenced by sewage infrastructure overflows that occur on occasion. Toi Te Ora (Public Health Service – Bay of Plenty District Health Board) has issued a permanent health warning for bacterial levels at Kaiate Falls.

By comparison, river sites in the Tauranga Harbour Catchment have poorer water quality and six of seven sites reached the Red/Action Mode (single sample >550 *E.coli*/100 ml) during the 2013/2014 bathing season. These six rivers were Waimapu, McClarens Falls, Wairoa, Tuapiro, Uretara and Kaiate (Bay of Plenty Regional Council, 2014). Over the last five years (2009-2014) Ngamuwahine River, McLarens Falls, Wairoa River, Tuaprio Stream, Uretara River, and Kaiate Stream all exceeded the 550 *E.coli*/100 ml guideline (Red Action Mode) ≥5% of the time (Scholes, 2014). Although a portion of samples were above the Red/Action Guideline, no medians for all sites were above the Orange/Alert Mode over the last five years, indicating that on average all rivers were suitable for swimming (Scholes, 2014). Rivers in the Tauranga Catchment during the 2007-2009 study periods also show relatively high levels of faecal contamination with thirteen of the nineteen sites above the 550 *E.coli*/100 ml guideline >20% of the time (Scholes *et al.* 2011).

Table 5 Surveillance, alert and action levels for fresh and marine waters (MfE/MoH, 2003).

Mode	**Guideline - freshwaters** (*E.coli* count in colony forming units per 100 mL)	**Recommended management response**
Green/Surveillance	Single sample ≤ 260	Routine monitoring
Orange/Alert	Single sample > 260 and ≤ 550	Increased monitoring, identify possible sources
Red/Action	Single sample > 550	Public warnings, increased monitoring, source investigation

Mode	**Guideline - marine** (Enterococci count in colony forming units per 100 mL)	**Recommended management response**
Green/Surveillance	Single sample ≤ 140	Routine monitoring
Orange/Alert	Single sample > 140 and ≤ 280	Increased monitoring, identify possible sources
Red/Action	Two consecutive single samples > 280	Public warnings, increased monitoring, source investigation

2.1.2 Suitability for recreation grading

The Suitability for Recreation Grade (SFRG) is generated from the combination of a qualitative assessment, the risk of a site to faecal contamination (sanitary inspection), and direct measurements of the appropriate bacteriological indicator at the site (Scholes, 2014). The five grades in the SFRG are very poor, poor, fair, good and very good (Table 6). These grades are based on:

- Potential sources of faecal contamination and hence the susceptibility of the water body.
- Five years of microbiological indicator results to provide an actual measurement of the water quality over time.

Only one of twelve estuarine sites in the harbour (Te Puna Waitui Reserve) was given a poor SFRG rating in the recent 2013/2014 Recreational Waters Surveillance Report (Scholes, 2014). The poor SFRG indicates the site is susceptible to faecal pollution, and is not always suitable for swimming. During dry weather conditions, it is advised the swimming location is checked to be free of signs of pollution, and swimming is avoided at all times during and for up to three days following rainfall (MfE, 2013). This SFRG was likely to be due to the on-site wastewater treatment systems in the area putting the site at a higher risk of faecal contamination than others. The Te Puna Environmental Monitoring Results in March 2012 indicated that the Te Puna West Drain had high levels of bacteria and ammonium-nitrogen which may be a cause of the high faecal contamination risk (Bay of Plenty Regional Council, 2012). In summary, six of twelve estuarine sites were given a good SFRG rating in which the site is considered suitable for swimming most of the time, five were given a fair SFRG rating and only one was given a poor rating (Scholes, 2014).

All seven river sites (Waimapu, McLarens Falls, Wairoa, Tuapiro, Uretara, Kaiate and Ngamuwahine) tested in the Tauranga Harbour Catchment did not meet bacterial contamination recommendations and were given poor to very poor Suitability for Recreation Gradings (Scholes, 2014). Waimapu River had a SFRG of ‘very poor’ whereas all other sites were graded as ‘poor’. The primary impact of contamination in these rivers with the exception of Uretara Stream was likely to be largely linked to agricultural effluent due to the predominantly agricultural land uses in the catchment. The results show that river sites pose a higher risk to bathers as they are more vulnerable to pathogen loading from rainfall run-off. The estuarine sites are lower in faecal matter due to harbour and estuarine waters mixing and becoming diluted with coastal waters.

Table 6 Suitability for Recreation Grading.

SFRG	Description
Very good	The site has generally excellent microbial water quality and very few potential sources of faecal pollution. Water is considered suitable for swimming for almost all of the time.
Good	The site is considered suitable for swimming for most of the time. Swimming should be avoided during or following heavy rain.
Fair	The site is generally suitable for swimming, but because of the presence of significant sources of faecal contamination, extra care should be taken to avoid swimming during or following rainfall or if there are signs of pollution such as discoloured water, odour, or debris in the water.
Poor	The site is susceptible to faecal pollution and microbial water quality is not always suitable for swimming. During dry weather conditions, ensure that the swimming location is free of signs of pollution, such as discoloured water, odour or debris in the water, and avoid swimming at all times during and for up to three days following rainfall.
Very poor	The site is very susceptible to faecal pollution and microbial water quality may often be unsuitable for swimming. It is generally recommended to avoid swimming at these sites.

2.1.3 National Objective Framework (NOF) attributes for ecosystem health/ human health

The National Policy Statement on Freshwater Management (NPSFW) includes a National Objective Framework (NOF) which sets values for freshwater to protect 'human health for recreation' and 'ecosystem health' (Scholes and Carter, 2014). The NOF defines thresholds for numeric attributes which are categorised into four bands (A-D), this allows the water quality of a water body to be assessed and compared to 'National Bottom Lines' (Table 7). For the human health for recreation attribute the C banding (national bottom line) is reached when the bacteriological level is greater than 540 *E.coli*/ 100ml (Table 8).

Table 7 Attribute state and related effects on ecosystem health and human health (Source: Scholes and Carter, 2014).

Value	Attribute State (Bands)			
	A	B	C (Bottom-line)	D
Ecosystem health	Communities are healthy and resilient, similar to natural reference conditions. High conservation value systems. 99% species protection level.	Communities are slightly impacted. 5% potential toxicity impacts particularly on sensitive species. Occasional minor stress on sensitive organisms.	Communities are moderately impacted. 20% toxicity impacts particularly on sensitive species. Moderate stress on a number of aquatic organisms.	Communities have undergone or are at high risk of a regime shift to a persistent, degraded state. Potential for acute toxicity impacts. Significant, persistent stress on a range of aquatic organisms.
Human health for recreation	Very low risk.	Low risk (secondary contact) or moderate risk (primary contact).	Moderate risk for secondary contact, below minimum acceptable state for primary contact.	High risk.

Table 8 E.coli numeric values for attribute state and associated health risk (Source: Scholes and Carter, 2014).

Value	Attribute state (*E.coli*/100 ml)			
	A	B	C (Bottom-line)	D
Numeric state	≤260	>260 and ≤ 540	>540 and ≤1,000	>1,000
Human health for secondary* contact (annual median)	Very low risk of infection (<0.1%) secondary exposure.	Low risk of infection (up to 1%) secondary exposure.	Moderate risk of infection (<5.0%) from secondary exposure.	High risk of infection (>5.0%) from secondary exposure.
Human health for primary contact (95th Percentile)	Low risk of infection (up to 1%) primary exposure.	Moderate risk of infection (<5.0%) from primary exposure. **Minimum Acceptable State**		

From 2009-2013 river sites in the Tauranga Harbour Catchment were analysed in relation to the national objectives framework for *E.coli*. All 18 river sites had 95^{th} percentiles above the minimum acceptable standard for primary contact recreation[1] (Scholes and Carter, 2014). This indicated that ≥5% of the time the sites were above the 540 *E.coli*/100 ml guideline throughout the 2009-2013 period. Therefore, at times there was a high risk of infection from primary contact at these sites (Table 8). Comparatively, when assessed for secondary contact recreation[2] no sites annual *E.coli* medians for 2013 were above the national bottom line, and all sites excluding Waimapu received an A grading. However, in previous years (2010 and 2011) four Tauranga Harbour sites annual medians have fallen into the C banding for secondary contact recreation (Kopurererua @ SH 29, Waimapu @ 100 m d/s of SH 29, Wairoa @ SH 2 Bridge, and Waitao @ Spencer's Farm).

2.1.4 **Trends**

It has been found that the enterococci levels at ten sites in the harbour have been stable over the analysis period 1991-2013 for the southern harbour, and 1998-2013 for the northern harbour. There were three sites (Otumoetai, Te Puna, and Ōmokoroa) with a meaningful significant increasing trend in enterococci over the 1991-2013 monitoring period. This was likely to be associated with faecal contamination from freshwater inputs, particularly given the proximity of the Wairoa River to these sites, the largest freshwater inflow to the harbour (Bay of Plenty Regional Council, 2014).

Comparatively, one of 18 river sites (Omanawa @ SH 29) showed a meaningful improvement in *E.coli* levels over the last ten years whereas the other 17 sites showed no trend i.e. there has been no significant increase or decrease in *E.coli* levels (Scholes and Carter, 2014).

2.1.5 **Sources**

From analysis of the research on the Tauranga Harbour the primary source of contamination in the harbour appears to be from agricultural activities in the catchment. This is evident from the generally higher health risk bathing in rivers poses in comparison to estuarine sites. Exceedances of faecal guidelines generally correspond with high rainfall when there are elevated levels of pathogens loading into the adjacent water body. There are also other sources which contribute to bacterial contamination; however these are likely to be of secondary importance to agricultural run-off. For example:

- On-site wastewater treatment systems pose a relatively large risk. In Te Puna in 2003 approximately half of the on-site wastewater treatment systems did not meet the maintenance criteria, and monitoring from 2006 showed four drains with high bacterial contamination (Sinner *et al..* 2011). The cumulative effects of on-site waste water systems could contribute to a relatively large portion of bacterial contamination in the harbour.
- Bay of Plenty Regional Council reports conclude that as discharge from ocean outfalls such as Ōmanu and Katikati have remained within enterococci consent limits from 2004 to 2008 (at the exception of three elevated readings in February 2005 for the Katikati ocean outfall) there is a low risk of contamination from these sources.

[1] Primary contact recreation: Full immersion activities e.g. swimming.
[2] Secondary contact recreation: Activities will occasional immersion with water e.g. boating, wading.

- Three small seepages were identified and measured from Te Maunga oxidation ponds, two seepages had low coliform counts, and one was elevated. However due to the small scale of the seepages this is not likely to have a large impact (Sinner *et al.* 2011).
- Avian populations remaining in one area can contribute a significant amount of waste which poses a risk to microbiological water contamination; however microbiological contamination is likely to be minimal and effects localised (Lawrie, 2006).

2.2 Pollutants

The risk pollutants pose to the ecology of the harbour is difficult to determine as different species and organisms may have different tolerance levels and sensitivity to heavy metals and PAH's (Sinner *et al.* 2011). However, the general findings from studies of the harbour was that the heavy metal levels throughout most of the harbour is well below relevant guidelines thresholds and below many other estuaries in New Zealand and overseas (Ellis *et al.* 2013). The highest levels of heavy metals were generally found in the depositional inner areas of the harbour such as Te Puna Estuary and more urbanised/commercialised areas, particularly near stormwater outlets (Park, 2014; Ellis *et al.* 2013).

- The Bay of Plenty Marine Sediment Contaminants survey 2012 found that with the exception of Mercury at the Matahui Site, there were no concentrations which exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) ISQG low value when based on the <500 μm particle size (Park, 2014). However, sediment contamination is highly correlated with the percentage of mud content due to their adherence to finer particles, therefore, when standardized to the 100% mud fraction (i.e. analysing for a worst case basis) there were some concentrations for localised regions which exceeded the ANZECC ISQG low value (e.g. Waimapu, Rereatukahia and Te Puna Estuaries for lead and zinc, and Waikareao Estuary for zinc) (Park, 2014).
- When compared to previous sampling years (2003, 2006 and 2009), the 2012 sediment contaminants survey of heavy metals and PAH's produced very similar results, therefore no strong upward or downward trend in PAH's or heavy metals was observed. However, given that there are only four data points, it is difficult to show statistical significance. Trends will become clearer when a longer time series of data has been collected. It was identified that one site in Waimapu Estuary (Fraser Cove) may possibly be displaying an upward trend (Park, 2014).

The Manaaki Taha Moana Ecological study (Ellis *et al.* 2013) of the Tauranga Harbour found similar results to the Bay of Plenty Marine Sediment Contaminants Survey 2012, and also provided insight on the effect stressors (e.g. heavy metals, N and P, and sedimentation) have on the ecology of the harbour. It was found that Te Puna had the highest levels of contamination in the harbour for copper and lead and the second highest zinc concentration, this was likely to be a factor of the high levels of mud (76% silt and clay). Most species displayed clear differences in abundance in an area as a function of sediment type, nutrient loading or contaminant levels. For example Te Puna Estuary had low species richness but a relatively high abundance of the few species that were present. This was likely to be due to a combination of the parameters studied e.g. high mud content, comparatively high nutrient levels, and the levels of contaminants at the site. It was found that shellfish in particular showed either a negative or polynomial trend to the parameters, which suggests that shellfish species are either sensitive to high mud content, nutrient loading, or contaminants, or sensitive to these stressors beyond a certain point (Ellis *et al.* 2013).

2.3 Nutrients

Many of the nutrients derived from intensive farming practises and fertiliser applications eventually reach estuaries/coasts and can result in nutrient enrichment in these environments. Low levels of nutrient enrichment can have a positive effect on benthic communities due to greater primary productivity. However, beyond a critical level accelerated eutrophication can have adverse effects on benthic communities and start a cascade of negative effects throughout the ecosystem (Ellis *et al.* 2013).

Comparisons of Tauranga Harbour with other New Zealand estuaries indicates that the harbour generally sits within a slightly, to moderately enriched condition (Ellis *et al.* 2013). The nutrient sediment concentrations in the harbour tend to decline with distance from the inner harbour and associated rivers, with Te Puna Estuary having the highest sediment nutrient levels with nitrogen and phosphorus concentrations of 1,900 and 580 mg/kg respectively (Ellis *et al.* 2013). Nitrogen loadings modelled of stream and rivers entering Tauranga Harbour predicted that Te Puna Stream would have relatively high nitrogen loadings, possibly explaining the high levels of nutrients observed. The high nutrient concentrations are also likely to be linked with the high mud content present in Te Puna Estuary (76% silt and clay) (Ellis *et al.* 2013).

Kauri Point and Maungatapu had the highest median total phosphorus concentrations (for the 2006-2011 period); however these values were still below the Australian and New Zealand Environment and Conservation ANZECC guideline levels (ANZECC, 2000). Other parameters measured such as dissolved inorganic nitrogen (TOx-N and NH_4-N) were above the ANZECC guidelines for most sites, however, as Bay of Plenty's oceanic waters are naturally much higher in nitrogen concentrations this may not be an appropriate comparison (Scholes, 2010).

Chlorophyll-a is an algal pigment which gives an indication of the phytoplankton productivity in the area. Phytoplankton is dependent on nutrients and serves as the basis of the aquatic food web, and therefore is important in aquatic ecosystems. Phytoplankton productivity increases as a response to increased levels of nutrients. However, beyond a critical level accelerated phytoplankton biomass can result in eutrophication which depletes the oxygen in the water and may cause death to aquatic animals. Pahoia had the highest median chlorophyll-a concentrations in Tauranga Harbour followed by Kauri Point (Scholes, 2014). However spring-summer concentrations of dissolved phosphorus at these sites were low, indicating that phosphorus may be limiting phytoplankton growth in these areas (Scholes, 2014).

2.3.1 National Objective Framework (NOF) attributes for Ecosystem Health/ Human Health

The National Objective Framework (NOF) also has parameters such as nitrate and ammonia which are ranked into A-D attribute bands based on numeric values. This allows levels of nutrients and associated water quality to be assessed against ecosystem health (Table 9 and Table 10).

Table 9 Nitrate numeric values for attribute state and associated ecosystem risk.

Value	Attribute State – Rivers – Nitrate (Toxicity) (mg/L)			
	A	B	C (Bottom-line)	D
Numeric state: Annual median (95^{th} Percentile)	≤1.0 (≤1.5)	>1.0 & ≤2.4 (>1.5 & ≤3.5)	>2.4 & ≤6.9 (>3.5 & ≤9.8)	>6.9 (>9.8)
Ecosystem health	High conservation value system. Unlikely to be effects even on sensitive species.	Some growth effect on up to 5% of species.	Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.	Impacts on growth of multiple species, and starts approaching acute impact level (i.e. risk of death) for sensitive species at higher concentrations (>20 mg/L).

Table 10 Ammonia numeric values for attribute state and associated ecosystem risk.

Value	Attribute state – Rivers – Ammonia (Toxicity) (mg/L)			
	A	B	C (Bottom-line)	D
Numeric state: Annual median (maximum)	≤0.03 (≤0.05)	>0.03 & ≤0.24 (>0.05 & ≤0.40)	>0.24 & ≤1.30 (>0.40 & ≤2.20)	>1.30 (>2.20)
Ecosystem health	99% species protection level: No observed effect on any species tested.	95% species protection level: Starts impacting occasionally on the 5% most sensitive species.	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species).	Starts approaching acute impact level (i.e. risk of death) for sensitive species.

16 of 18 Tauranga Harbour River sites were considered to have a high ecosystem health in 2013 with all annual median nitrate concentrations banded in the A category (Scholes and Carter, 2014). Kopurererua @ SH 2 and Omanawa @ SH 29 were both placed in the B band for 2013, and Omanawa consistently had relatively high annual nitrate median concentrations throughout the years tested (being placed in the B band for 2009, 2010, 2011, 2012 and 2013). This defined the ecosystem health as ‘communities are slightly impacted with 5% potential toxicity impacts particularly on sensitive species’ (Table 9). Occasional minor stresses were expected on sensitive organisms with growth effects on up to 5% on species (Table 9).

For ammonia most river sites were also banded in the A category for 2013[3] (Scholes and Carter, 2014). Only Kopurererua @ SH 29 and Rocky @ Mangatawa had annual median ammonium concentrations which placed them in the B banding. Interestingly, these sites were placed in the B banding for all years tested (2009-2013).

2.3.2 Harbour trends

Although fluctuations of nutrient concentrations in the harbour have occurred, Scholes (2005) found that levels of nutrients within the harbour generally declined over the monitoring period from 1991 to 2005 (Sinner *et al.* 2011). More recently, (from 2006-2011) five of ten sites in the southern harbour displayed a decrease in total phosphorus, and three of the sites also showed a decrease in dissolved phosphorus (Scholes, 2014). Trends in the water quality of the southern harbour are described in more detail for various areas/sampling points below.

Town Basin

While no trends in dissolved nitrogen were observed at the Grace Street (1991-2013) and Waipu Bay (2004-2013) town basin sites, Maungatapu has displayed an increase in both dissolved inorganic forms of nitrogen (NH_4-N and TOx-N) over the past two decades. In addition, higher concentrations of dissolved nitrogen were observed at Maungatapu compared to the other two town basin sites (Scholes, 2014). This may be a reflection of the streams entering the Maungatapu area and/or be due to the lower influence of oceanic water mixing at this site (Scholes, 2014). Maungatapu has also shown a meaningful decreasing trend in total phosphorus for the monitoring period 1991-2013 and turbidity for the period 1996-2013, a trend which was repeated at the other two town basin sites (Waipu Bay and Grace Street). This may indicate an improvement in the amount of fine sediment being transported into Town Basin (Scholes, 2014). No significant trends in total nitrogen were displayed at all three sites from 2005-2013 (Scholes, 2014).

Otumoetai Channel

Common trends in the Otumoetai Channel sites (Otumoetai Beach Road - high tide, Otumoetai Kulim Avenue - low tide and Pilot Bay) were meaningful decreases in both total phosphorus (TP) and dissolved reactive phosphorus (DRP) (monitoring period 1991-2013 for the Otumoetai sites, and 2007-2013 for the Pilot Bay site). No significant trends were observed for dissolved nitrogen at all three sites (Scholes, 2014). The Otumoetai Beach Road site also displayed a meaningful increase in suspended sediment, however no significant trend was observed at the other two Otumoetai Channel sites (Scholes, 2014). In addition, Pilot Bay had a significant and meaningful increase in total nitrogen from 2005 to 2013. However, it is important to note that this monitoring period is shorter than the other parameters, and therefore may be influenced more strongly by annual variations (Scholes, 2014). It is possible that the unprocessed pine which is loaded onto the wharf near Pilot Bay is influencing the waters here with increased organic nitrogen; this may be affecting nitrogen trends (Scholes, 2014). Comparatively, no significant trends in total nitrogen were displayed at the other two sites (Scholes, 2014).

[3] Ammonia banding should be observed conservatively as data is not adjusted for pH or temperature.

South Basin

The sites monitored predominantly in the southern basin were Te Puna and Ōmokoroa, with Pahoia being added in 1998. A dissolved inorganic nitrogen parameter, TOx-N showed a meaningful increasing trend over the monitoring period 1991-2013 at the Ōmokoroa Site. Interestingly, both inorganic nitrogen parameters (TOx-N and NH_4-N) have strong seasonal patterns (maximums in winter and minimums in summer) which are reflected by freshwater inputs and uptake by marine plants (macroalgae and phytoplankton). No significant trend was observed for total nitrogen in recent data (2006-2013), and TN was not analysed from 1996 to 2005, however annualised data for Ōmokoroa and Te Puna indicate TN has increased from 1994 to 2013 (Scholes, 2014).

2.3.3 River trends

Some of the rivers entering the harbour have shown decreasing nutrient trends due to improved rural practises and management; however there are still many rivers and streams entering the harbour which have elevated levels (Ellis *et al.* 2013).

From 1989 to 2008 many of the rivers entering Tauranga Harbour showed differing trends which was likely to be related to effluent and runoff management in the surrounding areas e.g:

- Rocky Stream had a significant decrease of 9.42% of total nitrogen per year, total oxidised nitrogen showed a similar trend.
- Waitao Stream had a significant decreasing trend of all dissolved and total nutrients.
- Waipapa River had significant decreasing trends of total phosphorus, dissolved reactive phosphorus, total nitrogen and total oxidised nitrogen.
- Kopurererua Stream had a significant increasing trend of total oxidised nitrogen.
- Omanawa River had significant increasing trends of total oxidised nitrogen and total nitrogen. Agriculture was likely to be the cause and average concentrations at this site were above the ANZECC guidelines for lowland streams.
- Wairoa River had significant increasing trends of total phosphorus.
- Waiau had a significant trend of increasing total phosphorus (Scholes, 2009).

More recently (from 2003 to 2013) most rivers and streams in the Tauranga Harbour Catchment have displayed no trend in total nitrogen, total oxidised nitrogen (sum of nitrate and nitrite), ammonia, dissolved reactive phosphorus and total phosphorus (Land Air Water Aotearoa, 2015). One of 18 river sites in the Tauranga Harbour Catchment (Omanawa @ SH 29) had a meaningful degradation in nitrate, however, interestingly also displayed a meaningful improvement in ammonia. Te Mania @ SH 2 also displayed a meaningful improvement in ammonia concentrations, whereas all other sites displayed no trends. Overall, the health of the regions soils is fair but there is concern over the increasing levels of nutrients found in agricultural and horticultural soils which is eventually likely to accumulate in coastal areas (estuaries and harbours) (Bay of Plenty Regional Council, 2014).

Part 3: Sedimentation

Increasing rates of sedimentation is one of the largest issues facing Tauranga Harbour as it affects many aspects of harbour ecology. Although changes in sedimentation rates have been largely driven by historical events when there was little control on development, sedimentation is bringing increasing concern to the public and will continue to grow as the catchment changes and climate change becomes increasingly felt (Parshotam *et al.* 2009). Sedimentation can cause changes in sheltered estuaries and low energy environments:

- Become muddier and shallower.
- Reduce water clarity/quality.
- Infill the channel.
- Clog the gills of filter feeders.
- Reduce the colonisation success and survival of shellfish in their juvenile and larval stages.
- Smother seagrass beds.
- Reduce the foraging ability of fin fish.
- Decrease the amount of food available to benthic species.
- Decrease the amount of burrowing animals such as marine worms which perform important roles such as oxygenating the sediment and breaking down the organic matter.
- Change the benthic community structure (Lohrer *et al.* 2004).
- Result in the expansion of mangroves due to higher amounts of sediment settling in the harbour. This raises the level of the intertidal seabed allowing more area suitable for colonisation (Sinner *et al.* 2011).

The highest rates of deposition are in sheltered, low energy environments as finer particles are more likely to drop out of suspension in these areas. Sediment accumulation in Tauranga Harbour is low compared to other estuaries in New Zealand and is only likely to become a problem in sheltered bays, mangroves, saltmarshes, tidal flats and tidal creeks (Hancock *et al.* 2009). The most depositional sub-estuaries in the southern harbour are Te Puna inner, the mouth of Waipapa River, Mangawhai Bay inner and Apata Estuary (Hume *et al.* 2010). The rest of the southern Tauranga Harbour is likely to have much lower rates of sediment accumulation due to its high energy environment and large exposure to waves; this prevents it from being a long-term sink for fine terrigenous sediments (Hancock *et al*. 2009).

Increased or decreased rates of sedimentation are generally associated with land use change or weather fluctuations, as sediment yield primarily depends on land use, land slope, soil type and rainfall (Elliot *et al.* 2009). There has been a significant increase in the mud content of many of the western estuaries in Tauranga Harbour e.g. Welcome Bay, Waimapu Estuary and Waikareao Estuary, this may suggest possible land use changes or increased rainfall in the catchment.

From land use and slope modelling it was found that pasture (34% of the catchment) makes up the largest contribution to sediment yield in the Tauranga Harbour (63% of total), forested areas (44% of catchment) contribute to 27%, and orchard and cropland (5% of catchment) contribute to only 0.3% of the sediment yield (Elliot *et al*. 2009). Interestingly, uncontrolled earthworks had the highest yield, but this portion has decreased to only 0.5% of the total sediment yield due to the controls put in place (Hume *et al*. 2009). These results suggest that the focus for management should primarily be on pasture land, particularly steep areas in the catchment which are likely to have high sediment yield.

Although different land uses have been modelled and found to result in different sediment yields in the catchment, it was recognized that the relative contribution of different processes such as bank erosion or mass movement to sediment yield needs to be established to properly understand sedimentation dynamics and sources (Hughes and Hoyle, 2014). The Kopurererua Stream Catchment was selected as a pilot catchment to determine the contribution river bank erosion makes to sediment yield, and to regulate the areas of the streams in which sediment loads are the highest (Hughes and Hoyle, 2014).

Although bank erosion is a naturally occurring process in streams, human disturbance has likely resulted in increased rates of bank erosion in many New Zealand catchments including Kopurererua. For example disturbance may include changes in catchment hydrology due to a change in natural vegetation cover, direct channel modification, and/or the introduction of large heavy mammals to catchments (Hughes and Hoyle, 2014). Riparian barriers have been widely promoted as a desirable catchment wide solution to significantly reduce erosion rates; however the assumption that riparian barriers significantly reduce erosion rates may be largely catchment and scale dependent. The effects of riparian barriers or 'interventions' may differ relative to the stream reach studied and the erosion processes that occur.

For example:

- In headwater streams where stream power is low and bank heights are small sub-aerial processes dominate e.g. drying of banks, freeze-thaw, stock trampling.
- In mid-reaches stream power increases and fluvial entrainment e.g. scour dominates.
- In lower reaches of catchments where bank heights are high mass-failure mechanisms such as bank slumping dominate.

In lower reaches of the catchment the removal of stock from riparian areas and/or the planting of flax, small shrubs and grass may therefore have a slight positive effect on sediment yields but is unlikely to significantly reduce the amount of sediment contributing to these reaches due to the mass failure erosion processes operating (Hughes and Hoyle, 2014).

From the inspection of the Kopurererua Catchment it was observed that there was:

- Considerable sediment loading from the upper reaches of the Kopurererua and Tautau Streams as evidenced by the large sand sheets on the bed of the Tautau Stream and turbid water and silty deposits on the bed of the Kopurereua Stream (Hughes and Hoyle, 2014).
- It was also observed that bank erosion was a source of sediment loading along the middle reaches of the Kopurereua Catchment. Severe erosion was present along the more sinuous reaches of the Kopurererua Stream and much of the channel had dense overgrown vegetation which appeared to be placing increased pressure on the banks (Hughes and Hoyle, 2014). Erosion could be improved by removing the vegetation in the channel and replacing it with suitable riparian vegetation.

- The lower reaches of the Kopurereua are relatively straight and stable and the banks are well vegetated. Erosion appears to be very minor along these reaches (Hughes and Hoyle, 2014).

Overall it has been found that only 57% of sediment generated in the catchment reaches the estuary, therefore the sediment derived from erosional processes on land and delivery may not necessarily coincide (Elliot *et al.* 2009). Sediment transport patterns are important to understand in order to provide some background on how changes in sediment runoff from land get changed into sedimentation in the harbour (Green, 2009). Fine sediment loss to the ocean is greatest from sub-catchments which discharge close to the southern mouth of the harbour (Green, 2009). For example Wairoa Sub-catchment contributes the majority of sediment to the southern harbour (46% of total load), however the majority of fine sediment discharged from Wairoa River (95%) goes out to the ocean, with a much lower loss of coarser sediment.

3.1.1 Future scenarios

Different catchment development scenarios have been modelled in Tauranga Harbour to predict estuarine sedimentation and to support decision-making (Green, 2009). The model provides:

- Predictions of sedimentation in different parts of the estuary.
- Predictions of change in bed composition over time, which reflects the degradation of habitat and potential adverse ecological effects.
- An analysis of the links between sediment sources in the catchment and sediment sinks in the estuary (Green, 2009).

By 2051, (under current climate conditions) mean annual sediment loading to the harbour was predicted to decrease slightly ~1% due to pasture land being replaced by lower-yielding urban land under the SmartGrowth scenario (Hume *et al.* 2009). However, as the Tauranga climate is expected to have a higher mean annual rainfall due to climate change, the amount of sediment delivered from all river catchments to the Tauranga Harbour is predicted to increase substantially (Green, 2009). The mean annual sediment yield delivered to the harbour by 2051 is predicted to increase by 43%, with even larger predictions projected for sheltered estuaries; this could have major implications for the harbour's water quality and ecology (Elliot *et al.* 2009). Sub-estuaries which were predicted to have a high potential for adverse ecological effects were Speedway, Rangataua Bay, Welcome Bay, Waimapu, Waikareao, Waikaraka, Te Puna outer and Waipapa (Hume *et al.* 2009). Sub-catchments which were identified as having a high potential for mitigation were Waitao, Kaitemako and Waimapu (Hume *et al.* 2009). Sub-catchments identified as having optimal mitigation efforts[4] were Waitao, Kaitemako, Waimapu, Kopurererua, Otura, Te Puna and Waipapa (Hume *et al.* 2009). Management in these sub-catchments is likely to substantially reduce sedimentation impacts in the sub-estuaries Speedway, Rangataua Bay, Welcome Bay, Waimapu, Waikareao, Waikaraka, Te Puna outer and Waipapa (Hume *et al.* 2009).

[4] Situations where the potential for adverse effects in receiving sub-estuaries is high and the opportunity for mitigation in the sub-catchment is high/medium.

Part 4: Ecology

Tauranga Harbour has an outstanding ecosystem for wildlife, including marine mammals, shorebirds and fisheries, and is also recognised as a wetland of international importance for wading birds. However, it is apparent that both anthropogenic and natural influences have caused losses in biodiversity and changes to the ecosystem of the harbour.

4.1 Seagrass

Seagrass provides a number of ecosystem functions to estuarine habitats, e.g. enhances primary production and nutrient cycling, stabilises sediment, protects the coast from erosion and supports a number of animals and plants. Therefore its 34% decline over 1959 to 1996 in Tauranga Harbour and 90% decline in sub-tidal areas were of great concern. Sedimentation and nutrient loading have largely been responsible for the degradation of seagrass habitats due to the reduction of available light from eutrophication and suspended sediments. In the 1990s the decline appeared to be slowing in some areas, this was attributed to better environmental management, particularly the removal of point source nutrient discharge (Park, 1999).

4.1.1 Black swans impact on seagrass

Black swans graze on intertidal seagrass and therefore may also constitute to seagrass degradation. Spatial and temporal black swan grazing activity was examined in Tauranga Harbour to estimate the site specific and estuary-wide impacts black swans have on seagrass (Dos Santos *et al.* 2012). It was found that black swan grazing was temporal, with foraging occurring primarily at high tide (both during the day and night) and spatial, being more numerous at sites with larger meadows, particularly in autumn. Grazing resulted in circular de-vegetated patches (average size ~0.28 m^2) with 92% of shoots, 25% of roots and 99% of rhizomes removed (Dos Santos *et al.* 2012). The average seagrass consumption rate was measured to be 394 g dry mass $swan^{-1}d^{-1}$. However, in localised areas of intense grazing, it can cause the removal of 19-20% of the average seagrass biomass (Dos Santos *et al.* 2012). In these intensely grazed areas there was a substantial decline in plant biomass in the subsequent growing season (43-69%) (Dos Santos *et al.* 2012).

4.1.2 Shellfish and other marine invertebrates

The shallow and intertidal coastal areas in which many macrofauna live are susceptible to a range of water quality issues. Monitoring of macrofauna (abundance and diversity) is therefore undertaken in order to track habitat changes and manage them accordingly. Monitoring of benthic macrofauna communities at seven sites in the harbour have shown no significant decrease in species diversity (Park, 2011). There have been some minor fluctuations in species composition however these appear to be natural occurrences (Park, 2011). Otumoetai and the town reach site had a reduction in mud and an increase in cockles; however, this was observed to correspond with the loss of seagrass cover due to swan grazing and therefore was not considered a positive trend (Park, 2011). The site with one of the highest species diversity (both in numbers of species and evenness) was the Pio's Beach site, which was stable (no change) over time (Park, 2011).

4.1.3 Stressors (sedimentation, nutrient loading, and heavy metals) impact on shellfish

Although macrofauna diversity has been stable over time, it is evident that water quality stressors have an influence on macrofaunal communities. The community composition and key species characterizing sites with different texture, nutrient, and contaminant loadings were found to vary (Ellis *et al.* 2013). Shellfish response curves to the stressors (sedimentation, nutrient loading and heavy metals) were either negative or polynomial indicating that most shellfish species were sensitive to elevated silt/clay, nutrient loading or contaminants, or sensitive to these stressors beyond a critical point (Ellis *et al.* 2013). The abundance of cockle, wedge shell and nut shell populations decreased as silt/clay content increased, whereas the shellfish (*A.bifurca*) had a polynomial response (Ellis *et al.* 2013). The abundance of *A.bifurca* increased with an increase in percent of mud content followed by a decrease past a certain point (Ellis *et al.* 2013).

4.1.4 Contamination of shellfish

Bacterial contamination of shellfish (*E.coli*, faecal coliforms and enterococci) was analysed over the monitoring period 2012 to 2014 in various areas of the Tauranga Harbour (not heavily monitored due to efforts focused in eastern estuaries) (Scholes, 2014). Cockle, pipi, oyster and tuatua were the shellfish analysed and the results were expressed as MPN (most probable number) per 100 g of flesh. Elevated faecal coliform and enterococci results were detected in various locations in the Tauranga Harbour in December 2012 but *E.coli* levels remained low. This may be due to other bacteria such as *Enterobacter* or *Klebsiella* accumulating in the shellfish (i.e. bacteria not originating from a faecal source) (Scholes, 2014). The only bacterial indicator which exceeded the MoH safe consumption guideline (330 MPN/100 g) was faecal coliform. This was prevalent at Tilby Point, Pilot Bay and Pio's Beach-Yellow Point in pipi samples in 2012, and additionally Pio's Beach in 2014 for a cockle sample (Scholes, 2014).

Health warnings for paralytic shellfish poisons have also been put in place along the Western Bay of Plenty for the majority of the last two seasons. The New Zealand Food Safety Authority (NZFSA) has undertaken routine monitoring and analysis for toxic phytoplankton species since 2003 to inform shellfish collection closures (Sinner *et al.* 2011). The first closure was enforced in 2008; however there had previously been some biotoxin warnings in place for some limited areas (Sinner *et al.* 2011). The phytoplankton species responsible for the closures have been *Alexandrium minutum* and *A. catenella* which produce toxins which can cause paralytic shellfish poisoning (Sinner *et al.* 2011).

4.1.5 Recreational impact on shellfish

Concentrated urban development, overharvesting, dragnetting, sedimentation, and the increasing use of vehicles on harbour beds have also had negative impacts on shellfish beds (Environment Bay of Plenty, 2008).

4.2 Fish

A range of fish species are found in Tauranga Harbour. Amongst these, common commercial species are sand flounder, yellow-belly flounder, grey mullet, snapper and trevally (Sinner *et al.* 2011). The species found within the harbour generally move between the sea and the harbour (very little fish stock is resident in the harbour) and are a part of the larger Bay of Plenty region's fish stocks. The harbour is considered a very important spawning and migration ground for many different species e.g. whitebait, short-finned eel, long-finned eel and lamprey, and the total fish and species richness in the Tauranga Harbour is comparable to many other northern estuaries in New Zealand of temperate mangrove forests (Sinner *et al.* 2011).

Unfortunately, catch reporting reveals little about the health of fish stocks within the Tauranga Harbour; however observations from local fishermen and tangata whenua can give an indication of changing fish stocks. Tangata whenua have noticed a decline in many fish species, including flounder, shark, snapper, kingfish, trevally and mullet, which they believe may be correlated to commercial fishing (Sinner *et al.* 2011).

Fishery stocks are monitored by the Ministry of Primary Industries. Monitoring is carried out within large regions, and data is not available for local areas such as Te Awanui Tauranga Harbour.

4.3 Birds

The birds identified in the Tauranga Harbour include 20 endemic species, 28 native species, 8 migrant species and 15 introduced species (Sinner *et al.* 2011). There are also nationally critical birds (black stilt, grey duck, and white heron), nationally endangered birds (bittern, black-billed gull), and nationally vulnerable birds (banded dotterel, Caspian tern, New Zealand dabchick, pied shag, reef heron, wrybill, northern New Zealand dotterel and red-billed gull) which visit the harbour.

Increasing coastal pressure and development can affect bird species that use the harbour e.g. it can reduce the area or result in the complete loss of their high tide roosting sites. High tide roosting and nesting birds need the option of several high tide roosts to minimize the effects of adverse weather conditions, wind direction, timing, height of tide, overlap of habitat, and disturbances from people and animals. Therefore, care needs to be taken to safeguard nationally and internationally important breeding, migrant, and wintering shorebirds which depend upon these places as a habitat (Environment Bay of Plenty, 2008).

The Ornithological Society of New Zealand (OSNZ) has been monitoring wading bird species around Tauranga Harbour biannually since 1984 (Sinner *et al.* 2011). The bird species have shown variations in population trends with four of the eleven wading bird species studied showing an increasing population trend, five showing a decreasing trend, pied stilt showing a mixed trend and Pacific golden plover not having enough sightings to show a trend (Sinner *et al.* 2011).

4.4 Mangroves

Mangroves vary considerably from location to location not only due to natural environmental gradients (such as shore height, exposure, hydraulic connectivity and salinity), but also anthropogenic factors (sedimentation, nutrient loading, and climate change) (Win and Park, 2015). Sedimentation is the main factor influencing mangrove spread, and its coverage in the Tauranga Harbour has increased by 160% between 1943 and 2003 due to increased sedimentation (Park, 2004). More sediment settling in the harbour raises the levels of the seabed and allows mangroves to colonise areas that were once frequently inundated by the tide. It also results in positive feedbacks as mangroves are effective at trapping fine sediment, further raising the inter-tidal seabed.

According to the public, mangroves/mangrove spread is considered as one of the key issues facing Tauranga Harbour and many residents would like to restore colonised areas back to the previous open water and estuary habitats. Mangroves are considered to compromise cultural, recreational, access and amenity values, and are also believed to influence ecosystem dynamics (Sinner *et al.* 2011).

Although research overseas has found that mangroves play a number of important ecological roles e.g. nitrogen cycling, sediment trapping, and providing habitat diversity, gaps remain in mangroves ecological role in New Zealand, and it has been recognised that because mangroves have the potential to reduce the area of intertidal flat, they can also alter benthic invertebrate composition (Win and Park, 2015; Sinner *et al.* 2011). This can affect larger fauna which feed on benthic invertebrate and thereby have follow-on ecological effects for higher trophic levels. The problem in Tauranga is that mangrove colonisation/expansion has occurred to an extent which is having negative ecological effects on the estuarine habitat (Win and Park, 2015). The reduction in estuarine/salt marsh bird habitat and loss of mudflat areas in which kaimoana e.g. shell fish and seagrass reside has led to management actions such as removal being undertaken. However, studies suggest that the likelihood of successful restoration is rarely considered when undertaking mangrove removal, and the recovery of mangrove removal areas in Tauranga Harbour is not well studied (Win and Park, 2015).

Mangrove removal has polarising views in the community, and as there are large gaps in our knowledge of estuary responses to mangrove removal in New Zealand it should be considered on a case by case basis. Harbours differ in mangrove characteristics, estuarine hydrology, and sediment characteristics from location to location; therefore mangrove removal may have different effects in different circumstances e.g. local sediment characteristics, sediment inputs, freshwater influx, method, size of area.

- Mangrove removal in Mangawhai Estuary caused changes in the sediment characteristics and abundance of macrofauna within the habitat. The alteration from mangrove to mudflat habitat was suggested to immediately increase species abundance and diversity. However faunal characteristics continued to change two to five years later (Win and Park, 2015).
- Mechanical removal in Tauranga Harbour (Te Puna, Waikaraka) resulted in minimal recovery to sandflat communities after a 12-month period, and substantial mulch biomass remained on site after 12 months.
- Mulching at three sub-estuaries was monitored in Whangamata and it was found that mulch and anoxia persisted for eight months after removal, in addition there was 100% mortality of both infaunal and faunal communities following the removal (Lundquist *et al*. 2010).

Smaller areas of mangroves removed by hand have been found to recover faster than larger mechanically removed areas (Win and Park, 2015).

4.5 Sea lettuce

Additional nutrients (N and P) in the harbour allow nuisance species such as sea lettuce to grow and dominate the ecosystem. This can have a number of adverse effects on the ecosystem:

- Seagrass and shellfish beds can become degraded due to sea lettuce smothering (Park, 2007).
- Sea lettuce can prevent the settlement and recruitment of some shellfish larvae.
- Sea lettuce can disrupt water circulation and therefore limit the food supply to filter feeders.
- Prevention of some species from foraging effectively.
- Communities may shift from benthic macro invertebrates to grazers and crustaceans which feed on the algal mats and shelter underneath them.
- Cause trophic cascades in which the loss of inhabiting species negatively affects bird and fish populations which prey on them for food.

Although sea lettuce can become a problem ecologically, it is mainly an issue for residents visually and can cause an odour which may make recreational activities such as walking on the beach or swimming less enjoyable. However, it does offer benefits to some species, e.g. it provides food and shelter for molluscs and crustaceans, and can also be quite an effective source and sink for nutrients by helping to recycle nutrients through the water column and sediment.

It has been found that although terrestrial and anthropogenic nutrient inputs to Tauranga Harbour should be considered when assessing the cause of harbour wide sea lettuce blooms, they are not the main driver; rather the blooms are largely controlled by natural events (Bay of Plenty Regional Council, 2011). Year to year variations in sea lettuce blooms are linked to the El Nino weather pattern in which persistent westerly winds drive coastal water offshore. The coastal water is then replaced by deeper oceanic water which is rich in nutrients, allowing sea lettuce to thrive (Bay of Plenty Regional Council, 2014).

4.6 Invasive species

The Port of Tauranga does not currently have substantial numbers of invasive species and those that are present have not yet caused significant harm (Sinner *et al.* 2011). The spread beyond the port environment is not known, but there have been no indications of invasive species causing major problems in the wider harbour (Sinner *et al.* 2011). As new invasive species can easily be introduced from commercial shipping, aquaculture equipment and recreational vessels, there is a high risk of marine pest incursion to Tauranga Harbour. Increased biosecurity surveillance has been established to prevent new species from invading/becoming established in the harbour, and also to reduce the spread of established pests into other areas.

4.6.1 Asian date mussel

The Asian date mussel is an invasive well-known fouling organism which was first found in Tauranga Harbour in 2005 (Murray, 2007). The mussel forms large mats over shallow seabeds and competes with other organisms for food and space. The large mats often smother other organisms and supress the growth, richness and abundance of other species in the vicinity of the mats (Sinner *et al.* 2011). A survey of the Tauranga Harbour in 2006/2007 found populations of Asian date mussel in four of 22 sites (Murray, 2007).

4.6.2 *Didemnum vexillum* (sea squirt)

Didemnum vexillum is a filter feeding sea squirt which colonises the bottom of the sea bed and can quickly build over most substrates and organisms (Sinner *et al.* 2011). Alike many other invasive fast growing species the sea-squirt has the potential to out-compete other species and smother marine habitats e.g. mussels growing on long lines (Sinner *et al.* 2011). The sea squirt has become established in the Tauranga Harbour.

4.6.3 Mediterranean fan worm

The Mediterranean fan worm was identified in Tauranga Harbour in 2013. An elimination programme is underway. It can grow in dense, thick mats that compete with native plants for nutrients and space. They can also interfere with boat equipment and aquaculture causing an increase in maintenance costs.

4.6.4 Asian kelp (*Undaria pinnatifida*)

The Asian kelp is found in most New Zealand ports, and although tends to do better in colder water (e.g. the South Island). It has the potential to out-compete native species in the harbour (Sinner *et al.* 2011). Asian kelp was first found in the Tauranga Harbour in 2005, and has been observed on shell banks in the harbour entrance and on man-made structures at the southern end of the port wharves (Sinner *et al.* 2011).

4.6.5 Dinoflagellate (*Alexandrium tamarense*)

Dinoflagellate is a species which is known to produce saxitoxin, a neurotoxin which can cause paralytic shellfish poisoning (Sinner *et al.* 2011). A survey in 2005 found *Alexandrium tamarense* in the Tauranga Harbour (Sinner *et al.* 2011).

4.6.6 Clubbed tunicates (sea squirt)

In terms of potential threats, the clubbed tunicate is a sea squirt which is of particular concern to the Tauranga Harbour due to the high amount of vessel traffic between the Hauraki Gulf (in which it has become established) and the port (Sinner, *et al.* 2011). The clubbed tunicate is capable of out-competing other species for space and may reduce the complexity/biodiversity of the marine habitat. The clubbed tunicate may also out-compete native filter feeders for food (phytoplankton and/or zooplankton) due to its high filtration rates (Kluza *et al.* 2006). It was detected in Tauranga Harbour in 2013.

Part 5: Recreation/access

Overall it is considered that the Tauranga Harbour has relatively good accessibility, however improvements can always be made and some people identified boat access and facilities in the northern harbour to be a significant problem (Harrison Grierson, 2012). There is a need for a balance between providing access for a broad range of activities, caring for the ecology of the area, and maintaining the harbours open space qualities. Recreational access needs to acknowledge that users often participate in multiple harbour related activities, e.g. boating, walking, picnicking, swimming, kaimoana gathering and kayaking.

Public recreation and access may become an increasing issue due to growing problems such as:

- Mangrove expansion.
- Infilling of navigation channels from sedimentation.
- Land use development.
- Activities and structures in the marine area.
- Increasing population.

As the population continues to grow the number of people wanting to use the harbour for recreational purposes will increase, resulting in increased pressures of accessibility and conflicting recreational uses around popular areas:

- Increasing use of vessels and ongoing development around the harbour margins can conflict with access to traditional Māori fishing and cultural activity areas.
- On-going tensions between recreational and commercial fishing in Tauranga Harbour.
- Noise and activity around the harbour can conflict with Marae ceremonies.
- Vessels (boats and jet skis) pose a danger to children swimming.
- Increasing number of people wanting to use boat ramps, car parks etc. (Environment Bay of Plenty, 2008).

Due to the high recreational use of the Tauranga Harbour it is also important to ensure that there is a balance between recreational use and protecting parts of the harbour for their ecological values. These ecological issues have been mentioned in the previous section however as they are related to recreation/access they are also relevant to this section:

- People and dogs can disturb high roosting and nesting birds.
- Use of vehicles on harbour beaches and foreshore areas can impact shellfish beds (emerging issue particularly in the northern harbour when the ramps are busy or not useable at low tide).
- Increasing vessel use (boats, jet skis) can cause erosion from the wake.

Part 6: Public perception

Past research has indicated that public perception of Te Awanui Tauranga Harbour can be different from monitoring results of environmental quality (Environment Bay of Plenty, 2008). The table below illustrates the public's perception of the biggest issues current facing the harbour as surveyed in 2012 and 2015.

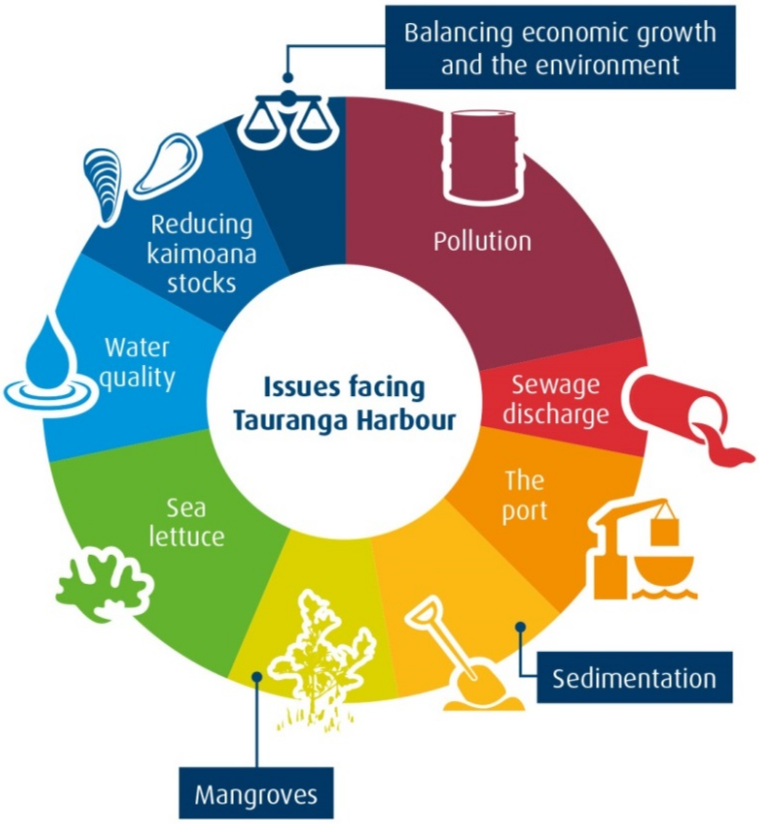
Table 11 Public perception of current/biggest issues facing Te Awanui Tauranga Harbour.

Issue	2012 survey results (top 11)*	2015 survey results (top 11 and corresponding figures for 2012 top 11)
Pollution – general	36%	12%
Sea lettuce	34%	24%
Water quality	26%	-
Sedimentation	22%	-
Mangroves	21%	7%
Pollution – from port	21%	8%
Balancing economic growth and environment	19%	7%
Sewage discharges	15%	-
Stormwater pollution	13%	3%
Dwindling fish stocks	12%	4%
Dwindling shellfish stocks	11%	2%
Oil spills	-	11%
Pollution – from farming	-	6%
Lack of facilities	-	5%
Pollution – from industrial activity		4%
Port traffic – small boat safety	-	5%

**Respondents were able to indicate more than one issue.*

Source: Key Research, 2012; Versus Research, 2015.

Figure 7 2012 public perception survey – issues of concern. Source: Bay of Plenty Regional Council.



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