OPPORTUNITIES AT THE END OF THE PIPE - A RECONFIGURATION OF THE TP10 CONSTRUCTED WETLAND

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ABSTRACT

A reconfiguration of the TP10 constructed wetland design has been undertaken to extend detention to 10 days while still maintaining extreme event stormwater attenuation. The reconfigured design was developed during appeal mediation of a granted consent for combined treated wastewater and stormwater disposal. Located in Ruakaka the 6ha wetland, when fully developed, will receive stormwater runoff from up to 180ha mixed land use and 3000m³/day dry weather treated wastewater flows. The wetland discharges to Ruakaka Estuary with wildlife sanctuary, which in turn drains into Bream Bay with seawater takes for the Bream Bay Aquaculture Park. Appellants' concerns provided much of the design brief and included long detentions times, mixing of waste water and stormwater, containment of accumulated contaminants during extreme events, containment of wetland water in event of spills and early warning systems; meanwhile the stormwater attenuation requirements were achieved within the same footprint. The reconfiguration includes a wetland partition, drop weirs and bypass flume. Investigation was undertaken with MIKE Urban by DHI with UHM and Kinematic Wave + Infiltration models for design events and four year rainfall record respectively. Analysis included flows, effect on upstream ponding, detention times, and exacerbation of wetland water levels for plant health.

KEYWORDS

Constructed wetland, stormwater treatment, extended detention, attenuation, monitoring, alert systems

PRESENTER PROFILE

Adrian Tonks is a consulting Civil & Environmental Engineer with specialist interest in all aspects of stormwater management and design. Adrian has a Bachelor of Engineering in Engineering Science and brings a broad set of programming, analysis, and database skills to his modelling and engineering work.

1. INTRODUCTION

Marsden City, located in Northland, is a mixed use environment that has evolved from two industrial subdivisions of 95ha and 35ha, with construction completed in 2009. Both subdivisions achieve stormwater quantity compliance in separate wet ponds that discharge to the Ruakaka Estuary, and in turn to Bream Bay. While the ponds provide a treatment function, the water quality compliance requirements remain the responsibility of the upstream lot owners.

A future issue for the growth of Marsden City and the wider Ruakaka area is waste water treatment and disposal. During construction of the northern 95ha subdivision and associated 6ha wet pond a resource consent for the disposal of MBR quality treated wastewater to this structure was sought, with its conversion to a TP10 constructed wetland being one of the conditions. Consent was granted and subsequently appealed by NIWA's Bream Bay Aquaculture Park, Iwi, and a local environmental group. Whilst the consent application was for wastewater discharge, the appellants concerns principally related to stormwater quality. The appeal was successfully mediated outside of court and resulted in a revised wetland design. This paper discusses the parties' objectives, how these were achieved in the reconfigured wetland, and opportunities that the design offers.

Treated wastewater disposal to the wetland is dependent on the upgrade of the Ruakaka wastewater treatment plant which is presently on hold due to the economic environment. As a result the reconfigured design is yet to be constructed.

Figure 1: Marsden City & 6ha wet pond – construction monitoring aerial photograph 2009

2. DISCUSSION

The wetland redesign developed through balancing the requirements of both parties while working within the physical constraints of the site.

The appellants sought:

- An extended hydraulic retention time (HRT) of the mixed stormwater and treated waste water, ideally at least 6 days under most conditions.
- Enhanced stormwater and waste water mixing within the wetland.
- Reduced scouring out of accumulated sediments and reduced damage to wetland plants / associated biofilms by high velocity inflow.
- Reduced flushing of contaminant laden water and containment of accidental spills or WWTP malfunction.
- Increased monitoring frequency to enable early warning, giving time to enact a management response at the NIWA's Bream Bay Aquaculture Park research facility.

Meanwhile the applicant's team required:

- No negative effect on the flooding upstream within Marsden City.

- Water quantity compliance to be maintained (the districts environmental engineering standards require attenuation of the post development 5yr and 100yr ARI plus climate change events to be mitigated to 80% of the pre development pre climate change peak flows of the corresponding events with a UDSA TR-55 Type 1A hyetograph).
- Additional attenuation capacity over and above the present requirements to be preserved for future use, as best as able.

1.1. THE ORIGINAL WETLAND DESIGN

The wetland proposed in the original design has a 6ha footprint and conforms to the ARC TP10 banded bathymetry constructed wetland, with sediment forebay, and ephemeral and deep water zones. Due to the wetland size islands were incorporated to limit short circuiting. Treated wastewater disposal into the wetland is via a gravel bed, located adjacent to the sediment forebay and furthest from the wetland outlet. The average dead storage depth is 0.56m and live storage to emergency spillway (OTP 4.85m) is 3.2m. The wetland orifice outlet (IL OTP 1.65m) discharges to a farm drain, with 315ha catchment, which in turn to discharges to Ruakaka River.

Upstream of the wetland is a 95ha mixed use urban catchment comprising of three sub catchments. State Highway 15A separates Marsden City from the wetland and as a consequence the lower reticulated network conveys both the primary and secondary flows via three Ø1650 pipes at grades of 0.25%, these discharge into the wetland at IL OTP 2.2m. Within Marsden City the lowest elevation catchpit grate is GL OTP 4.9m.

The subdivision reticulation and pond were designed with a MIKE Urban UHM SCS hydrological and hydraulic model. In addition, this study has also utilities the Marsden Point OTA rainfall record from October 2006 to October 2010 with a Kinematic Wave + RDI hydrological model. Both the unit hydrograph and rainfall runoff have been scaled to utilise the wetland full attenuation capacity. The Marsden Point rainfall record includes the March and June 2007 tropical cyclone events, which caused widespread flooding throughout Northland.

1.2. RECONFIGURED WETLAND ELEMENTS & FEATURE

The reconfigured wetland is split into two 3ha sections, with the sediment forebay and wastewater gravel bed included in the first section. Separating the two sections is an intra-wetland weir with crest level at OTP 3.5m. The two sections are linked by an intra-wetland Ø225 orifice with IL OTP 1.5m. The intra-wetland link is positioned below the permanent water level to contain and aid TPH volatilisation within Section 1.

The inlet Ø1650 pipes are laid at a negative 9% gradient over the final 10m length and discharge to a bypass flume with IL OTP 2.9m. The bypass flume discharges into the second wetland section, Section 2. Spliced externally to the invert of the Ø1650 pipes are low flow pipes ranging from Ø300 to Ø450, with sizing based on the water quality event from the contributing catchments. The spliced low flow pipes act as drop weirs, and are laid to the same gradient as the upstream pipe run. The low flow pipes are fitted with back flow prevention gates at the outlet to the sediment forebay.

To increase hydraulic retention Section 1 is deeper with a dead storage depth of 1m, although the sediment forebay is 2m deep. Section 1 is essentially a wet pond, although would suit floating vegetated islands, which subject to the development of research based evidence demonstrating their potential for phosphorous removal FVI may prove beneficial in reducing the alum dosing regimen at the waste water treatment plant.

Section 2 maintains its TP10 constructed wetland banded bathometry characteristics and has an average dead storage depth of 0.56m.

1.3. DESIGN APPROACH AND SIZING

The reconfigured design follows progressive although somewhat iterative steps:

1. The high flow negative gradient pipes are adjusted up to the point that there is not an observed change in ponding depth within the upstream catchment for the 100yr ARI +cc design event.
2. The low flow pipes and intra-wetland orifice are sized for the design water quality event, with surcharge within the high flow pipes not exceeding the outlet invert to the bypass flume. Two design water quality events were accessed, the NZTA 90th percentile event of 22.5mm/24hours and the ARC TP10 1/3 2yr ARI event of 37mm/24hours. On inspection of the reconfigured wetland function over the four year

rainfall record the NZTA WQV event was ultimately selected for sizing purposes as it produced greater detention times and on average resulted in four bypass events per year over the rainfall record.

3. The intra-wetland weir crest level is adjusted to the point that water from Section 2 flows back into Section 1 for the 5yr & 100yr ARI +cc design event, along with larger bypass events from the rainfall record. Above the crest level the two sections function as a single attenuation volume, as the water level recedes the back flow prevention gates on the low flow pipes stop water from Section 1 short circuiting the intra-wetland weir via the bypass flume.
4. The wetland outlet orifices are sized as normal to achieve water quantity discharge compliance.

The design objectives are to preferentially hold onto both the stormwater first flush and waste water for as long as possible, for these to dilute each other and not be flushed out during extreme weather events, while still achieving the stormwater peak flow mitigation requirements. Figure 2 shows the water level decay rate of the reconfigured and TP10 wetlands for the water quality event over fourteen days.

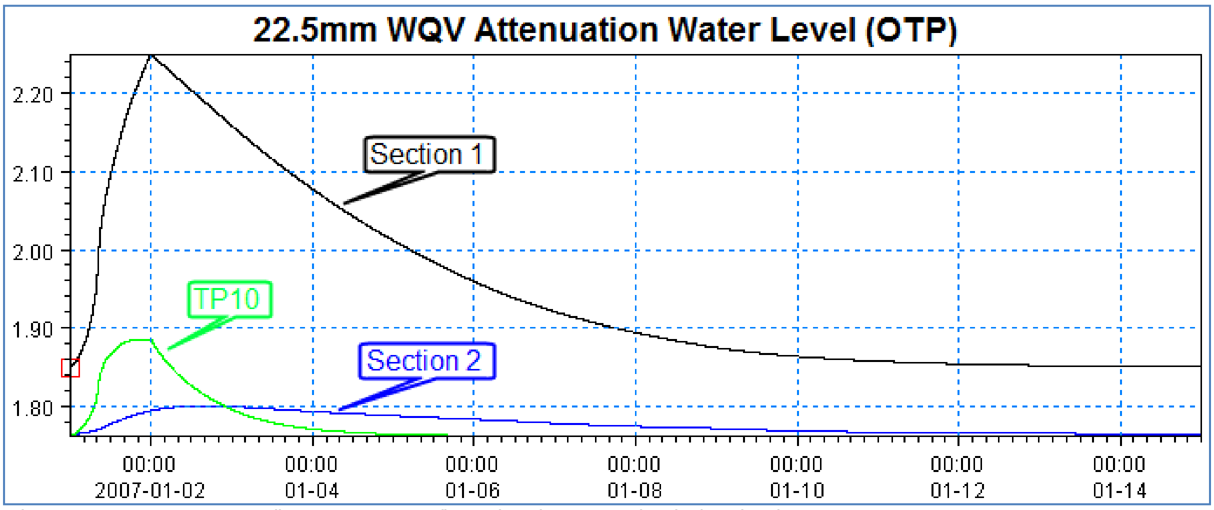


Figure 2: 22.5mm water quality event - reconfigured and TP10 wetlands (14 days)

Both the reconfigured and TP10 wetland outlets have been sized to achieve compliant discharges for the 5yr & 100yr ARI plus climate change events, and therefore both wetlands have the same design event peak discharge. Figure 3 below shows that the reconfigured wetland requires 4% greater attenuation volume than the TP10 wetland, although the difference is likely to vary with compliance requirements within other districts.

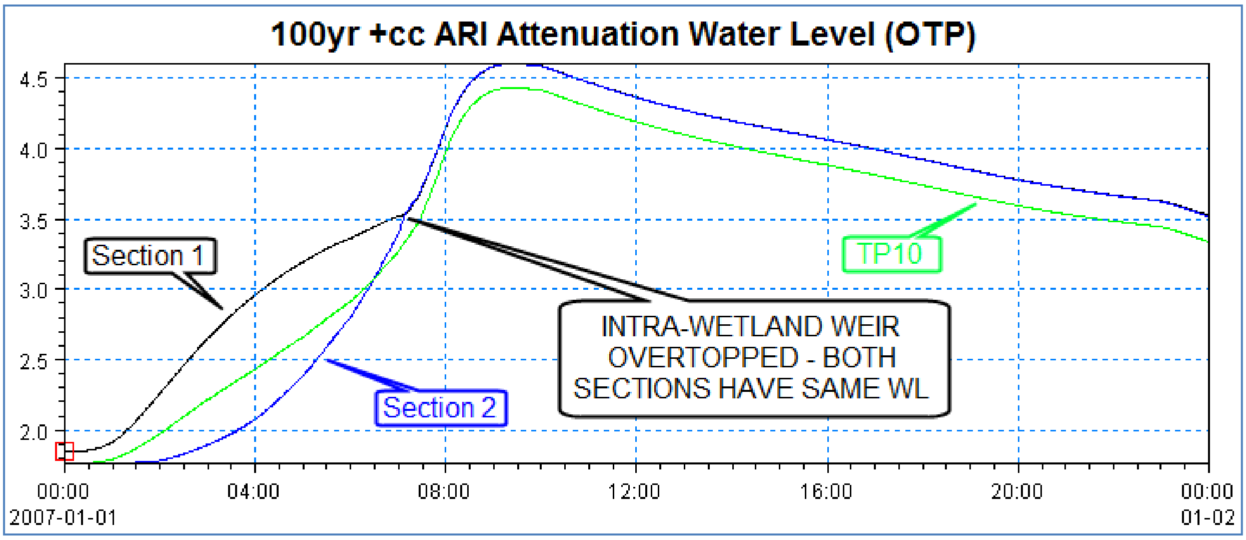


Figure 3: Attenuation of 100yr +cc ARI design event with waste water inflow

One of the design objective was to reduce flushing of contaminant laiden water from the wetland during extreme events. This has been acheived through the intra-wetland weir crest level, demonstrated in Figure 4 below.

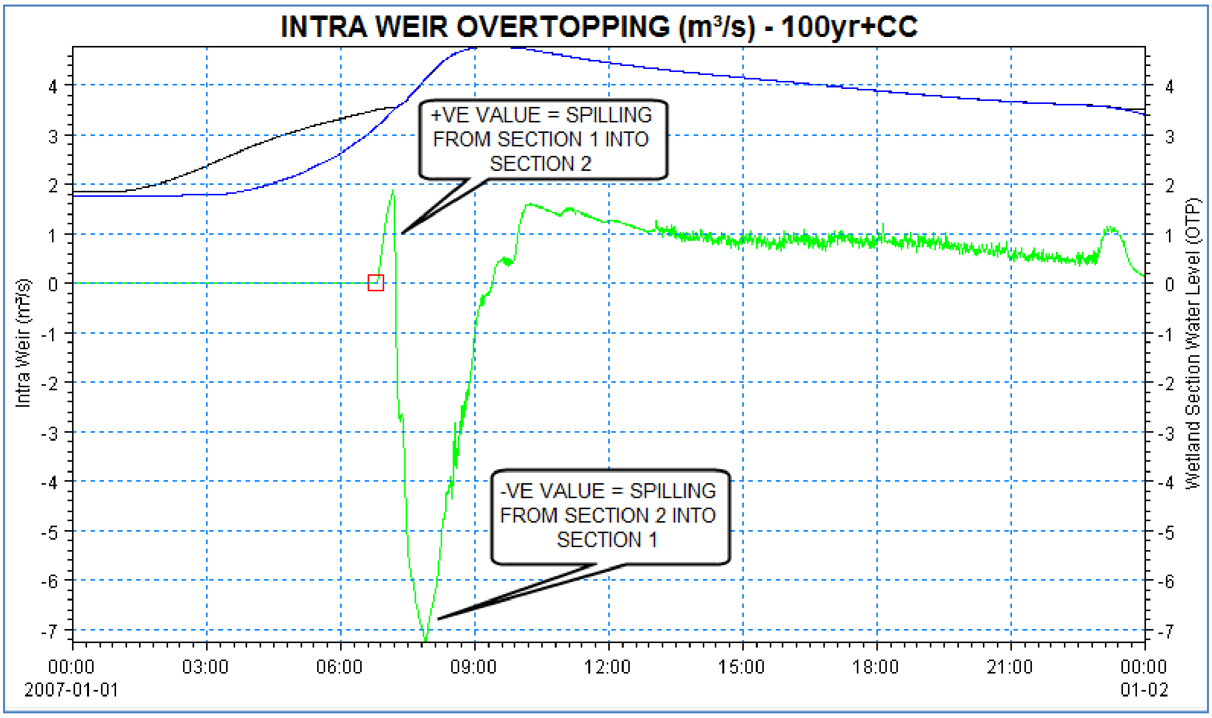


Figure 4: Section 1 flushing resistance

The four year rainfall record from Marsden Point (10/2006 – 10/2010) has be used to evaluate the effect of cumulative events on the reconfigured wetland.

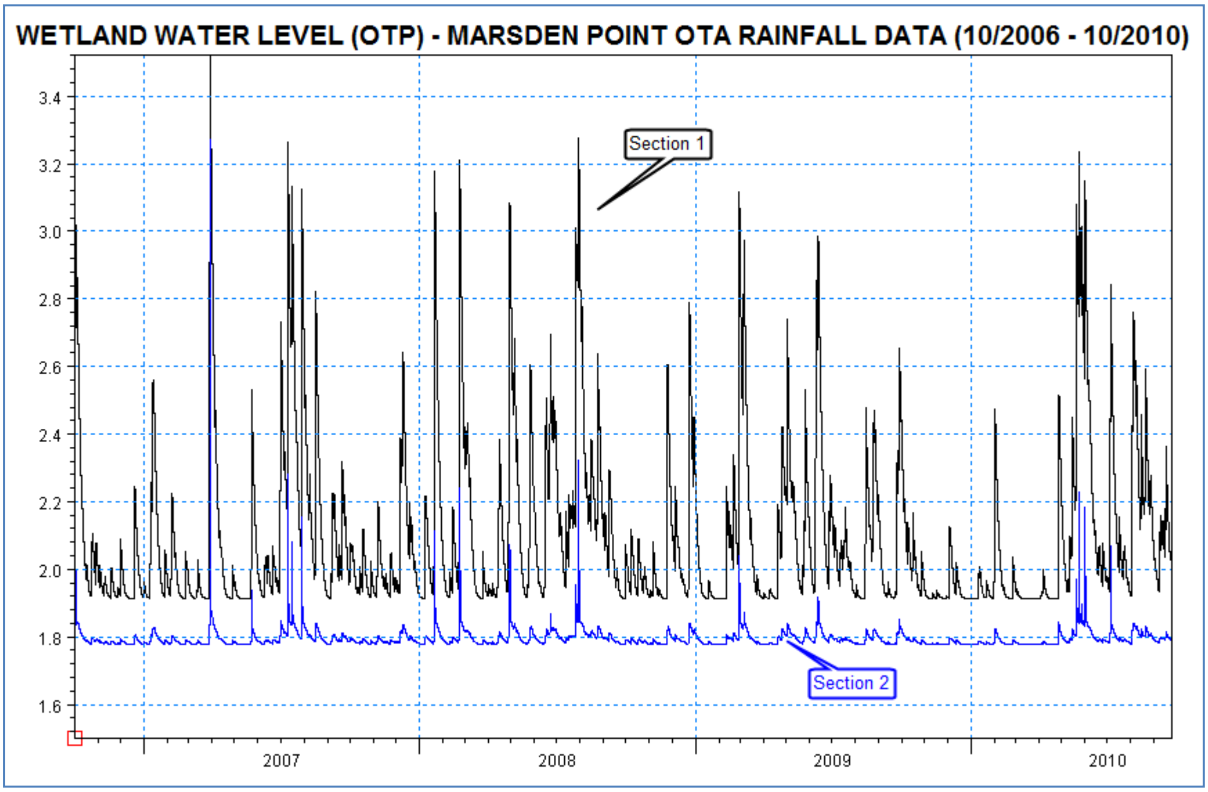


Figure 5: Four year rainfall record continuous simulation – cumulative effect on reconfigured wetland water level

Wetland Section 1 - analysis (long term minimum live storage water level = 1.914m OTP)							
Depth Exceeding	>10mm	>50mm	>100mm	>200mm	>400mm	>800mm	>1600mm
Instances	57	86	83	69	48	24	4
Maximum Duration (days)	102.94	66.15	52.06	35.91	20.09	8.96	0.03
Average Duration (days)	20.12	10.17	8.22	6.59	4.49	2.41	0.02

Wetland Section 2 - analysis (long term minimum live storage water level = 1.778m OTP)							
Depth Exceeding	>10mm	>50mm	>100mm	>200mm	>400mm	>800mm	>1600mm
Instances	77	33	20	14	7	1	0
Maximum Duration (days)	56.53	15.93	1.90	1.19	0.80	0.40	0.00
Average Duration (days)	9.39	3.32	0.77	0.47	0.20	0.40	0.00

Table 1: Four year rainfall record - summarised wetland water levels

The purpose of Table 1 to aid interpretation of the water level graphed in Figure 4 above and to also investigate whether wetland plant health would be adversely affected. As expected wetland planting would not be suitable in Section 1 unless floating vegetated islands are utilised. Note: Depth exceeding is the depth above minimum operational level, i.e. the live storage, Instances is the number of times a given live storage depth is exceeded, Maximum Duration is the longest duration of a single instance and Average Duration is the sum of instance durations divided by the number of instances.

The following figure shows high flow bypass instances verses rainfall intensity and Section 1 water level (red line at 2.9m OTP). Bypass occurs either when Section 1 water level exceeds 2.9m OTP or where inflow discharge (m³/s) exceeds the low flow pipe capacity, such as during convective thunderstorm events. The latter provides a mechanism to moderate velocity entering the stormwater sediment forebay.

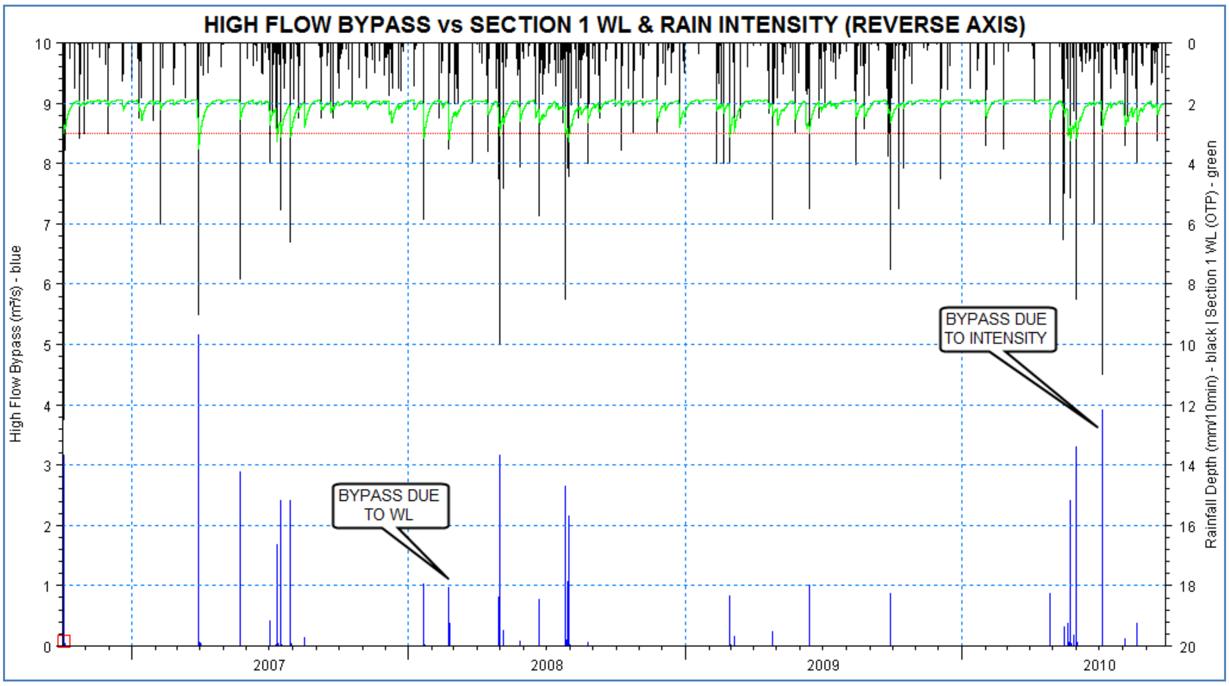


Figure 6: Four year rainfall record – high flow bypass

The Marsden Point four year rainfall record model run includes waste water inflow corresponding to either wet weather (69.4l/s inflow) or dry weather (34.7l/s inflow) conditions. Rainfall with >=8.4mm/hr intensity or >=20mm/day is treated as a wet weather flow.

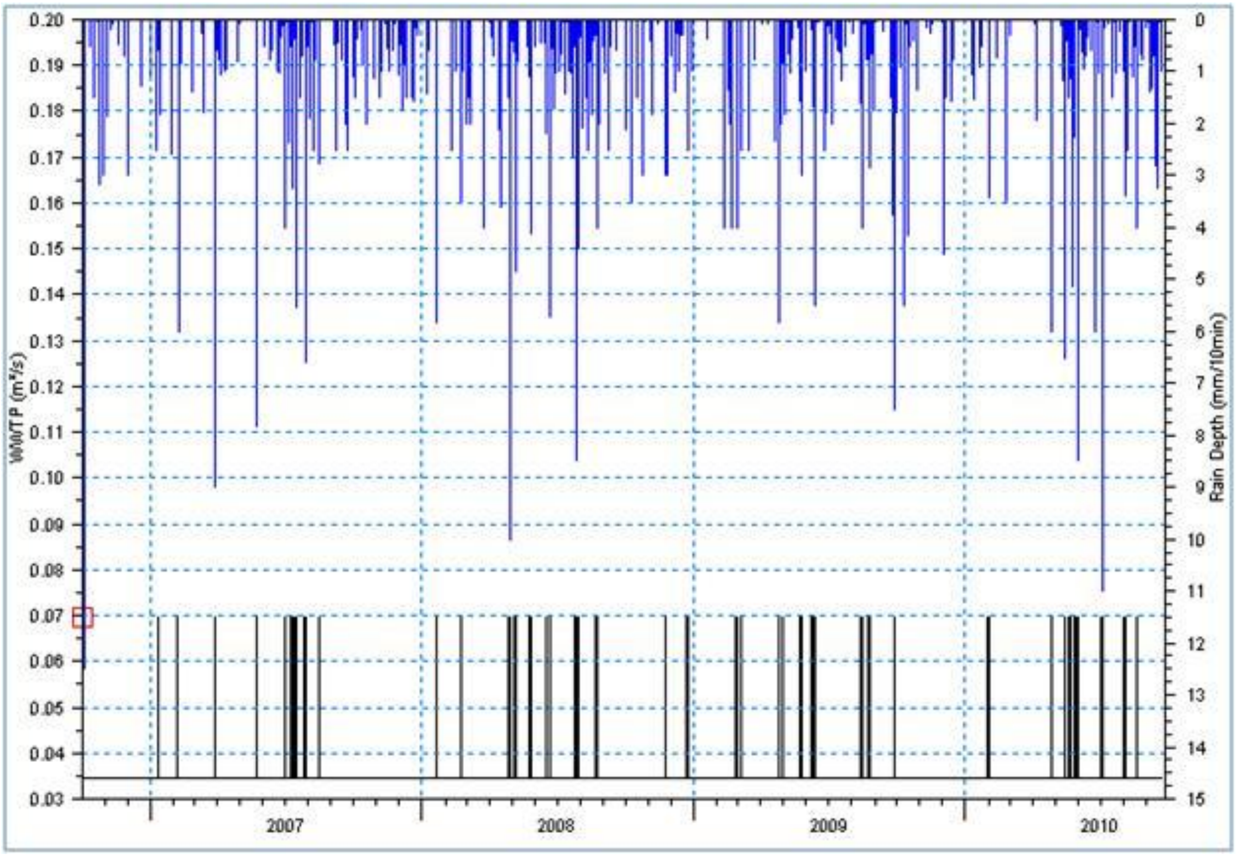


Figure 7: Four year rainfall record – waste water dry / wet weather inflow

A pivotal aspect of the redesign brief is extended detention. Hydraulic retention times have been compared between the reconfigured design and the TP10 wetland. Because HRT is a function of volume, two further scenarios have been compared; these are the reconfigured design without additional dead storage and the TP10 wetland over attenuated such that the water levels match the reconfigured design.

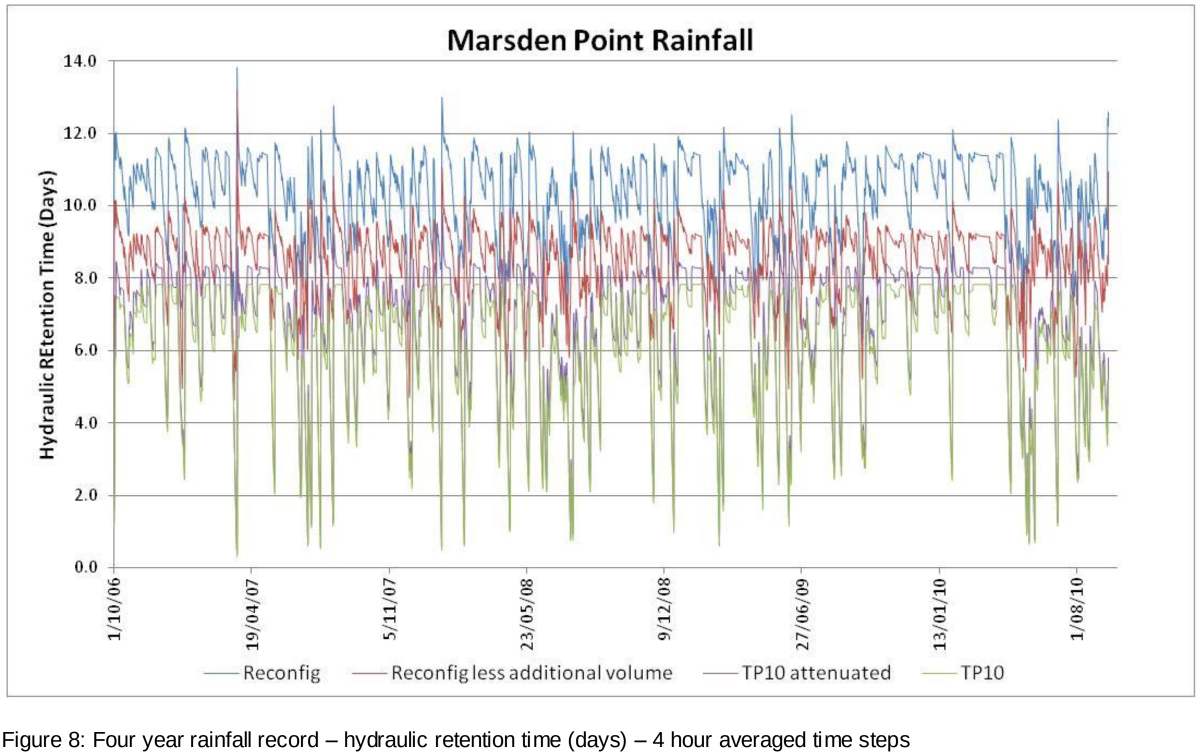


Figure 8: Four year rainfall record – hydraulic retention time (days) – 4 hour averaged time steps

		Reconfigured	TP10	Reconfigured less additional volume	TP10 Attenuated
Overall	Min	6.2	0.3	4.7	0.4
	Lower Q	9.6	5.3	8.0	5.6
	Median	10.5	6.6	8.8	7.1
	Upper Q	11.2	7.5	9.2	8.0
	Max	13.8	7.8	13.2	9.8
Dry Days	Min	6.3	1.4	4.7	1.5
	Lower Q	9.8	5.9	8.2	6.3
	Median	10.7	7.0	8.9	7.4
	Upper Q	11.3	7.7	9.2	8.2
	Max	13.0	7.8	11.1	9.8
Rain Days	Min	6.2	1.3	4.7	1.3
	Lower Q	9.1	4.2	7.5	4.6
	Median	9.9	5.4	8.2	5.9
	Upper Q	10.6	6.5	8.8	7.0
	Max	12.6	7.6	11.0	8.5
Wet Days	Min	6.5	0.3	5.0	0.4
	Lower Q	8.5	1.2	7.0	1.3
	Median	9.4	2.1	7.8	2.4
	Upper Q	10.4	2.7	8.7	3.2
	Max	13.8	6.2	13.2	7.0

Table 2: Four year rainfall record - summarised hydraulic retention time (days)

The hydraulic retention time has been calculated from 10 minute time step data of the water volume and discharge from each section. The discharge rate is used to look forward and determine the elapsed time for the water volume associated with that time step to be displaced, this is a first in first out queue and hence assumes no short circuiting occurs within the wetland. In the reconfigured wetland the sections are in series, the time elapse for the Section 1 volume to be displaced becomes the seed time step in Section 2 and the overall time elapsed time is the reconfigured wetland HRT. Due to the volume of data and processing requirements the 10 minute time step data is averaged in 4 hour steps with linear interpolation between averaged steps used to determine the elapsed time. Sensitivity checks using a shorter 1 hour averaged step found no significant difference compared with the longer time step results.

Figure 7 shows the hydraulic retention time for the various wetland scenarios over the four year rainfall record. Table 2 provides analysis of Figure 7. Dry Days are those where less than 2mm fell within 24 hours of the time step. Wet Days are consistent with the waste water disposal definition of wet weather and Rain Days are those that fit neither of those criteria. Of the 1454 days within the rainfall record 1150 were Dry, 255 were Rain and 49 were Wet.

The reconfiguration design objective of a minimum 6 days HRT under most circumstances is readily achieved with an Overall Median of 10.5 days. A significant difference between the reconfigured and TP10 wetland occurs during the rain and in particular the Wet days. A fair assessment between the wetlands is provided by comparing the Reconfigured Less Additional Volume, which has the additional dead storage removed, and the TP10 Attenuated, which is tuned to match the Reconfigured water level. As can be seen from this comparison the extended HRT is not solely due to the increased water volume.

1.4. EARLY WARNING & CONTAINMENT

Water quality monitoring proposed with the original design involved routine bimonthly grab sampling from a range of locations within and remotely of the wetland. Test locations within and adjacent to the wetland included the stormwater and wastewater influent, the outflow and the farm drain both up and downstream of the wetland outlet. Whole Effluent Toxicity Testing (WETT) was also to be undertaken annually on the discharged wetland water.

In an effort to provide an early warning system for the Bream Bay Aquaculture Park it was proposed by the appellants to refine the test regime granularity, however the increased frequency was unlikely to improve the warning quality.

For the reconfigured design an alternative monitoring approach is taken with the addition of a monitoring station, which continuously monitors parameters and spectral fingerprint. Data collected by this suite of instruments allows for remote real time monitoring, alert generation and automatic grab sampling for further lab testing. Elsewhere this technology is used for monitoring and automation in municipal raw water takes, waste water treatment plant discharge and a range of other water quality and process applications. Water samples are delivered from the test locations to the centrally located monitoring station by air lift pump, avoiding the need for electrical supply and pumps at each of the sample locations. The monitoring station will receive samples from six test locations, those proposed with the original design plus at the intra-wetland link. The monitoring station equipment includes a UV-Vis spectrometry analyser, conductivity probe, dissolved oxygen and temperature probe, NO_3, ammonia and pH probe, pneumatic air lift pump and telemetry equipment. While capable of continuous monitoring hourly sampling allows for switching between each test location, which are rotated every 10 minutes.

Through continuous monitoring and telemetry alert generation the Bream Bay Aquaculture Park will be provided with the level of early warning sought. A feature of the monitoring software is recognition of an out of the ordinary spectral fingerprint, which will potentially enable detection of contaminants that are neither perceived nor prescribed within the consent conditions, should these arise. Grab sampling and WETT testing is still required for some parameters due to technical limitation or sample point proximity and to verify the continuous monitoring results. By reducing the grab sampling requirements the monitoring station provides significant long term cost savings.

A feature to the two wetland sections is that the outlet from Section 1 can be closed during a spill event management response with further influent stormwater diverted to Section 2 via the bypass flume.

3. CONCLUSIONS

The reconfigured wetland design uses drop weirs to separate the first flush water quality volume from influent stormwater and a bypass flume to divert the remaining volume from larger events. The two water volumes are separated by an internal partition, which is overtopped during extreme events, at which point the two sections function as a single volume thereby preserving the extreme event attenuation capability. The live volume requirements are 4% greater in the reconfigured wetland compared to the TP10 wetland.

Section 1 has a dead storage depth of 1m. Irrespective of the permanent water depth Section 1 is not suitable for wetland planting due to prolonged elevated water levels, although the use of floating vegetated islands would be suitable.

Scouring and flushing out of Section 1 is reduced by the combination of the wetland partition, which is sized so that Section 2 overtops into Section 1 during extreme events, and by the drop weir low flow pipes that diverts high influent flows associated with short duration high intensity rainfall events.

The hydraulic detention time is extended by the reconfigured design which has an overall Median HRT of 10.5 days verses the TP10 overall Median HRT of 6.6 days. More significant is the HRT during Rain (Median 9.9 and 5.4 days) and Wet (Median 9.4 and 2.1 days) periods for the respective wetlands. The reconfigured wetland extended detention is in part due to the increased water volume, although primarily the effect is from the wetlands function.

The automatic monitoring station with telemetry provides an early warning system along with significant cost savings over time when compared to grab sampling. In the event that a spill or malfunction occurs Section 1 of the reconfigured wetland can be closed with all stormwater bypassing to Section 2 while a management response is implemented.

ACKNOWLEDGEMENTS

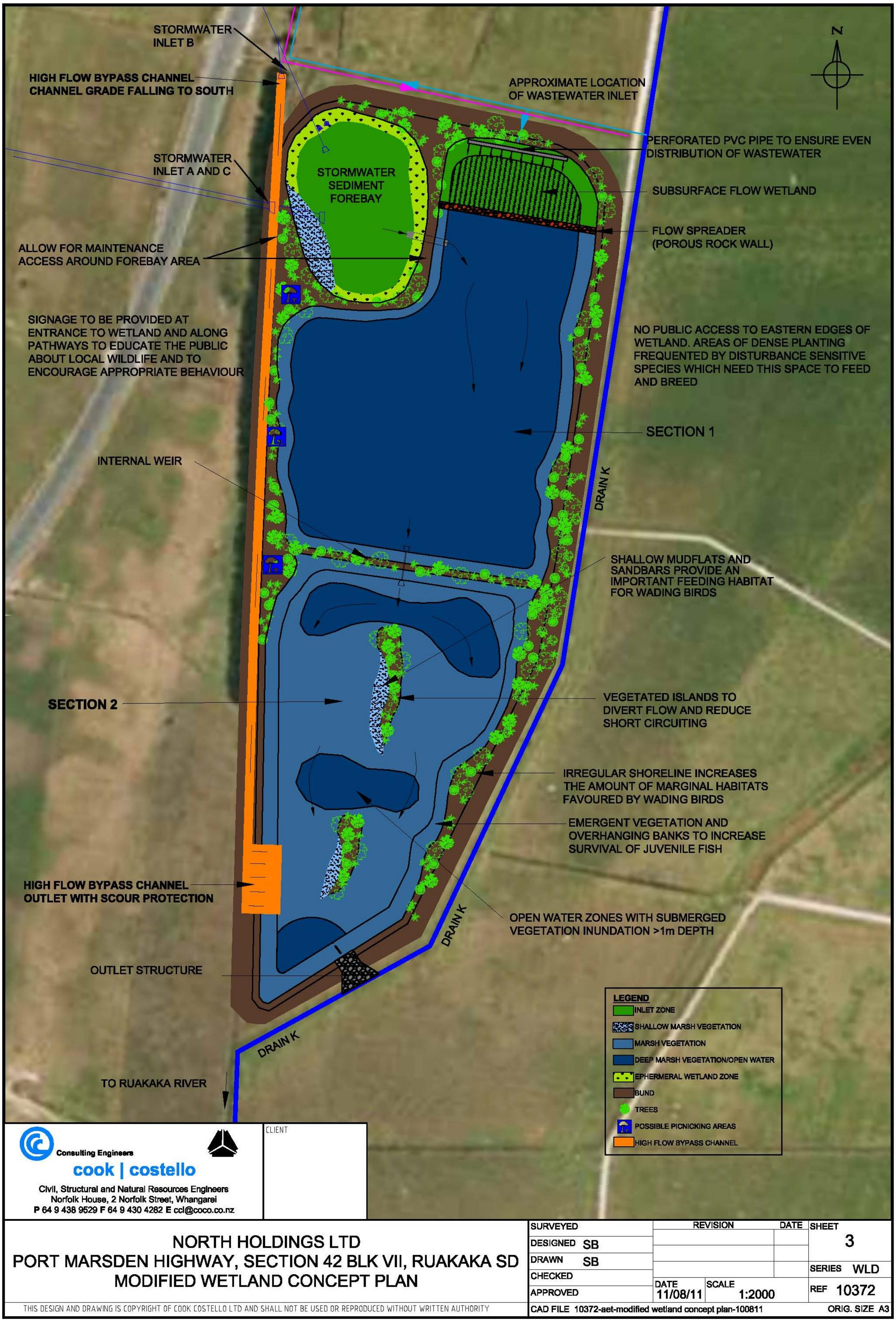
Dr Susan Clearwater, et al. National Institute of Water & Atmospheric Research Ltd (NIWA)

Tara Okan, Rob Dexter, et al. DCM Process Control Limited

REFERENCES

Auckland Regional Council (2003) ‘Technical Publication 10 – Design Guideline Manual: Stormwater Treatment Device’, ‘Chapter 6 – Wetland Design, Construction & Maintenance’

APPENDIX 1: RECONFIGURED WETLAND PLAN



APPENDIX 2: RECONFIGURED WETLAND SECTION

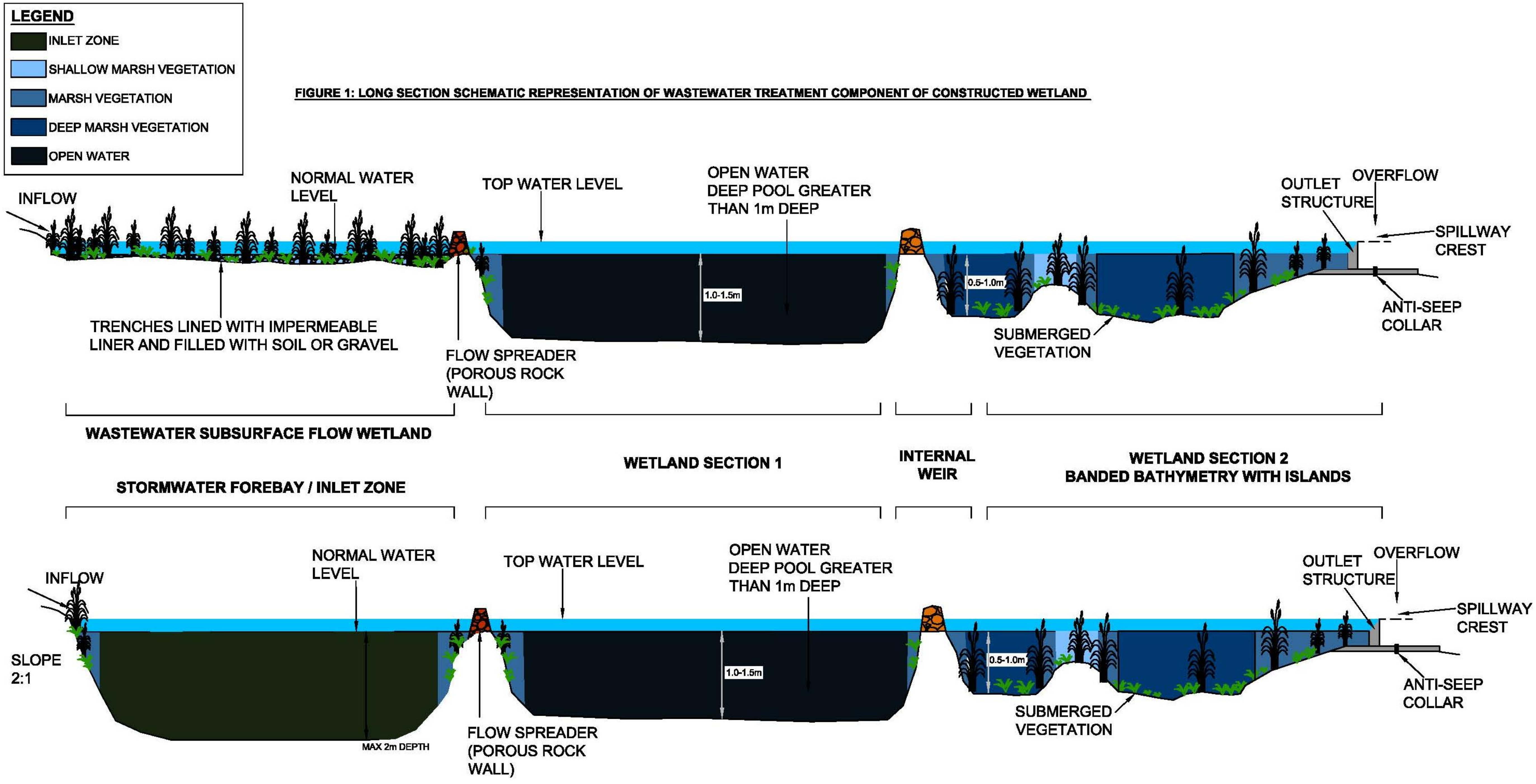


FIGURE 1: LONG SECTION SCHEMATIC REPRESENTATION OF WASTEWATER TREATMENT COMPONENT OF CONSTRUCTED WETLAND

FIGURE 2: LONG SECTION SCHEMATIC REPRESENTATION OF STORMWATER TREATMENT COMPONENT OF CONSTRUCTED WETLAND

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CLIENT

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PORT MARSDEN HIGHWAY, SECTION 42, BLK VII RUAKAKA SD
LONG SECTION SCHEMATIC OF WETLAND

SURVEYED		REVISION	DATE	SHEET 5
DESIGNED	AT			
DRAWN	SB			SERIES WLD
CHECKED	AT			
APPROVED		DATE 11/08/11	SCALE NTS	REF 10372
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Appendix 3: Monitoring parameters, frequency and locations

Parameter	Units	WWTP Influent	Stormwater	Wetland Within 20m Radius SW SS	Wetland Mid Point	Wetland Outlet	Drain K Upstream	Drain K Downstream	Drain K @ McCathie	Ruakaka R Upstream	Ruakakak River Downstream
E. coli	MPN/100mL	Instrument	2		-	12 / 4	Instrument	Instrument	12 / 4	12 / 4	12 / 4
F-specific bacteriophage	Number per 50 L	2 / 0.5	-		-	-	-	-	-	-	-
WETT	-	-	-		-	4 / 2	-	-	-	-	-
Total Nitrogen	mg / L	Instrument	-		-	-	-	-	-	-	-
Nitrate/Nitrite	mg / L	Instrument	-		-	-	-	-	-	-	-
Total Ammonia	mg/L	Instrument	-		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Dissolved Reactive Phosphorous	mg / L	Instrument	-		-	-	-	-	-	-	-
Total Phosphorous	mg / L	Instrument	-		-	-	-	-	-	-	-
Total Organic Carbon	mg/L	Instrument	-		Instrument		-	-	12 / 4	12 / 4	12 / 4
Dissolved Oxygen	% Sat	-	-		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Carbonaceous Biochemical Oxygen Demand	mg / L	Instrument	-		-	-	-	-	-	-	-
Total Suspended Solids	mg / L	Instrument	Instrument		Instrument	-	-	-	-	-	-
Total petroleum hydrocarbons	mg/L	-	Instrument		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
VOC & sVOC	g/m³	-	-		-	4	4	4	4	4	4
pH		Instrument	Instrument		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Alkalinity (as $CaCO_3$)	mg/L	12 / 4	2		-	12 / 4	12 / 4	12 / 4	-	-	-
Conductivity	mS	-	-		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Temperature	°C	-	-	Instrument	Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Salinity	ppt	-	-		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Flow metering	m³/day	Instrument	-		-	Instrument	-	-	-	-	-
Visual check (oils, scum)		-		12	-	12	12	12	12	12	12
Visual Clarity	black disk	-	-		-	4	4	4	4	4	4
Hue	Munsell scale	-	-		-	4	4	4	4	4	4
Turbidity	mS	-	-		Instrument	Instrument	Instrument	Instrument	12 / 4	12 / 4	12 / 4
Aluminium	µg/L	4	-		-	4	4	4	4	4	4
Cadmium	µg/L	4	-		-	4	4	4	4	4	4
Chromium	µg/L	4	-		-	4	4	4	4	4	4
Copper	µg/L	4	2		-	4	4	4	4	4	4
Lead	µg/L	4	2		-	4	4	4	4	4	4
Mercury	µg/L	4	-		-	4	4	4	4	4	4
Nickel	µg/L	4	-		-	4	4	4	4	4	4
Zinc	µg/L	4	2		-	4	4	4	4	4	4
Arsenic	µg/L	4	-		-	4	4	4	4	4	4
Beryllium	µg/L	4	-		-	4	4	4	4	4	4
Selenium	µg/L	4	-		-	4	4	4	4	4	4
Silver	µg/L	4	-		-	4	4	4	4	4	4
Thallium	µg/L	4	-		-	4	4	4	4	4	4

Frequency in times per year, i.e. 12 / 4 is initially monthly, the 3 monthly