CONSTRUCTED WETLAND DESIGN PRACTICES AND PERFORMANCE: AN OVERVIEW

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ABSTRACT

Constructed wetlands are a commonly used stormwater treatment device. There are several methods used to design stormwater wetlands, each design differing in the volume of permanent water and dry detention volume above the wetland permanent water level.

This paper discusses the literature cited constructed wetland design procedures for stormwater treatment. The main design methods for wetland are: catchment area ratios, volume capture, hydraulic retention time and the kinetic (k-c*) models.

Four sets of TP10 designed wetlands (designed using TP10 specifications) were considered for four different catchment sizes. The wetland surface areas were determined by assuming average pond depths as 1.0m, 0.75m, 0.5m and 0.25m. The wetlands were assumed to comprise 60% shallow vegetated areas and 40% deeper pool areas as recommended in banded bathymetry design. Dimensions of the wetlands were calculated based on a standard 3:1 length to width ratio. Sizing methods identified from the literature and hypothetical wetlands were compared to evaluate the appropriateness of current sizing criteria. Constructed wetland performances were compared based on literature information.

KEYWORDS

Wetland, constructed stormwater wetland, TP10, stormwater management

PRESENTER PROFILE

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1. INTRODUCTION

TP 10 wetland and wet pond design follows similar processes. Wetlands however have plants in a shallow pool and a deeper pool provides storage for runoff volume. As stormwater runoff flows through the wetland, pollutants are removed by settling, soil adsorption and biological uptake. Wetlands are among the most effective stormwater treatment practices in terms of pollutant removal and also may have ancillary values, such as plant and animal habitat.

TP10 wetlands are designed based on sizing a stormwater retention pond. Treatment is dependent on the water retention time within the wetland. Retention time is primarily dependant on the size and depth of the permanent pool in relation to the total catchment runoff volume.

The paper mainly evaluates the constructed wetland sizing methodologies and compared the treatment performances between free surface water and sub-surface wetlands based on literature cited values.

2. SIZING METHODS FOR STORMWATER WETLANDS

2.1 TP 10 Method

The current design practice of sizing constructed wetlands is based on capturing a specific volume of stormwater run off (ARC, 2003). The storage volume determined depends on the purpose and function of the wetland – i.e. whether it is for water quality, erosion protection or water quantity purposes. The water quality volume is determined by calculating the run off volume generated by one third of the 2 yr rainfall depth. For erosion protection purposes the wetland volume also needs to be designed to contain the runoff from 34.5 mm of rainfall. For water quantity purposes, the wetland volume also needs to size to be designed to attenuate the 2 yr and 10 yr post development peak flows to pre development rates.

The TP10 permanent wetland water volume is determined by sizing a stormwater retention pond to capture the water quality volume, identifying the surface area from required depth/storage/elevation pond relationship and then applying the TP10 wetland bathymetry to that surface area. This means that the wetland volume will be less than the wet pond from which it is sized. This approach was adopted in TP10 to provide an incentive for constructing wetlands and to ensure that wet ponds were not always selected as a treatment device instead of a wetland because they would have a smaller surface area (Shaver, 2010).

The suggested water depths for the permanent pool in TP10 range between 0.5 m and 1.0 m.

2.2 Literature cited methods

The other methods of sizing constructed wetlands are:

- The wetland surface area is a proportion of the catchment area, (Mungasavilli et al., 2006)

- The wetland captures a certain volume of stormwater runoff (expressed by a variety of methods, such as a proportion of events, or, percentage multiples of a runoff event size), (Mungasavilli et al, 2006), (Shutes et al., 2005), (ARC, 1992)
- A design flow or event is required to have a certain retention time, (Mungasavilli et al., 2006), (Shutes et al., 2005)
- A "particle fall number" model, based on sedimentation principles, (Li et al., 2007)
- First order kinetic models, adapted from wastewater wetland designs. (Mungasavilli et al., 2006), (Wong et al., 2002)

2.3 SURFACE AREA TO CATCHMENT AREA METHOD / CAPTURING SPECIFIC VOLUME

These are empirically based methodologies and have been generally verified by in field monitoring of wetland performance. There is little monitored data available to define the performance relationship for small or large wetlands. That is, while monitoring may indicate that 60–80% Total Suspended Solids (TSS) is removed in a wetland that captures 80-90% of storm events, there is virtually no information to predict what typical removal rate is achieved when 50%, or 99% of storm events are captured. In fact, available information suggests that some wetlands that are smaller than average, perform just as well as larger ones, and, some larger than average, perform more poorly than smaller ones (Carelton et al., 2001).

2.4 RETENTION TIME METHOD

Retention time (i.e. the average time water is contained within the wetland) has also been promoted as a key means for sizing stormwater wetlands. However, to size a wetland in this way, a design event needs to be selected, so that the retention time can be calculated for a given flow. Events larger than the design event would have a shorter retention time and smaller events a longer retention time. Mungasavalli et al. (2006) suggested retention time should be greater than 24 hrs. Shutes et al. (2005) suggested if retention time is greater than 36 hrs, contaminants like TSS, heavy metals, Petroleum Aromatic Hydrocarbon (PAH) and herbicides can be removed.

2.5 PARTICLE FALL NUMBER METHOD

Li et al., (2007) have promoted the "particle fall number" model. For any particle, this model represents a ratio of horizontal travel time through the wetland to vertical settling time. The implication of this is that wetlands with longer horizontal travel times (or flow paths) and shallow depth will be more efficient than wetlands with shorter horizontal travel times and deeper depths. The method is essentially therefore a retention time method with removal rates calculated for different sized particles. The method relies on empirical calibration constants for which there is extremely limited data available.

2.6 KINETIC MODEL METHOD

A few authors (notably Wong and Gieger, 1997) have tried to adapt wastewater kinetic models (the "k-c*" model) to sizing stormwater wetlands. In wastewater treatment, these models use an exponential function to represent the reduction of contaminants as a function of time within the wetland. This is well suited to the die-off of bacteria following a biological decay rate, but possibly less well suited to other contaminants, which are removed by different physical or chemical processes. Limited success with this method has been reported, because of a lack of real-world information on the required input parameters and the need to assume that input parameters are constant, when in fact those parameters vary considerably due to the stochastic nature of stormwater flows.

The flow rate and contaminant concentration through a stormwater wetland is highly variable. The contaminant removal rate is a function of the retention time of the flow for different storms and the amount of contaminants passing through the wetland. However, the amount of contaminants passing through the wetland depends upon the proportion of runoff passing through the wetland and contaminant loading in the catchment. Even though the key removal processes are well established, numerically representing those processes is very difficult. Hence the design methods found in the literature generally rely on a simple sizing methodology that has generally been verified through monitoring data.

3 REVIEWING SIZING METHODOLOGY

Two sets of four hypothetical wetlands were considered (sized using the TP10 specifications), for comparison of different wetland sizing methodologies stated above. These wetland sizes assume erosion protection and flow attenuation volumes are not required.

The wetlands were sized for:

- varying catchment sizes - 5, 20, 50 and 100 ha
- four different average depths 0.25 m, 0.5 m, 0.75 m and 1.0 m (which give different wetland surface areas).

Catchment characteristics were assumed to consists of 85% residential (35% impervious), 14% commercial (70% impervious) and 1% industrial (70% impervious) for all calculations.

The water quality volume, calculated for each catchment area, is divided by different average wet pond depths to give different wetland surface areas. This step is a simplification of the TP10 process whereby a depth/ storage/ surface area relationship is established using site topography and proposed pond contours.

When a shallow average pond depth is chosen, the wetland surface area is large. The resulting surface area of each wetland (from the 1.0 m to 0.25 m average depth) was calculated as either 1.15% to 4.6% of the catchment area.

The actual wetland treatment volume is then calculated based on the banded bathymetry sizes and depth specifications from TP10.

3.1 AREA/ VOLUME BASED METHODS

The following main criteria for area and volume based sizing methods were identified:

- Wetland to Catchment Area Ratio (WCAR) should be greater than 2%. If extended detention volume is incorporated into the design; the ratio should be greater than 1% (Mungasavalli et al., 2006)
- The wetland surface area to the contributing catchment area ratio (WCAR) should be between 2% and 5% (Shutes et al., 2004).

- The treatment volume of the wetland should be large enough to capture 90% volume of all storm events (Mungasavalli et al., 2006). This was taken to refer to the runoff volume of the 90th percentile storm.
- The wetland should capture the volume of total runoff from 80–90% of annual storm events (Shutes et al., 2005). This criterion was taken to refer to the 80th to 90th percentile storms.

The water quality volume required for each catchment size was calculated following the methodology specified in TP 10 and TP 108.

Two rainfall or runoff frequency analyses were performed. Firstly, from fifteen years of daily rainfall data, 85th, 90th and 95th percentile rainfall depth values were determined.

Catchment generated runoff volumes were calculated by TP108 method for the daily rainfall record. These are shown in columns 2, 3 and 4 of Table 2 below and are used for comparison to the water quality volume and wetland volume shown in Table 2.

Secondly, the cumulative runoff volume for the entire rainfall record was calculated. By trial and error, wetland storage volumes were adjusted until 80% of the cumulative runoff of all rainfall events was captured. Results for this are shown in column 6 of Table 2.

Table 2: WQV values and percentile runoff volumes for each hypothetical catchment

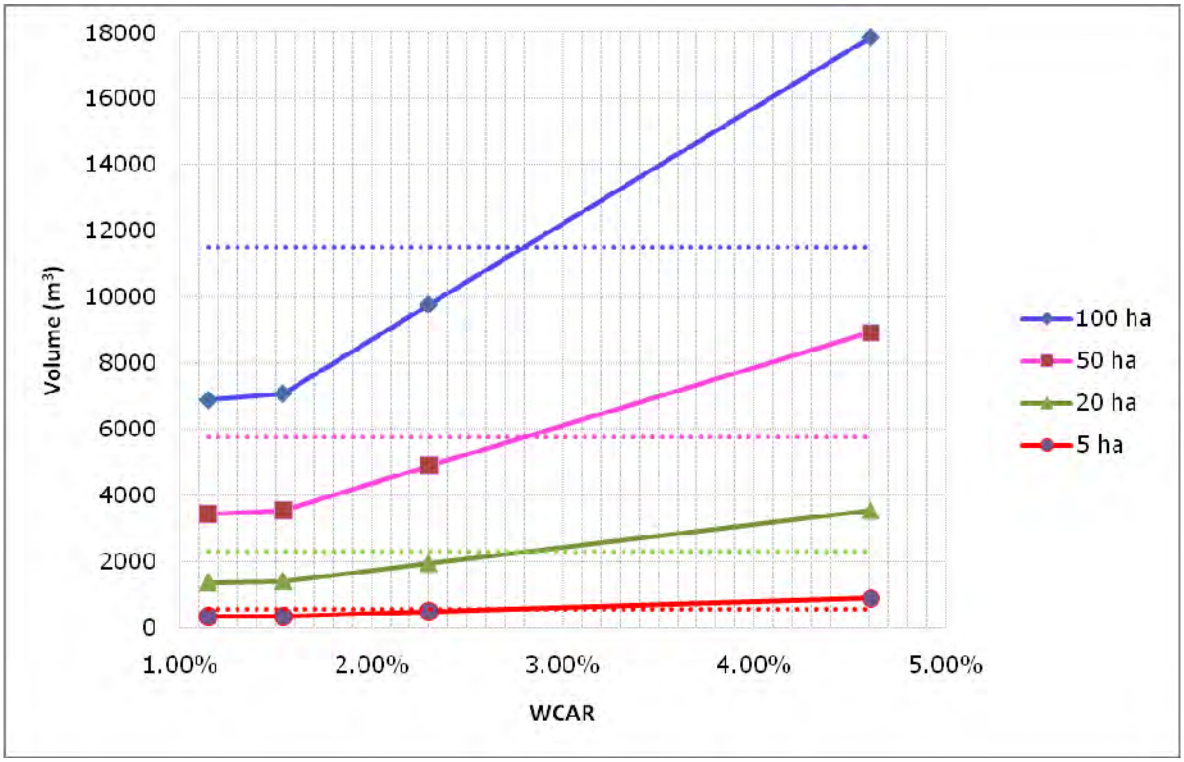
Catchment area (ha)	Water quality volume (m^3)	85th percentile runoff event (m^3)	90th percentile runoff event (m^3)	95th percentile runoff event (m^3)	80% of the runoff volume of all storm events (m^3)
100	11515	4075	6095	10875	13000
50	5758	2040	3050	5440	6480
20	2303	815	1220	2175	2600
5	576	205	305	545	650

The different wetland surface area to catchment area ratios (WCAR) were used to determine the wetland storage volumes and results are presented in Table 3 and Figure 1. The WQV values are shown in dotted lines in the Figure 1.

Table 3: Comparison of volume of hypothetical wetlands to volume sizing methods

WCAR	Average Depth (m)	Wetland Volume (m^3)			
		100 ha	50 ha	20 ha	5 ha
1.15%	1.00	6909.0	3454.8	1381.8	345.6
1.54%	0.75	7100.9	3550.8	1420.2	355.2
2.30%	0.50	9787.8	4894.3	1957.6	489.6
4.61%	0.25	17848.3	8924.9	3569.7	892.8

Figure 1: Comparison of volume of wetlands to volume sizing methods



Note: Dotted lines are representing the calculated WQV volume for individual catchments

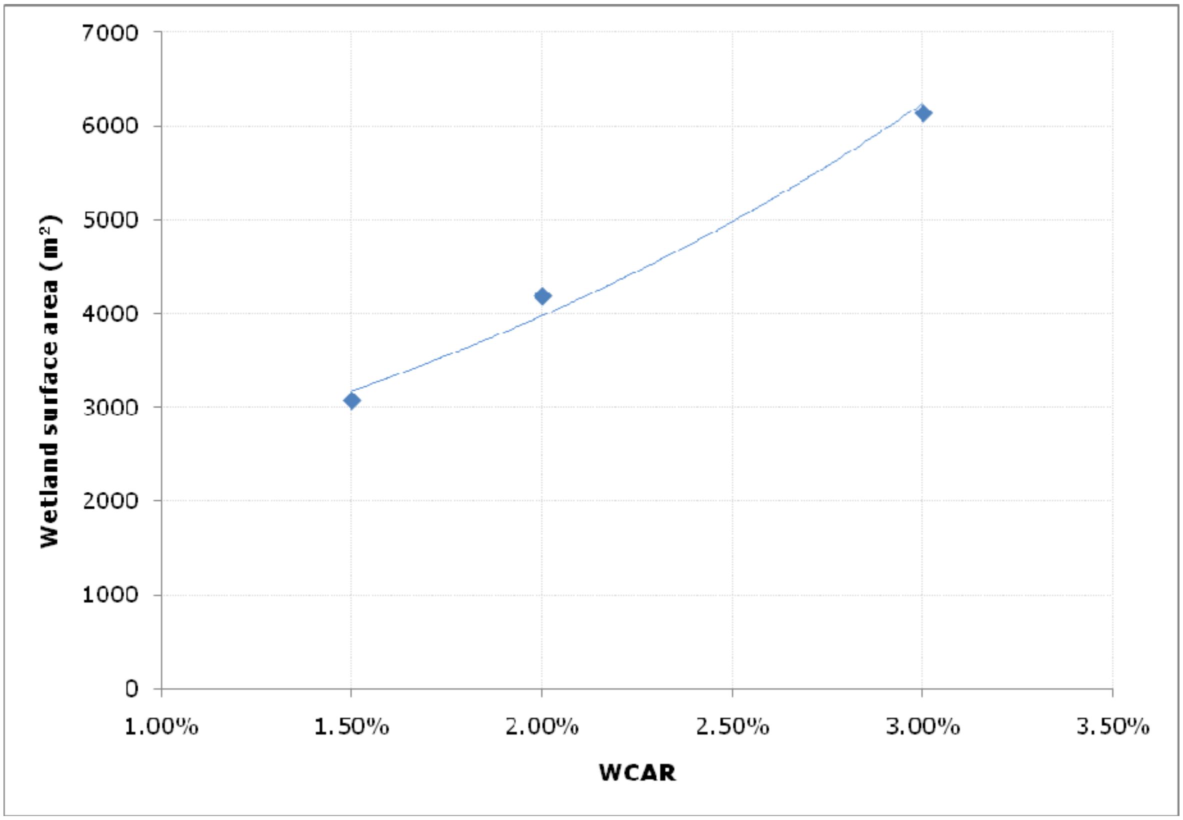
The graph shows that the WCAR less than 2.5% do not provide the required storage volume to treat the WQV (dotted line in Figure 1).

The Mungasavilli et al. (2006) and Shutes et al. (2005) criteria can be assessed by comparing the wetland volumes (Table 3 and Figure 1) with the percent event runoff volumes (columns 3, 4 and 5 in Table 2). The wetland volume for the WCAR less than 1.5% would be greater than the 85th percentile runoff volume but slightly less than the 90th percentile runoff event volume. This suggests that WCAR less than the 1.5% hypothetical wetlands would catch between 85% and 90% of storm events and WWAR more than the 2% hypothetical wetlands would catch between 90% and 95% of storm events. If the WCAR is more than 2.5%, the calculated wetland volume would be sufficient to treat WQV, (Figure 1).

Therefore, this comparison shows that the hypothetical wetlands would meet the Mungasavilli et al. (2006) criterion of WWAR should be greater than 2%, and Strecker et al. (1992) and Ellis (1999) criteria of 2% <WCAR < 5%. The runoff volume capture is also between 85% and 90% of storm events and therefore meets the Shutes et al. (2005) criterion.

However, we note that such sizing criteria may pose considerable land-take difficulties and also do not account for potential safety considerations. The increase of WWAR results in a greater amount of land required to construct the wetland (as shown in Figure 2 for a 20ha sized catchment).

Figure 2: Comparison of wetland surface area with WCAR for 20 ha catchment



3.2 RETENTION TIME METHOD

The hydraulic retention times (HRT) have been calculated for the hypothetical wetlands using the wetland volumes and the average water quality storm flow rate (from the water quality volume divided by 24 hours) and compared to the recommended times. Note the hypothetical wetlands are based on a 3:1 length to width ratio and no reductions for effective volumes were made, as the vegetated section was assumed to extend across the full width of the wetlands – meaning the calculated retention time are maximums for this geometry. At average water quality storm flow rates with full plug flow, the storm passes through the WCAR 1.15% wetlands in 12 hours and through the WCAR 4.6% wetlands in 36 hours, (Table 4). To achieve hydraulic retention times more than 24 hrs, WCAR should be greater than 3%.

Table 4: Hydraulic Retention Time (HRT) of hypothetical wetlands

WWAR	Average Depth (m)	HRT (hrs)
1.15%	1.00	12
1.54%	0.75	12.5
2.30%	0.50	18.0
4.61%	0.25	36.0

3.3 KINETIC METHOD

The kinetic method has been used to estimate the removal of TSS and zinc from the hypothetical wetlands on a water quality storm event basis. Given the variation in storms over the period of a year, an annual average flow analysis (as would be used for wastewater wetlands) was considered inappropriate.

The water quality volume was used to determine the average flow entering the wetlands over a 24 hour period. The kinetic method requires input assumptions of inflow concentrations and irreducible concentrations of the contaminant. Estimates of typical inflow concentrations were taken as the average urban contaminant EMCs from “The Urban Runoff Databook” (Williamson, 1993) and the irreducible concentrations as the average effluent concentrations from the “BMP database” (Geosyntec, 2008).

This leaves the areal decay rates, or k values, to be selected. A number of researchers have tried to calculate k values for using this method with stormwater wetlands. Care must be taken when applying these, as a number of different components of k have been assessed by different sources. These include; TSS removal values of 500 to 5000 m/year (Scholes et al, 2008), a value of 1300 m/year for sedimentation of metals and values around 400 to 600 m/year for other physico chemical removal of metals (Walker et al, 2002). Walker et al recommend adding the k values for the sedimentation and other processes together to get a k total value for the wetland. Weiss et al (2006) provides k values for the sorption of dissolved metals onto sediment and uptake of metals by plants. Given the range of values noted by Scholes, it appears there is considerable scope for local wetland conditions (eg geometry, planting and rainfall patterns) to affect the performance of individual wetlands.

Values of 1000 and 1300 m/year were selected. TSS removal efficiencies were 65 – 71% for the WCAR 1.15% hypothetical wetlands and 79 – 81% for the WCAR 4.6% hypothetical wetland. The results indicate that a wetland with a larger surface area removes a greater amount of sediment and the hydraulic loading rate is reduced by the greater surface area.

However, overall, given the limited database of k values available and that testing of other k values gives considerable variability in results , it is not considered appropriate to recommend the use of this method.

3.4 INTERNATIONAL SIZING METHODS

A number of design manuals were searched for information on wetland sizing methods in other jurisdictions. Selections were made for their use in areas of general similarity to Auckland conditions, relevance to Auckland and international prominence and are summarised in Table 5.

Table 5: Constructed stormwater wetland design guideline sizing methods

Area	Criterion	Reference
Christchurch	Capture of the first 15mm of runoff in a detention basin followed by a surface flow wetland with: • Hydraulic residence time: 2 days minimum; • Operating water depth: 0.15m; • Wetlands shape aspect ratio: 10L:1W; • Wetland vegetation porousity: 0.75	“Waterways, wetlands and drainage guide”, (Christchurch City Council, Feb 2003)
Florida	The state of Florida is in the process of developing a unified stormwater BMP sizing rule. This report summarises current treatment volume sizing criteria from various water management districts which are generally either; the retention of runoff from 1” [25mm] storm, or, 1.25” [31mm] times the impervious area.	“Evaluation of current stormwater design criteria within the State of Florida”, (Harper et al, 2007)

Maryland	The permanent storage volume for the wetland equals the permanent storage volume used for a wet retention pond. This volume is the runoff generated from a 1" [25mm] storm (in the eastern zone, or 0.9" [23mm] runoff in the western zone of the state). A wetland consists of: • A forebay with a volume to capture 0.1" [2.5mm] of runoff • A wetland with a surface area of at least 35% less than 6" [150mm] deep and at least 65% less than 18" [450mm] deep; • A micropool at the end of the wetland to prevent outflow clogging and minimise re-suspension. The wetland surface area shall also be at least 1% of the total catchment area, or 1.5% for a shallow wetland design.	"Maryland stormwater design manual, Volumes I and II, (Maryland, Department of Environment, effective October 2000)"
Portland	The permanent storage volume for the wetland equals the permanent storage volume used for a wet retention pond. This volume is twice the runoff generated from a 0.83" [21mm] storm over 24 hours. Vol = 2 x 0.021m x impervious area The wetland surface area consists of : • Forebay: 5% • Micropool: 5% • Deep water 40% • Wetland 150-450mm: 25% • Wetland < 150mm: 25%	"Stormwater Management Manual", (Portland, City of, adopted July 1 1999, revised Sept 1 2004)
New Zealand state highways	The wetland surface area should be at least 2% of the catchment area.	"Stormwater treatment standard for road infrastructure", NZTA, draft July 2008
USEPA	The 1999 fact sheet is the current pdf version and does not record specific sizing criteria as these are set at local government or state level. This 1999 fact sheet refers to the Metropolitan Washington Council of Government criteria for wetlands from 1992 as capturing the runoff from 90% of runoff producing storms. It then refers to the state of Maryland wetland criteria at length. The web version uses the 1% area ratio criterion as a minimum size.	"Storm Water Technology Fact Sheet: Storm Water wetlands", USEPA, Sept 1999 and later version on web

To be able to compare criteria using rainfall depths or events to Auckland, the local climatic conditions need to be considered. The data in Table 6 allows an approximate comparison to be made.

Table 6: Rainfall characteristics and resulting water quality volumes of areas quoted in Table 5

Area	Annual rainfall, mm, approx	2 year 24 hour rainfall depth, mm, approx	Water quality volume
Auckland	1250	75	Runoff from 25mm of rainfall (1/3 of 2 yr)
Christchurch	650	53	15mm of runoff (1/3 of 2 yr)
Florida (state wide)	1370	125 (varies 90 – 150)	Runoff from 25 - 31mm of rainfall
Maryland	1035	90	Runoff from 23 - 25mm of rainfall
Portland	940	75	2 x Runoff from 21mm of rainfall

These methods are generally consistent with the empirical volume and sizing methods identified by Mungasavilli et al. (2006) and Shutes et al. (2005) and already used in TP10. However, they also indicate that the required wetland volume should be closer to the full water quality volume calculated by TP10.

4 WETLAND PERFORMANCES

Wetlands fall broadly into two categories. Free water surface flow (SF) wetlands have a permanent pool of water with submerged / emergent vegetation (specified in TP10). Sub-surface flow (SSF) wetlands have a gravel filter substrate through which water flows and plants grow.

4.1 SURFACE FLOW WETLAND PERFORMANCE

Performance data for surface flow wetlands has been gathered from literature. Geosyntec et al (2008), present data for median effluent event mean concentration (EMC) and whether effluent concentrations have a statistical reduction from inflow concentrations (Table 7). Results from the CWP database (2007) are shown in Figure 3. The CWP assessment uses percent reduction data based on either, the difference in EMC influent and effluent concentration data or the difference in contaminant mass. It is noted the difference in contaminant mass is the more accurate and the preferred method.

Table 7: Wetland performance summary from individual storm events (after Geosyntec et al, 2008)

Contaminant	Number of BMPs[1]	Median of effluent EMCs (95% confidence interval)	Was a significant difference between influent and effluent EMCs identified?
Total suspended solids	14	9.40 mg/L	Yes
Total copper	4	3.00 ug/L as Cu	Yes
Total lead	5	1.20 ug/L as Pb	Yes
Total zinc	9	22.00 ug/L	Yes
Total phosphorus	12	0.20 mg/L as P	No
Dissolved phosphorus	4	0.05 mg/L as P	Yes
Total nitrogen	7	1.21 mg/L as N	No
Total kjeldahl nitrogen	7	1.09 mg/L as N	Yes
Total nitrate nitrogen	5	0.20 mg/L as N	Yes
Total nitrate + nitrite	5	0.06 mg/L as N	Yes

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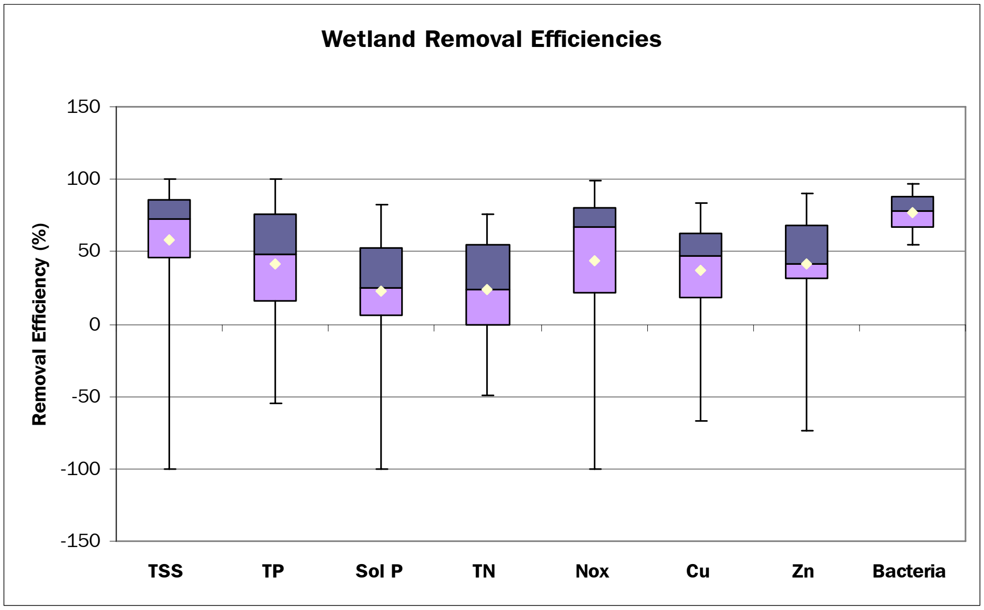
[1] BMPs = Best management practices, a US term for stormwater treatment methods

Figure 3: Wetland basin performance summary from individual storm events (CWP, 2007)



NOTE: Results are from five or more events were presented

Percent removal values are misleading and may not accurately represent performance, (Geosyntec et al. 2008). These values are generally derived from individual storm events and are then often used to predict long-term device performance, potentially giving a false impression of the amount of contaminant removed. As an example, if inflow concentration is high, the percent removal efficiency will generally be high for contaminants removed by settling processes. However, the outlet concentration may still be relatively high, which could above the environmental limits. The data in Figure 3 should therefore be used cautiously and in conjunction with other performance data such as that from Geosyntec.

4.2 SUBSURFACE FLOW WETLAND PERFORMANCE

Limited data was found to characterise the performance of SSF constructed stormwater wetlands.

Scholes et al (2008) present a review of data from five different United States and European databases of BMP removal efficiencies with the aim of comparing the performance of different BMPs. Their TSS removal rates (+/- one standard deviation) are 81+/- 11% for SSF wetlands and 71 +/- 8% for SF wetlands.

Shutes et al (2004) present a data set of wetlands which included 90 SF and 11 SSF wetlands. The results for suspended solids are 76% removal for SF wetlands receiving urban run-off (with a range of 36 to 95% removal) and a range of 13-99% removal for SSF wetlands receiving highway runoff.

This data suggests SSF wetlands may be more efficient than SF wetlands. In a review of constructed wetlands for stormwater management, Mungasavalli et al (2006) commented that SSF flow wetlands are more efficient than SF wetlands at removing pollutants at high application rates. However, they noted that overloading, surface flooding and clogging of the media in sub-surface wetland cells can result in reduced efficiency.

5 IMPROVING PERFORMANCE

5.1 GENERAL

Carleton et al (2001) present monitoring data against the wetland to catchment surface area ratio. A range of performance monitoring data is available for any given wetland size (Carleton et al. 2001). This indicates that increasing the wetland size will generally improve performance, while poor design (by short-circuiting for example) could equally mean a large, poorly designed wetland, performs worse than a small, well designed wetland.

A few researchers have carried out testing to represent contaminant removal, either sediment or metal, by vegetation and/or study the relative importance of removal by sedimentation or vegetative sections of wetlands. The consensus appears to be that sedimentation is the more dominant removal process for particulate contaminants and therefore improving the hydraulic efficiency can improve the removal of sediment and metals. In addition to this, vegetation was identified as playing a key role in spreading flows, thereby reducing flow velocity and promoting sedimentation and promoting the contact of dissolved contaminants with soil around the base of plants.

Walker et al, (2002) had developed areal decay rates (k values) for the sedimentation and physico-chemical removal processes. The k value for sedimentation was estimated at 1300 m/year while the values for copper, lead, zinc, chromium and arsenic were 630, 680, 420, 210 and - 1000 m/year respectively. Sedimentation was therefore identified as the primary contaminant removal process.

Three key methods identified to improve performance are therefore:

- Increasing the hydraulic efficiency and therefore increase retention time;
- Adopting a layout of vegetation to promote sedimentation;
- Increasing water contact through the vegetation root zone/ sub stratum area to improve metal removal.

5.2 HYDRAULIC EFFICIENCY

A number of researchers promote the use of improved hydraulic design through a wetland as a key to improving sedimentation and contaminant removal. Jenkins (2005) (after Persson et al, (1999)) describes the key factors affecting the hydrodynamics as:

- the wetland aspect ratio (length to width ratio)
- the configuration of the inlet and outlet
- the obstruction designation.

Jenkins et al, (2005) carried out modelling of hydraulics and dispersion rates through ponds / wetlands. They found that for small length to width ratios (< 1.4), the recirculation zones are so large that the effective volume is less than 20% of the actual wetland volume.

Each of these factors was modelled by Su et al (2009) and an overall hydraulic efficiency factor, lambda, developed – with a value of lambda > 0.75 recommended. The scenarios studied are shown in Figure 4 and the results in Table 8. They indicate that a length to width ratio of at least 3:1 is required, a distributed inflow (or level spreader) is beneficial and baffles are of most use when they extend at least half way across the width of a flow path.

Figure 4: Geometry tested for hydraulic efficiency (after Su et al, 2009)

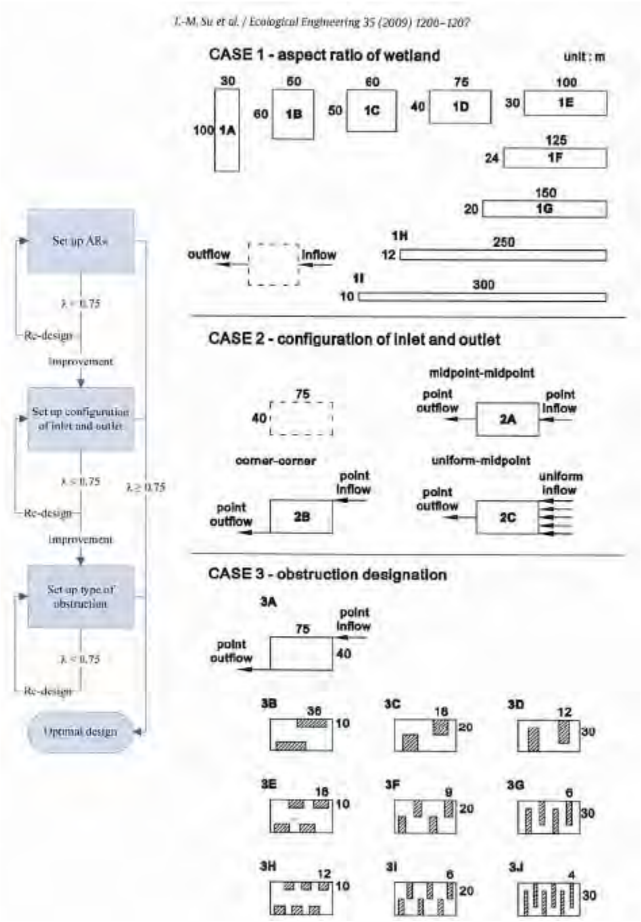


Table 8: Assessment of hydraulic efficiency factors (after Su et al, 2009)

Simulated Results of the Different Aspect Ratios of the Wetlands		Simulated Results for Different Configurations of Inlet and Outlet		Simulated Results for Different Obstruction Designations	
Case	**λ**	**Case**	**Λ**	**Case**	**Λ**
1A	0.14	2A	0.71	3A	0.65
1B	0.39	2B	0.65	3B	0.93
1C	0.54	2C	0.88	3C	0.95
1D	0.71			3D	0.94
1E	0.85			3E	0.79
1F	0.9			3F	0.94
1G	0.93			3G	0.94
1H	0.96			3H	0.71
1I	0.97			3I	0.91
				3J	0.92

5.3 VEGETATION TO PROMOTE SEDIMENTATION

Jenkins et al (2005) also considered the case of vegetation fringing the wetland and found that the effective volume decreased (i.e. short circuiting increased) as the amount and density of fringing vegetation increased. Importantly and positively, they also tested vegetation banded across the full wetland width and found that this did not reduce the effective volume. That is, when vegetation was even and constant across the wetland it did not cause a smaller effective cross sectional flow path area to form and retention time was maximised.

Schmid et al, (2005) concluded that the presence of "vegetation" established a very constant (uniform) velocity distribution with depth as water travels through the wetland. Their experiment of flow through artificial stalks of vegetation across a flow path showed that sediment deposition rates had fallen to about 20% of their peak value within 6 to 7 m of entry to the vegetation section of the experimental flume, indicating that a significant proportion of sediment was removed by this point.

5.4 METAL REMOVAL PROCESSES

The paper "Constructed wetlands: a review" (Scholz et al, 2005) and "The Constructed Wetlands Manual" (DLWCNSW, 1998) summarise wetland processes including their chemistry. These and additional papers "Potential use of constructed wetlands for the treatment of industrial wastewaters containing metals" (Dunbabin et al, 1992) and "Removal of metals in constructed wetlands: review": (Yeh, 2008) provide good overviews of the metal removal processes taking place within wetlands.

The key processes for metal removal take place in the sub-stratum of saturated sediment near the plant roots. Here particulate metals may be adsorbed by hydrous and manganese oxides on the surface of soil particles and organic matter and dissolved metals can react to form hydrated compounds called metal complexes. However the balance of dissolved and particulate metal can change significantly depending on the physical and chemical conditions present. For example, less soluble forms of metals are common in neutral to alkaline sediments, while dissolved forms are more common in water with low pH and TSS.

Improvements to metal removal therefore depend upon factors such as ensuring water contact through the base of the roots and preventing erosion of sediments in this area (to prevent them being in advertently washed out of the wetland). This may generally be achieved by maximising water contact opportunity and flow paths through planted zones of the wetland and distributing flows to reduce through velocities. The use of banded vegetated bathymetry (rather than fringing vegetation) is the preferred method to achieve this.

Given that most metal adsorption occurs in the soil around the root zone, rather than within the roots themselves, vegetation harvesting was found to remove little metal in itself. However, the removal of the soil matrix surrounding the root zone in conjunction with harvesting may be of some use. This needs to be carefully managed to prevent sediment and metal export – one way to achieve this is to harvest/remove sediment in bands from the wetland over successive years – allowing harvested areas to stabilise and allow new vegetation to emerge before carrying out subsequent stages.

6 CONCLUSIONS

Three main types of wetland sizing methods were identified from the literature review. Areal and volume based sizing methods rely on empirical relationships to rainfall runoff volumes and are typically quoted as removing 80 to 90% of contaminants. The volume based method underlies the current TP10 wetland sizing, and is also used in several recognised international stormwater guidelines. Hydraulic sizing methods require a retention time for a given flow condition. These methods are based on the time required for a given size of particle to settle out during passage through the wetland. Kinetic sizing methods have been adopted from wastewater wetlands and empirically predict the outflow concentration for a given flow rate and inflow concentration. They rely on there being a good database of k value decay rate coefficients and need to be adjusted for stochastic rainfall conditions to provide estimates of long term stormwater contaminant removal.

Overall, there is insufficient information on wetland performances within Auckland region to develop a new theoretical based sizing method for stormwater wetlands. The main body of knowledge for sizing uses generalised volume or area based sizing methods which have been empirically verified internationally through monitoring.

A number of comparisons of example (typical) wetland sizes, based on the current TP10 methodology and from the various sizing methods identified from the literature were carried out. These comparisons show that typical TP10 wetlands with a larger surface area, i.e. (WCAR greater than 2.5% generally meet area and volume sizing criteria from the literature. Hydraulic retention time criteria is met if the wetland surface area is larger (WCAR > 3.0%).

It is noted that the size of the TP10 wetlands can be small compared to other sizing methods if a deep pond depth is used to determine the wetland surface area – as in the case of the WWAR 1.15% hypothetical wetland used in the assessment. If a shallow average depth is assumed for the initial wet pond used in the sizing, the resulting surface area would increase.

Sedimentation is considered the primary contaminant removal process occurring in a wetland by a number of authors. This may be assisted by the physical presence of vegetation (where vegetation spans the full width of the wetland) which can act as a buffer to spread flow. Wetland plants provide for the uptake of dissolved metal contaminants and the root zone of the vegetation is the key area where this occurs.

Hydraulic efficiency was identified by several authors as being important for improving contaminant removal rates associated with settling. Key recommendations are to; spread flows at the inlet, have a length to width ratio of at least 3 and prevent short-circuiting. The use of banded vegetation across the wetland is considered to be a key means of spreading flows, achieving a good hydraulic efficiency and optimising the potential uptake of metals.

It is proposed to continue to use a volumetric sizing method for TP10 wetlands as this is consistent with the majority of sizing methods and monitoring information generally supports sizes developed in this way. However smaller volume wetlands are not expected to perform as well as larger volume wetlands. It is proposed to consider this further in the review of TP10 wetland sizing.

7 FUTURE WORK

As a result of the literature review it is proposed to consider the investigation of the following issues further:

- Further evaluate wetland performance from published in nationally and internationally literature over time to assist in the understanding of contaminant removal efficiency with wetland size.
- Establish a volumetric relationship (WCAR) to wetland performance and size based on local field monitoring investigations
- Update the current TP10 wetland design methodology based on the information gathered.

ACKNOWLEDGEMENTS

Thanks to Earl Shaver for his advice with regard to the existing TP10 wetland design methodology.

This study was funded by the Auckland Regional Council through the Stormwater Action Plan. Viewpoints expressed in this paper are those of the authors and do not reflect policy or otherwise of the Auckland Regional Council.

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