MANAGING WET WEATHER SEWAGE SPILLS IN A CHALLENGING ENVIRONMENT

Andrew Carvell; CPEng, MIPENZ

ABSTRACT

Sewage spills into the Whangarei harbour during wet weather cause a public health risk to those using the harbour for contact recreation and shellfish collection. Solving the cause of the spills, inflow and infiltration of stormwater into the sewer network, is made difficult for a number of reasons including: the inability of the community to fund large capital projects, Whangarei's high rainfall rate, the private and public sewer network is aging, and the soil type exacerbates inflow and infiltration.

Whangarei District Council developed a range of innovative solutions to manage the effects of the spills. The benefits of these solutions were assessed using sophisticated hydrodynamic dispersion and risk models to determine the impacts on public health.

These innovative solutions included:

- An award winning upgrade of an existing pump station;
- Design of a 1,000 cubic metre overflow storage system that acts as a treatment process in extreme wet weather events;
- Disinfection of highly dilute wastewater using ultraviolet light, with a treatment level based on public health benefits;

The works programme is into year 3 of 7 with $13.5M committed to date. Further projects, totaling an estimated $23M, will be developed in line with the Councils 2012/2022 long term plan.

KEYWORDS

Sewage overflows, infiltration and inflow, wastewater treatment, UVT, public health

1 INTRODUCTION

Whangarei is surrounded by some of the world's most beautiful coastlines, home of iconic marine reserves, flora and fauna. Although the economic conditions in Whangarei are improving it currently has one of the lowest GDP per capita figures in New Zealand.

As shown in Figure 1 the city lies at the head of the 10,000 hectare Whangarei harbour. The harbour has, and continues to be, a major source of kaimoana (seafood) for locals, and attracts many tourists each year. A range of species are collected from the harbour which include fin fish such as snapper and kingfish, and shellfish including oysters and cockles. Oysters and cockles are also commercially farmed within the harbour.

Management of water pollution in the harbour is a major issue. The city of Whangarei, with just over 60,000 residents, discharges its stormwater and wastewater at the top of the harbour, where it mixes with land runoff during storm events. As a result of degraded harbour water quality after storms the local health department may close the harbour to recreational use for 5 days and shellfish gathering for 28 days. There can be 10 wet weather events per year and the impact on the community is considerable.

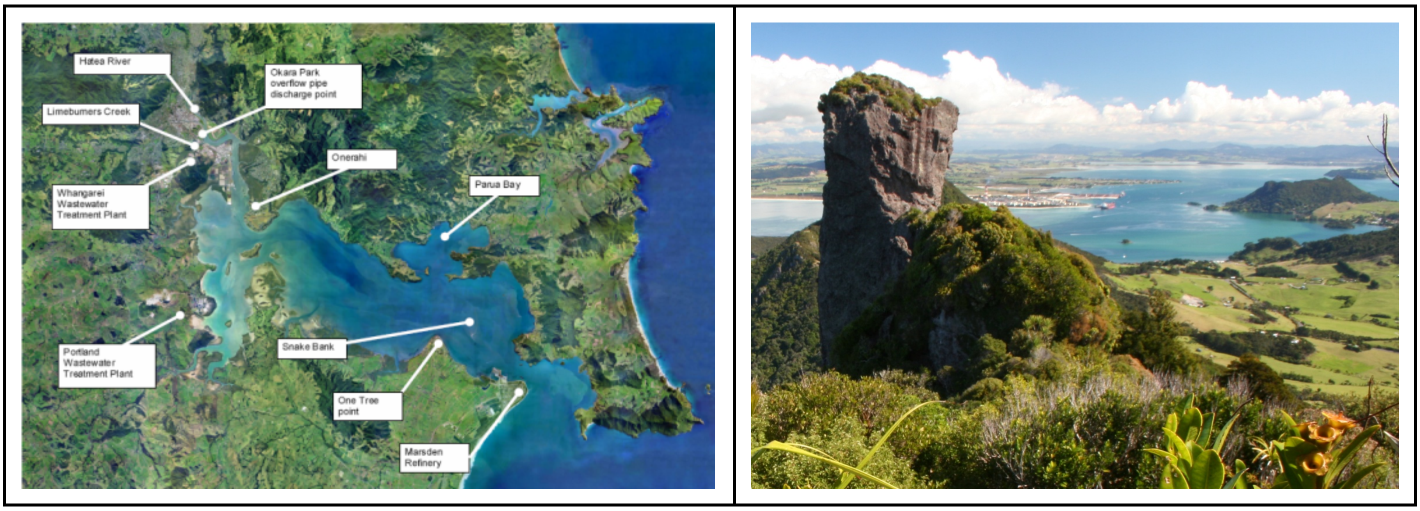

Figure 1: Overview of Whangarei Harbour

The city's 500 km of sewer network consist of a mixture of earthenware, asbestos cement and PVC sewer pipes installed respectively from 1905 – 1950, 1950 – 1990, and 1990 to present. The pipe network, that has remained relatively unchanged since installed, has been laid predominantly in heavy clay soils that swell and shrink as the soil moisture changes. The city experiences New Zealand's highest urban rainfall with an average just over 1,600 millimetres per annum.

Given the above physical factors it is not surprising that the sewer network has very high inflow and infiltration (I/I) of storm water, increasing the flow of wastewater during wet weather to well over ten times dry weather. These high flows cause sewage spills and peak flows at the treatment plant. A large proportion of the pathogens that end up in the harbour during storm events come from sewage discharges, directly contributing to closures.

The Whangarei District Council (WDC) has been under mounting pressure to address the issue of sewage spills. The cost of a district wide sewer renewal programme is not affordable for the community and would require significant investment from homeowners to repair private pipe work. To address public concerns the WDC needed to come up with an alternative strategy to manage the impacts of sewage discharges.

Key to this was understanding what the problem of sewage discharges is. Sewage discharges contribute to the number of pathogens in the harbour, meaning there is an elevated public heath risk to harbour users.

This differs to thinking of the issue as an I/I problem and prompts a range of management options to be considered. The processes that the Council worked through included:

- Defining the problem;
- Assessing options and developing a capital works programme
- Communicating with the key stakeholders and the community.

2 THE PROBLEM

2.1 INFLOW AND INFILTRATION

Central to understanding the extent of sewage discharges was the creation of a hydraulic model of the sewer network. Whangarei District Council (WDC) engaged AWT to prepare a model of the network using MOUSE software developed by the Danish Hydraulic Institute. The model was built from a combination of as-built information, GIS information and site surveys. The model was calibrated using sewer flow measurements in both dry weather and wet weather and checked against operational experience of where spills were known to occur.

The model was found to be reasonably accurate and lead to the discovery of at least one previously unknown spill location.

Perhaps not surprisingly the sewer network was found to be very leaky, particularly in the older areas of town. Figure 2 sets out a diagram showing the amount of spare capacity in the sewer network in dry weather and in an annual rainfall event. The extent of red pipe work indicates that in an annual event most of the network is flowing full, resulting in numerous sewage spills.

Pipe spare capacity in dry weather — Pipe spare capacity in a 1 year rainfall event

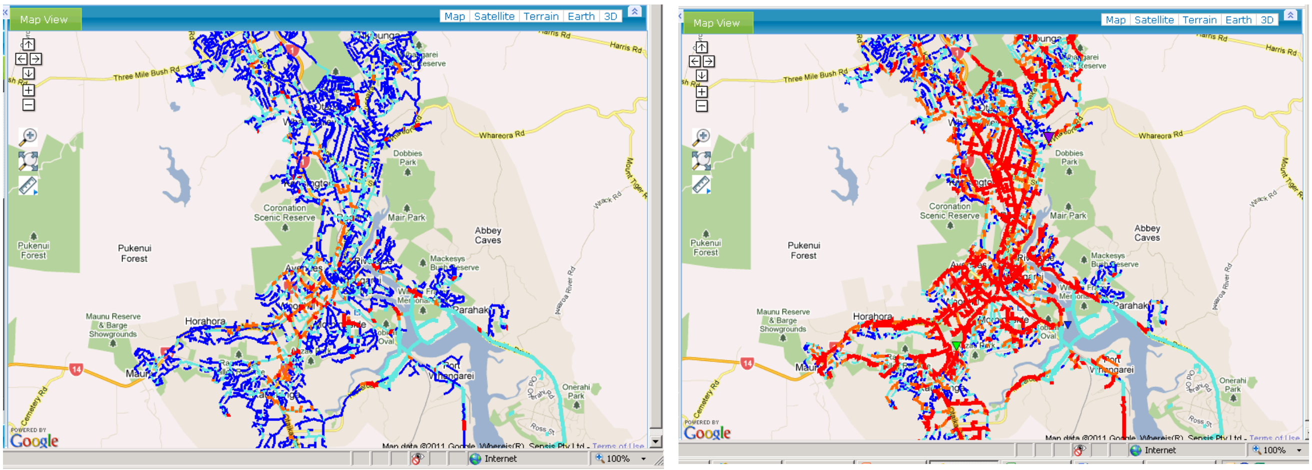

Figure 2: Model predictions of sewer pipe capacity (blue: spare capacity, red: 100% full)

2.1.1 SELECTION OF A DESIGN STORM

Following calibration it was necessary to establish design conditions for the model, i.e. what storm events could be used to design network improvements. It was clear from a number of early model runs that the network responded differently to similar rainfall patterns falling in summer compared to winter, as the dry ground in summer takes more storm water to initiate a network response.

To establish a design storm a coarse review of the model prediction for sewer flows was undertaken for 15 years of continuous rainfall data. From this 264 wet weather events were found to have occurred. These events were then ranked and the top 35 were run through the model in more detail and the network response assessed. The reason for selecting 35 events was to make sure the range of events that would be considered for assessing improvements, i.e. 5, 2, 1, and 0.5 year recurrence intervals, was covered.

The network response of these 35 events was then compared to NIWA's High Intensity Rainfall Design System events (HIRDS) to see if it could be used as a surrogate for real rainfall events. This was found to be the case and it was decided to use HIRDS rainfall for further design work.

From this point we were able to say that when a tank was sized to store the spill volume predicted in a 1 in 5 year storm this actually meant the estimated volume of spill when a 1 in 5 year HIRDS rainfall event fell on the catchment. It was necessary to make this definition so that the effects of different rainfall events on other contaminant sources, such as land runoff, could be assessed using a standard reference.

2.1.2 ESTIMATE OF SPILL VOLUMES

The model was also used to estimate where the wastewater was entering the harbour catchment and its relative magnitude. To do this predicted spills were grouped into the three main catchments of the upper harbour: Raumanga; Hatea; and Waiarohia, and totalized for different design storms. The results are presented in Table 1.

The aim of this work was to help prioritise tasks in an improvement programme and also allow an estimate to be made of contaminant loading to assess effects.

		Total overflow volume	*Total to treatment plant*	*Overflow + Treated*	*% of wastewater generated during a storm that overflows to a stream catchment*			
	Event Return period	***ML***	***ML***	***ML***	***Rau-manga***	***Hatea***	***Wai-arohia***	***Total***
					%	**%**	**%**	**%**
Current (2011)	6 mth	23	108	131	9.4	4.6	3.8	18
	1yr	33	131	164	9.9	5.7	4.2	20
	2yr	43	156	199	10.4	6.6	4.6	22
	5yr	63	181	244	11.9	8.6	5.2	26
Future (2041)	6 mth	31	108	139	10.4	8.1	3.7	22
	1yr	42	131	173	11.1	8.8	4.1	24
	2yr	52	156	208	11.3	9.3	4.4	25
	5yr	75	181	256	12.8	11.4	5.0	29

Table 1: Estimate of sewage spill volumes in large storms

To further emphasize the extent of leakage a modeling exercise was undertaken to increase the size of pipes and pumps in the network until no sewage spills occurred in a 1 in 5 year storm. This would require well over $100M in network improvements and would result in flow at the treatment plant in excess of 4,000 L/s. A large increase on its current peak flow of 1,450 L/s. Unless it could be treated at the treatment plant there would be no net gain in harbour water quality improvement.

2.2 THE EFFECTS

2.2.1 HYDRODYNAMIC DISPERSION MODEL

In order to better understand the effects of the sewage discharges, WDC, in conjunction with the Northland Regional Council and North Port engaged NIWA to develop a hydrodynamic dispersion model of the harbour. The model would be used to model contaminant transport within the harbour based on tidal movements, freshwater inputs and surface mixing.

The models developed included a hydrodynamic “particle tracking” model and DHI’s MIKE 3 FM Particle Tracking (PT) Module. The PT module can simulate advection and dispersion processes from a single point source (e.g. an outfall) or multiple sources. If the particle changes over time, such as the die-off of bacteria, a decay function can be applied to the model (Reeve et al, 2009 and 2010).

The model was used to assess the fate of the contaminants discharged into the harbour. Monitoring data had indicated significant upper harbour effects however it was difficult to assess the impacts of sewage discharges compared to background sources. The initial focus of the modeling work was faecal coliform bacteria, and concentration gradients within the harbour were developed for storms of various sizes

An example of the model output is provided as Figure 3, which shows the estimated effects of treatment plant bypasses (little treatment) during a 30 year return storm that occurred in January 2011 compared to disinfected effluent within the Whangarei harbour. The picture shows the discharge from the treatment plant (red colour in top upper left of the diagram) and reducing concentration of bacteria as the distance from the discharge point increases. The distance between the discharge point and mouth of the harbour (lower right of the diagram) is 18 kilometres. The model prediction assumes there are no other contaminant sources.

Untreated Bypass *Bypass disinfected to 1,500 FC/100mL*

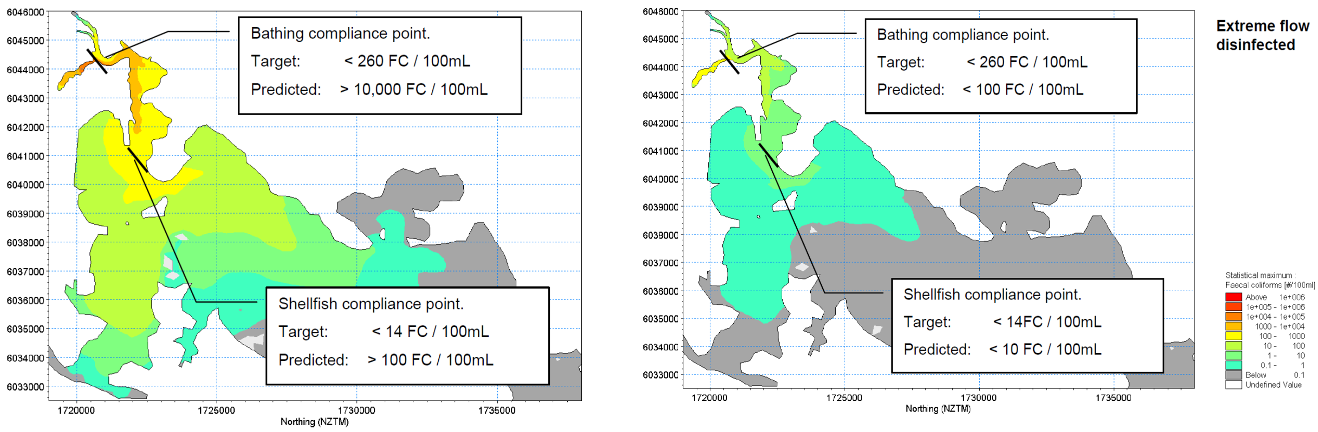

Figure 3: Model prediction of harbour contamination from bypasses in the Wastewater Treatment Plant

From a community perspective the model outcomes had some disturbing results. Firstly the model indicated that in dry weather particles could take up to 3 months to leave the harbour, as they get washed in and out with the tidal cycles. The model was also predicting high bacteria levels in recreational bathing areas and extending as far as some shellfish gathering areas even without sewage discharges.

2.2.2 QUANTITATIVE MICROBIAL RISK ASSESSMENT

NIWA were engaged by NRC, in collaboration with WDC, to estimate the risk wastewater discharges pose to public health while people are swimming, undertaking other recreational activities (e.g. Waka-ama), and eating raw shellfish collected from water at various locations within the harbour.

NIWA developed a Quantitative Microbial Risk Assessment (QMRA) and estimated the probability of specific pathogen, in this case a virulent virus (Rotovirus) predominantly found in sewage, making its way into the harbour and making people ill either through contact recreation or eating contaminated shellfish (NIWA, 2011). Due to the virility of the virus chosen, NIWA considers this allows a conservative representation of a range of pathogenic organisms.

A total of 72 scenarios were modeled using a 1-dimensional QUEST model, comprising combinations of various degrees of wastewater treatment and storage at the WWTP and at Network overflow sites and varying degrees of contamination from other (background) sources. The information presented in Table 1 was used as inputs into the model.

Details of importance are summarised here:

- The assessment took into account rotovirus input from three sources; treatment plant discharges, network overflows and background sources of pollution. Some scenarios were run without any background contribution to enable the effects of the wastewater to be analysed in isolation.

- The model incorporated a time-varying and season-varying microbial inactivation of faecal microbes in the River and Harbour water to examine cases where overflows may begin at night and therefore subject to minimal natural UV disinfection for some hours and compare predictions of microbial concentrations for summer versus winter conditions (less UV in winter).

- The model was run assuming dry weather, a small storm and a large storm (1 in 5 year storm).

- The quality of the wastewater treatment plant discharge in the large storm event varied from current (screening, primary treatment and no UV disinfection) to treated.

- The network overflow volumes were based on the wastewater model estimates of what happens in a 5 year frequency storm currently. In addition, all the scenarios were re-run with an improved background water quality to reflect longer term water quality improvements that may be able to be achieved within the catchment as a result of network improvements to the wastewater reticulation system. The stage 2 works is expected to eliminate spills at key sites for a 1 in 5 year storm event and an 80% reduction in volumes from other sites as discussed in section 3 of this paper.

- The output from the model is the risk of illness from undertaking activities in the harbour at the two locations nominated. NIWA determined what would constitute an "acceptable" or "good" beach quality at these sites in accordance with MfE/MoH (2003) national water quality standards. The determination recognises that all natural water bodies have a small health risk associated with contact recreation or shellfish gathering and that this risk increases as the water quality deteriorates. The threshold for this investigation was a 5% probability that a person received an infectious dose. Therefore, a risk less than 5% was deemed acceptable, greater than 5% deemed unacceptable.

The results of the QMRA can be summarised as follows (McBride, 2011):

- Under all scenarios the risks to users at the bathing compliance point (refer Figure 3), including swimming, are acceptable both in summer and in winter with current discharges.

- Under all scenarios the risks to persons collecting and eating shellfish collected at the shellfish compliance point (refer Figure 3) are acceptable in summer but not during winter.

- During winter wet weather conditions the individual illness risks associated with eating shellfish collected at the shellfish compliance point are reduced from ~14% (current regime) to ~9.8% by upgrading the WWTP and no further catchment or network improvements are done. This is a significant reduction but still in excess of what is considered acceptable. This is due to the impact network overflows have on water quality, on top of the effect of underlying water quality.

- The background water quality during a very large storm in winter without any sewage discharge, poses a risk for shellfish consumption estimated at 2.9%, and therefore contributes between 20 and 30% of the individual illness risks.

- Therefore, in order to achieve an acceptable winter shellfish consumption risk the QMRA work indicates that an upgrade of the WWTP, in addition with network improvements, are needed.

- The data therefore indicates that with the network upgrades, WWTP upgrade and some general improvement in background water quality the target of 5% can be achieved in a 1 in 5 year storm event.

3 DEVELOPMENT OF AN IMPROVEMENT STRATEGY

The above investigations have helped develop tools to assess the value of works and prioritise areas for improvement.

3.1 INFILTRATION AND INFLOW PREVENTION

Research was undertaken to assess the value of undertaking further inflow and infiltration mitigation work. The Council had previously undertaken a series of investigations and network repair that had resulted in little change in sewer flow rates. This same experience was found to have occurred in other communities that had invested in preventing water getting into the sewer. A large proportion of the sewer network, around 50%, is privately owned, and that any improvement works undertaken on Council pipe work would also be needed in private pipework as well. This was considered unaffordable for the community.

The work undertaken to see what changes would be needed in the network to stop all sewage spills also lead to a realisation that the pipe size was limiting sewer flows. That is, there was a lot more storm water that could potentially get in but couldn't fit. Undertaking significant investment in sewer upgrades could occur without making any difference to sewer flows, as mitigation work was just freeing up space for infiltration and inflow to occur from other sources. As such following a path solely relying on I/I mitigations appeared risky.

Some mitigation work would be valuable as it would reduce the occurrence of localized sewage spills, such as gully trap surcharging, and also allow homeowners to take more responsibility for their contribution to the issue of sewage spills.

3.2 MAXIMISING INVESTMENT

A key consideration in assessing network improvements was to make sure that as far as possible improvements could also address issues associated with renewals, levels of service shortcomings (e.g. provision of dry weather emergency storage) and growth.

3.3 OTHER TECHNOLOGY

A review of other wastewater management technologies in addressing infiltration and inflow was undertaken and an assessment was made on the replacement of very leaky catchments with pressure sewers systems. Pressure sewer systems can be constructed with very low leakage and were considered to be a viable alternative for sewer renewals. Council adopted a Pressure Sewer Policy to allow pressure sewers to be used as an alternative to gravity networks, and can also be requested as the preferred option in geologically unstable or water logged ground.

3.4 THE WORKS PROGRAMME

Throughout the modeling and effects investigations Council and its advisors were developing an understanding of priority improvement areas. A works programme was subsequently developed for a 7 year period that was split into two stages. The expected outcomes of the work were tested using the Network, QMRA, and hydrodynamic dispersion models. The programme included:

- Upgrade of the Okara Park pump station. This project included installation of a new 800mm diameter rising main and upgrade of the pump station from a pump capacity of 630 to 1,350 L/s.
- Provision of storage and treatment at the Hatea sewage pump station, which has very little storage and spills up to and estimated 15,000 m^3 in a 5 year storm. The discharge was also into the Hatea River upstream of the popular town basin.
- Upgrade of the Wastewater Treatment Plant. The treatment plant bypasses most of the treatment processes for flows in excess of 660 L/s. As the peak flow is in the order of 1,400 L/s the untreated portion can be significant in large storms;
- I/I mitigation
- Work at other spill locations. A number of other spill locations were also identified. Management of these required a staged approach.

A programme of works for the wastewater system for the period 2010 – 2013 (Stage 1) and a preliminary programme for long term engineering work for the period 2013 – 2019 (Stage 2) was developed. Stage 1 of the programme was adopted by Council in July 2010 with Stage 2 recommended for consideration for the 2012 – 2022 long term plan.

The goals of the strategy are:

- Key infrastructure projects are developed so that they contain/prevent/treat spills from a 1 in 5 year return period storm. This is the case for Okara Park pump station and Hatea treatment.

- Network discharges are reduced such that 80% of spills that are predicted to occur in year 2040, accounting for growth, are prevented or treated in an annual storm event. This is in comparison to what would happen if no investment took place.

3.4.1 OKARA PARK PUMP STATION UPGRADE

The upgrade works involved the replacement of the two existing large pumps and two small pumps. The replacement large pumps (each rated at 250kW) have a combined capacity of some 940 L/s when pumping through the new rising main and the two replacement small pumps (each rated at 75kW), can generate a further 470L/s through the existing rising main under peak load conditions.

The combined capacity of all four pumps operating is approximately 1,350 L/s, although the maximum rate of flow into the station is 1,100 L/s.

A new 800mm external diameter PE (polyethylene) rising main has been constructed between the pump station and the WWTP. The overall result is a pipeline with more capacity, more resilience and a predicted longer life than the existing rising main.

The existing 600mm diameter rising main will remain in service and has been connected to the new small pumps. The lower flows will reduce line pressures and extend the potential life of this asset. Having four operational pumps, a stand-by generator and two rising mains provides a high level of flexibility and resilience for the upgraded pump station and the ability to absorb a wide range of potential interruptions caused by asset failure or planned shut-down without overflows occurring.

United Civil Construction Ltd won the NZ Contractors Federation Construction Award for contracts in NZ between $1M and $10M for its work on the Okara Park PS upgrade. The total project cost was $4.5M.

Figure 5: New 250kW Okara Park sewage pumps

3.4.2 HATEA SEWAGE PUMP STATION STORAGE AND TREATMENT

The Hatea Sewage Pump Station is located adjacent to the Hatea River on Whareora Road. During extreme wet weather events the inflow to the station exceeds the pumping capacity, and untreated wastewater is discharged into the Hatea River as an overflow event. The sewer network model identified the Hatea pump station as being the third most significant point source discharge in the Whangarei area, after overflows at Okara Park PS and Extreme flow discharges from the Whangarei WWTP.

The current Hatea SPS has limited storage and several sewage discharges are likely to occur in an average year. Furthermore, it is known that the site is flood prone and the existing pump station is inundated on average three times a year.

In order to mitigate the problems at this site the following is being undertaken:

- Construct a 1,000m^3 emergency storage tank, which will provide storage of inflow for at least a 12 hour period in dry weather, thus preventing spills due to maintenance breakdowns (this is required regardless of success in I/I mitigation) and due to short duration high intensity storms;
- Construct a treatment facility that passes any discharge in excess of the emergency storage volume through screening, settlement and ultraviolet light (UV) disinfection;

- Construct the proposed facility such that it is still operational if the site is flooded;
- Construct the proposal in such a way as to minimise environmental, cultural and social impacts associated with the project.

This 1,000m^3 storage facility will eliminate spills in small to moderate storms. For larger storms the wastewater will be treated via chemically assisted sedimentation and disinfected before being discharged. Full containment of spills would require storage in excess of 10,000 m^3, which was prohibitive in cost and land area.

The total project cost is estimated at $5M. As of September 2011 the project is 40% complete.

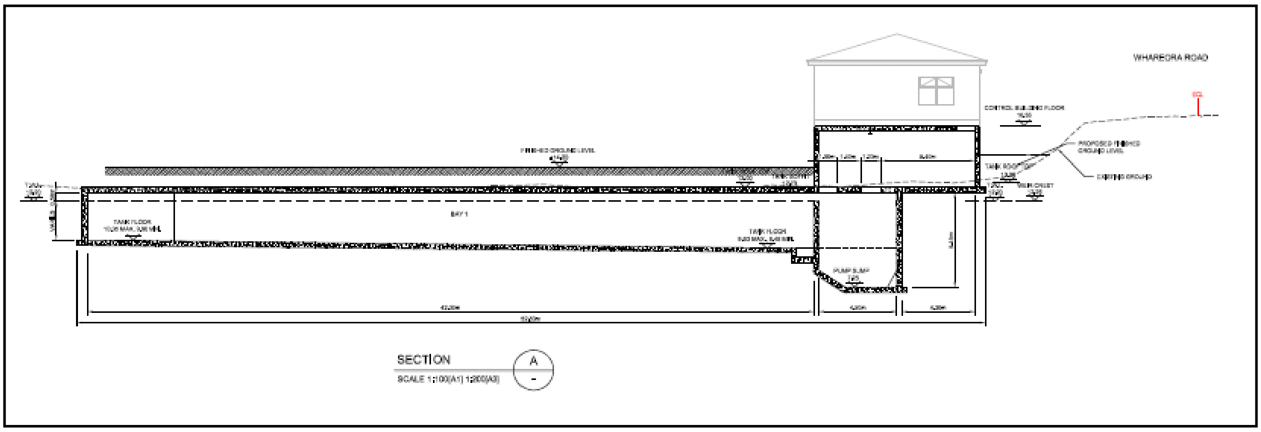

Figure 6: Section through the Hatea Storage and Treatment Facility (Opus 2011)

3.5 WHANGAREI WASTEWATER TREATMENT PLANT UPGRADE

Council proposes to treat all wastewater that enters the plant using UV disinfection to a level which would not impact on bathing or recreational water quality standards in the harbour in a 1:5 year storm.

Two activities were undertaken to determine a suitable treatment level. The first was to propose a standard that was technically possible to achieve utilising industry experience, and see how this would impact water quality in the harbour assuming freshwater dilution only (no die-off or tidal dilution). This was checked using the NIWA hydrodynamic dispersion model. The work indicated that an effluent with a median of 1,500 *E coli*/100ml would be diluted sufficiently at recreation and shellfish gathering compliance points (refer Figure 3).

The second investigation involved the Quantitative Microbial Risk Assessment (QMRA) discussed in section 2. The aim of this work was to help overcome some of the limitations of the use of water quality standards in assessing intermittent discharges when the background water quality is affected by other contaminant sources. It was found that the treatment levels determined in the dilution study were suitable, although further work was needed in the catchment to address overall contaminant levels.

The model also indicated that Council had to consider the cost benefit of its improvement works. There is a diminishing return on treating the effluent at the treatment plant to higher and higher standards during storms as the other contaminant sources (overflows and background) quickly dominant the overall harbour water quality. A balance is needed that addresses the effects of the discharge yet allows for funding to mitigate other discharges.

A number of feasibility exercises were undertaken to assess how easy it would be to disinfect the storm effluent to meet a possible standard of 1,500 cfu/100mL. This included work by engineering consultants MWH and AWT.

The output from an S:CAN monitor measuring Ultraviolet light transmissivity (UVT) of the treatment plant influent is included as Figure 7, plotted against influent flow rate. The results show that the UVT increases as the storm progresses reaching 40 – 60% just after the storm peak. The results supported earlier work that the UVT would be within a range suitable for disinfection.

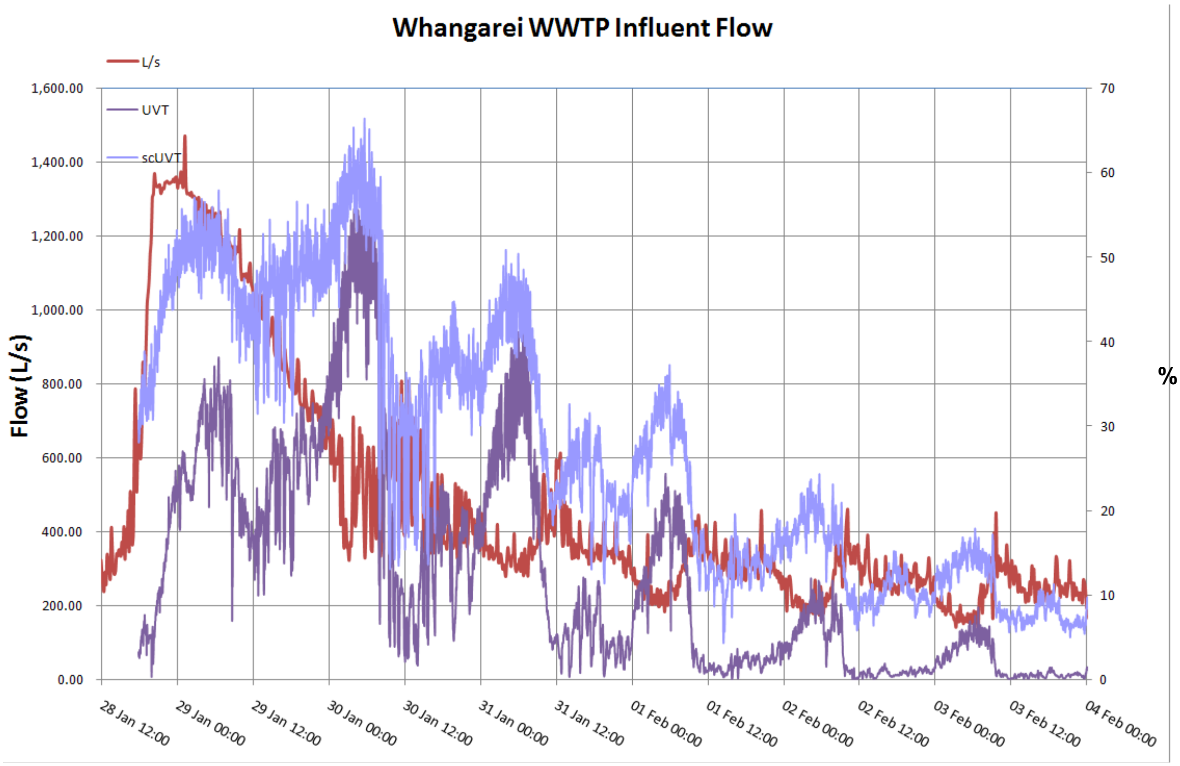

Figure 7: UVT, solids compensated UVT and TSS during 23 January 2011 storm

A proposed flow chart for the upgrade is included as Figure 8. The equalization basin shown in this diagram acts as a primary clarifier during large storm events and therefore offers primary treatment prior to UV. The council is currently working through consents associated with this discharge, the outcome of which will help direct the final plant configuration. The total project cost is estimated at $4M.

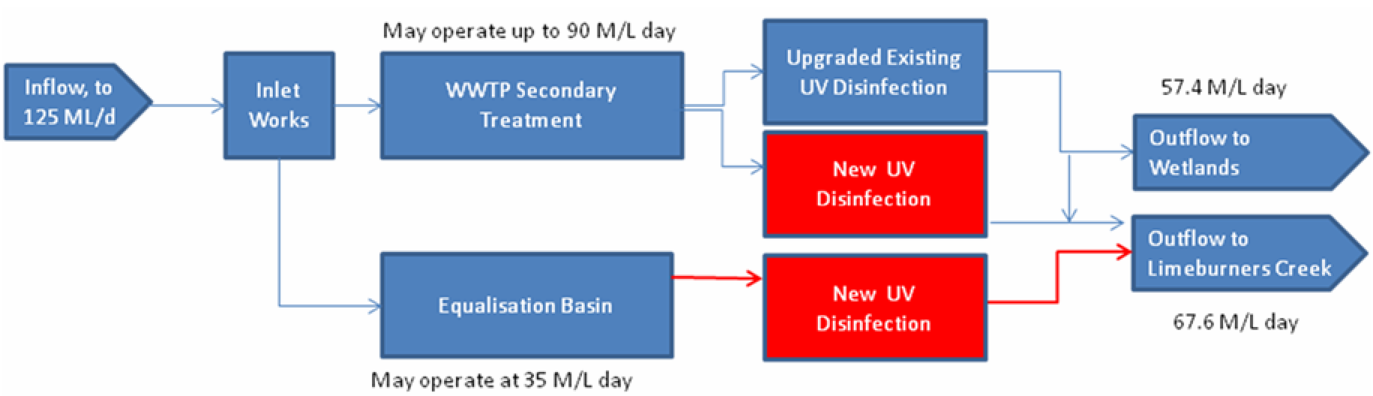

Figure 8: Simplified process flow diagram illustrating treatment plant upgrade

3.6 OTHER WORK IN SUPPORT OF THE CAPITAL WORKS PROGRAMME

Council has an ongoing programme of household inspections looking for direct stormwater connections. Over 2,800 properties were inspected last year with around 300 requiring work.

Work on a longer term strategy (50 years) has been progressed with community input, particularly Iwi/hapu. This has driven a move to look at other impacts on harbour water quality and initiation of the Whangarei Harbour Integrated Management Strategy.

Council has implemented a Quality Management system for its wastewater and stormwater activities, gaining accreditation under ISO 9001:2008. This is considered important in setting targets and improving the management of information relating to the wastewater system.

Community engagement has also been a focus for Council on wastewater issues. This has included: establishing regular meetings with iwi/hapu and other key stakeholders; community presentations; school education programmes; development of a community wastewater interest groups; regular newspaper articles; and making information easier to access using the internet, including up to date sewage spill information.

4 CONCLUSION

Sewage spills into the Whangarei harbour during wet weather cause a public health risk to those using the harbour for contact recreation and shellfish collection. Solving the cause of the spills, inflow and infiltration of stormwater into the sewer network, is made difficult for a number of reasons including: the inability of the community to fund large capital projects, Whangarei has the country's highest urban rainfall rate, the private and public sewer network is aging, and soil in the region exacerbates inflow and infiltration.

Whangarei District Council developed a range of innovative solutions to manage the effects of the spills with a high level of confidence while maximizing investment to assist issues associated with renewal of assets, level of service, and growth. The benefits of these solutions were assessed using sophisticated models to determine the benefits to public health.

These innovative solutions included:

- An award winning upgrade of an existing pump station;
- Design of a 1,000 cubic meter overflow storage system that acts as a treatment process in extreme wet weather events;
- Disinfection of highly dilute wastewater using ultraviolet light, with a treatment level based on public health benefits;

A major part of the work has included getting input from key stakeholders and communicating Councils strategy and progress to the community.

The works programme is into year 3 of 7 with $13.5M committed to date. Further projects, totaling an estimated $23M, will be developed in line with the Councils 2012/2022 long term plan.

ACKNOWLEDGEMENTS

The following people or organizations have contributed to the material presented in this paper:

Dr Rob Lieffering, Northland Regional Council
Dr Glenn Reeve and Dr Graham McBride, NIWA
Steve Couper and staff, AWT
Eric Thorn and Felix Richter, Opus International Consultants

REFERENCES

"Predictions of Human Health Effects Associated with Wet Weather Flows in Whangarei", G McBride and G Reeve, NIWA (2011). Report to Northland Regional Council.

"Whangarei Harbour Hydrodynamic and Dispersion Model", Reeve et al, NIWA (2010). Report to Northland Regional Council.