A REVIEW OF STORMWATER MANAGEMENT POND DESIGN WITHIN THE AUCKLAND REGION

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ABSTRACT

Stormwater management ponds are one of the most commonly used stormwater treatment options within the Auckland region. Ponds provide both quality treatment and quantity control of stormwater.

This paper presents the findings and recommendations from a review, commissioned by the Auckland Regional Council (now Auckland Council), into the design of stormwater management ponds within the Auckland region. It includes a literature review of current best practice and performance data, both internationally and within New Zealand.

The review focused on a number of issues that were identified in a gap analysis into pond design. These issues include updated performance data, the benefits of different ponds shapes and layouts, the inclusion of particle size and settling velocity distribution information for Auckland soils, and the performance of ponds that are not sized in accordance with design guidelines.

The review is currently undergoing international peer review and will be available later in the year as a Technical Report. The findings of the review will be incorporated in the next update to Stormwater Management Devices: Design Guidelines Manual, Technical Publication 10 (TP10).

KEYWORDS

Stormwater, stormwater management, stormwater treatment, ponds, contaminants, TP10

PRESENTER PROFILE

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1 INTRODUCTION

Stormwater management ponds (ponds) are designed to minimise the hydrological impacts of development. Ponds are a stormwater best management practice (BMP) device that serves to reduce the peak flow of rainfall events by capturing runoff and controlling its release for flood protection and stream bank erosion purposes, and provide water quality treatment through settling of suspended solids and associated pollutants. Ponds have been used in the Auckland region for many years.

The present pond design principles and methodologies used in the Auckland region are provided in Chapter 5 of the Auckland Regional Council's (ARC) *Stormwater Management*

Devices: Design Guidelines Manual, Technical Publication 10, Second Edition (TP10 2003).

Pond performance and design methodologies have been reviewed as part of the TP10 2003 revision process and a draft Technical Report (TR) has been prepared. The pond TR will provide the background for the pond guideline chapter within the revised stormwater management Guideline Document 01 (GD01). The TR focused on wet ponds and included a review of pond performance data in the Auckland region and internationally, and present international design best practice. Specific focus was placed on the pond design issues identified in a gap analysis of TP10 2003, by ARC and external service users and providers, which included:

1. A need to update the performance data with consideration to bands, or ranges, of performance
2. Consideration of the benefits of different pond shapes and layouts
3. Inclusion of particle size distribution (PSD) and settling velocity distribution (SVD) information for Auckland soils
4. Provision for guidance on the performance of ponds which are not designed to the recommended size in accordance with the design guidelines.

A step-by-step review of the design methodology of the various pond components was also carried out. However, this paper focuses on the issues identified in the gap analysis.

This paper summarises the review and recommendations of the four items identified in the gap analysis. A recommended pond design methodology to be carried forward into GD01 is also provided.

2 POND PRINCIPLES OVERVIEW

For the purposes of this paper it is assumed that the reader has some knowledge of ponds. Therefore, only a brief overview of the pond principles is presented.

There are two types of pond arrangement:

1. Dry (detention) ponds, which temporarily store runoff and control its release
2. Wet (retention) ponds, which have a permanent pool of standing water for water quality treatment, and a temporary (live) storage volume for stream erosion protection and water quantity control.

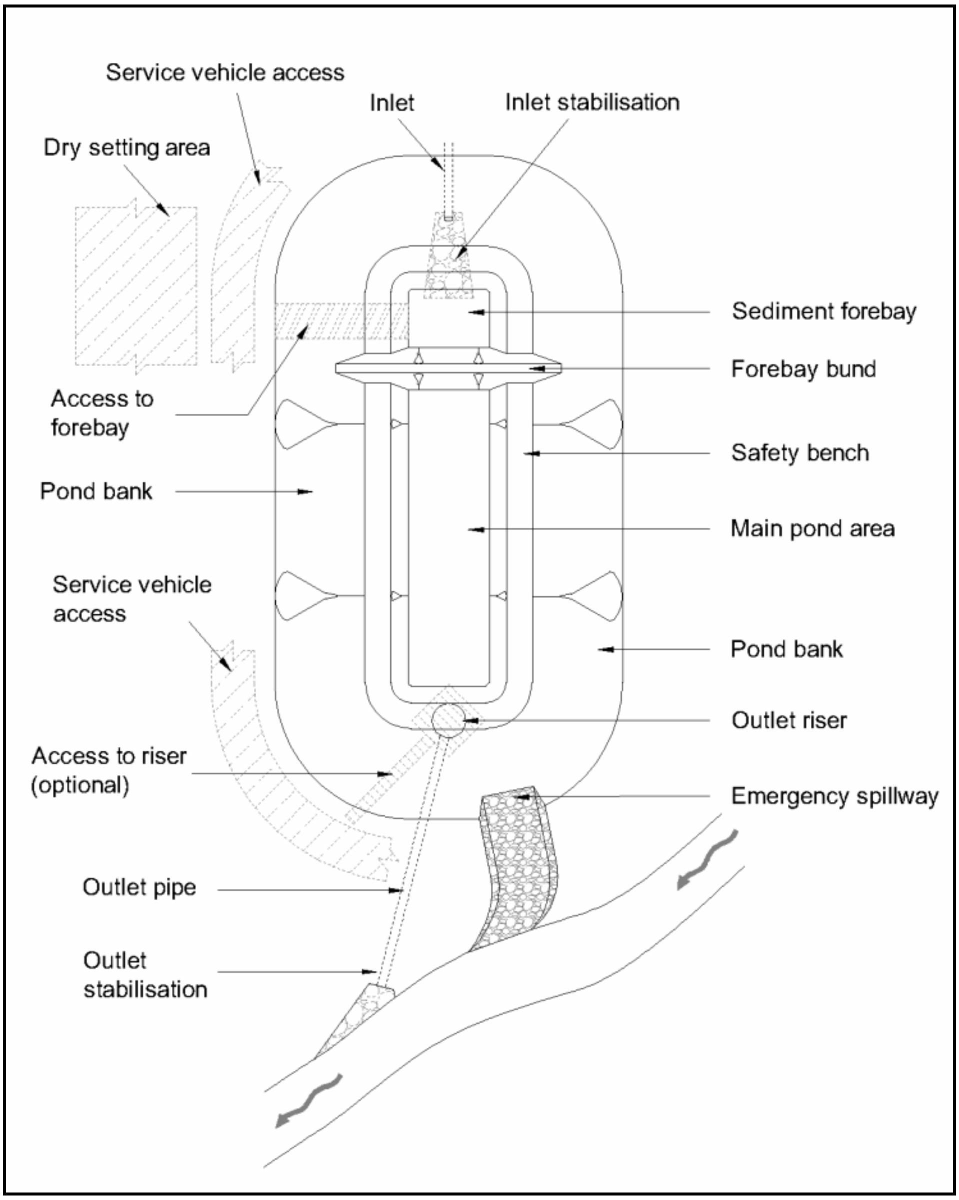
Ponds serve one or a combination of three primary functions, which are:

1. Water quality treatment, through the sedimentation i.e. settling of suspended solids as the runoff passes through the pond. Pond planting also provides treatment by physically filtering the water through vegetation and slowing the water velocity thereby promoting sedimentation. Trapped sediments are also further treated through the biological uptake of contaminants such as dissolved metals and nutrients.
2. Erosion control, to manage the effects of erosion within the downstream receiving environment due to greater and more frequent stormwater runoff during rainfall events, as a result of urban development. Erosion control is only required where discharge from a pond could cause downstream impacts on a receiving stream.

3. Quantity (flood) control, by capturing the runoff flow and releasing it into the downstream receiving environment at a lesser rate and over a longer period thereby reducing the peak of a given rainfall event (or events). Ponds can accommodate a large volume of water, so are therefore ideally suited to providing stormwater quantity control.

Ponds, whether wet or dry, typically consist of the components which are detailed in Figure 1 below:

Figure 1: Typical wet pond layout and details (not to scale)



The primary contaminant removal mechanism of all pond systems is settling or sedimentation of total suspended solids (TSS) (TP10 2003). Ponds capture and retain and/or detain stormwater runoff, which allows sediments to settle out before the water is released through the pond outlet and into the downstream receiving environment.

The removal efficiency (i.e. the amount of sedimentation) is dependent on the residence time of stormwater runoff within the pond. Generally, the greater the residence time the greater the sedimentation. However, many factors affect the pond residence time and the settling process within a pond, these include:

- Inflow
- Sediment load/concentration
- Particle size distribution
- Pond shape including length to width ratio
- Forebay design (removal of coarser sediments and flow spreading)
- Inlet and outlet arrangement (short-circuiting)
- Pond bathymetry (spatial variation of water depths)
- Vegetation (filtering flow and biological uptake)
- Temperature (water viscosity)
- Effects of wind on the pond surface.

The removal of TSS through sedimentation also removes other types of contaminants, which attach to and settle out with the sediment particles. Such contaminants that attach to sediment particles include positively charged heavy metals (DLWC, 1998), and polycyclic aromatic hydrocarbons (PAHs) which generally have a low solubility (Wium-Anderson et al, 2010).

Most ponds provide for areas of vegetative growth, such as around the safety bench and on the pond banks. Vegetation provides some additional treatment benefits by filtering the flow and trapping sediments, and providing mechanisms for the removal of nutrients and dissolved metals though biological uptake within the plants.

3 LITERATURE REVIEW PROCESS

The literature review focused on information published since 2003 i.e. after TP10 2003 was released. The review included national and international stormwater design manuals. The majority of design manuals sourced were from the United States of America (USA), of which the design manuals from Washington (Western Washington, Seattle), Oregon (Portland) and Maryland were given greater emphasis, due to their recent modifications and the similar rainfall conditions in these USA States to Auckland.

A literature review was also undertaken using on-line databases to access appropriate published articles. The electronic databases that were also used as part of the literature research included Google (last search: October 2009), Google Scholar search on “stormwater ponds” (last search: October 2009), American Society of Civil Engineers (ASCE) (last search: October 2009), and CIRIA.

A total of 16 design manuals and 21 articles/publications were used in the literature review.

4 CONTAMINANT REMOVAL PERFORMANCE DATA

4.1 REVIEW

Internationally, the following databases were identified, which provide detailed data and information on pond contaminant removal performance:

- Centre for Watershed Protection (CWP), updated in 2007
- International Stormwater Best Management Practices Database (BMP Database), updated in 2008. This database is maintained by GeoSyntec consultants and sponsored by USEPA, ASCE and others.

TP10 2003 references CWP data published in 1997. The majority of stormwater the design manuals and databases reviewed include and/or reference the pond performance information provided in one or both of the above publications.

The CWP publications present the performance data in terms of percent reduction, which is based on either the difference in event mean concentration (EMC) for influent and effluent concentrations, or the difference in contaminant mass. Where both methods were used, CWP select the contaminant mass method as it was considered more accurate.

Results from the CWP publications from 1997 (as presented in TP10 2003), 2000 and 2007 are provided in Table 1 for wet ponds.

Table 1: Wet pond median removal efficiencies (%)

Contaminant	TP10 2003 [1]	Winer 2000	CWP 2007 [2]
TSS	50-90	80	80 (60-88)
Total Phosphorus	30-80	51	52 (39-76)
Soluble Phosphorus	-	66	64 (41-74)
Total Nitrogen	30-60	33	31(16-41)
Total Nitrate/Nitrite	-	43	45 (24-67)
COD	30-70	43 [3]	-
Total Lead	30-90	-	-
Total Zinc	30-90	66	64 (40-72)
Total Copper	20-80	57	57(40-72)
Bacteria	20-80	70	70 (52-94)
Hydrocarbons	-	81	-

[1] As set out in TP10 2003;

[2] Includes 25th and 75th removal efficiencies in brackets;

[3] Organic carbons data includes COD, BOD and TOC removal data.

The BMP Database publications present the performance data in terms of effluent EMCs based on individual storm events, which places greater emphasis on sites where a larger number of events have been recorded.

Fassman (2010) received and compiled pond data from the BMP Database to assist in the preparation of the pond TR. The data was analysed to determine EMC reduction efficiencies (EMC_{RE}), as a percentage, for TSS and total dissolved zinc and copper. Only flow data with flow weighted composite EMCs and events with paired inflow and outflow EMCs were selected for analysis. Median EMC_{RE} for TSS, and total and dissolved zinc and copper are presented in Table 2.

Table 2: Median EMC percent removal (EMC_{RE}(%)) summary (Fassman 2010)

Contaminant	Retention (wet) pond		Detention (dry) pond	
	Global value [1]	One value per site [2]	Global value [1]	One value per site [2]
TSS	80.2	71.8	66.3	58.6
Total Zinc	64.1	59.2	61.5	63.9
Dissolved Zinc	50.0	41.7	0.0	-3.3
Total Copper	40.5	39.2	40.0	42.4
Dissolved Copper	25.0	33.3	0.0	0.0

[1] Based on pooling and assessing all data from all sites;

[2] The median EMC_{RE} was calculated for each site, then the median of the individual sites determined.

Barrett (2004 and 2008), analysed wet pond performance using the BMP Database with respect to pond volume requirements, which is discussed in more detail in Section 7.1.1.

In terms of national data TP10 2003 provided total suspended solid (TSS) removal monitoring data for three ponds within the Auckland region – Pacific Steel, Hyman Park and Unitech. However, no relevant data has been collected from these ponds since 2003.

With the exception of the data NIWA collected for the Redvale motorway pond in Silverdale (Moores *et al*, 2009,) no monitoring data has been obtained for any other ponds within the Auckland region. The NIWA data was collected for a copper and zinc sampling study for the New Zealand Transport Authority (NZTA). The data indicated that the TSS removal varied from 26 to 82%, with an average removal efficiency of 70%.

No other pond monitoring data from within New Zealand was found during the literature search.

4.2 RECOMMENDATION

It is recommended that the following contaminant removal performance data and information be provided within GD01:

- Table summaries of the most recent CWP data and the BMP Database data collated by Fassman (2010) in contaminant percentage removal/reduction format. Presenting the data in terms of percent removal is more user friendly than EMC. It should be noted that data represents sampling of different sized ponds and should be used for indicative rather than design purposes. The CWP data summary also include the upper and lower ranges

- A web link provided to CWP (www.cwp.org) and BMP database (www.bmpdatabase.org) to allow users to review up to date information if they wish.

It is also recommended, that given the lack of local data, consideration be given to establishing a monitoring programme to measure the contaminant removal performance of ponds (and wetlands) in the Auckland Region that have been designed in accordance with TP10 2003 (or GD01). This programme should cover a range of difference catchment types and relative sizes in terms of percentage of WQV.

5 POND SHAPE

5.1 REVIEW

TP10 2003 recommends that the pond shape fits into the existing site topography so that it "will look more natural and aesthetically pleasing". It also recommends a length to width ratio of 3:1 "to facilitate sedimentation". The other design manuals reviewed generally follow a similar philosophy recommending ponds of "irregular" shape with a long flow path, with length to width ratios carrying from 1.5:1 to 3:1. However, the Western Washington (2005) design manual recommends a tear-drop shaped pond, with the inlet located at the narrow end to minimise dead zones, such as corners.

A number of papers looking at various pond shapes were reviewed and are summarised below. It should be noted that the papers below assess flow through ponds, i.e. the incoming water is not held back by restrictions such as restricted outlets to allow for extended detention, which may negate the pond shape requirements to some extent.

5.1.1 ARC 2007

An ARC (2007) modelling study, undertaken by DHI, investigated the performance of ARC TP10 stormwater ponds (and ARC TP90 sediment control ponds) through sedimentation. MIKE 3 software was used to determine the "sediment deposition efficiency", based on an applied representative settling velocity.

Assuming fixed parameters, including pond volume (1000 m^3), pond depth (1.5 m), contributing catchment area (7.5 ha) and settling velocity, the study aimed to determine the optimal rectangular pond length to width ratio. Ponds with a length to width ratio of 1:1, 2:1, 4:1 and 7:1 were modelled.

The study found that of the pond ratios modelled the optimal sedimentation efficiency was achieved in a rectangular pond with a length to width ratio of 4:1. The 7:1 ratio pond was only slightly less efficient. It was concluded that the small decrease in efficiency of the 7:1 pond was due to increased velocities caused by the long, narrow pond layout. The 2:1 and 1:1 were the least efficient.

Following on, the study investigated the extent of modifications required to enable the 1:1, 2:1 and 7:1 ponds to achieve the equivalent sedimentation efficiency of the optimal 4:1 pond. The pond modifications analysed were:

- Solid baffles (bunds) extending above the water surface to increase the flow path
- Increasing the pond volume.

The sedimentation efficiency of trapezoidal, circular and L-shaped ponds compared to the optimal rectangular pond with a length to width ratio of 4:1 were also investigated.

In terms of pond modifications using baffles, the results concluded that for a 1:1 pond ratio the single baffle improves the pond performance, while a double baffle "does not perform significantly better than a single baffle". In the case of the 2:1 pond ratio the double baffle performs worse than a single baffle "due to the flow speeding up because of the narrow flow path that the baffles create".

The study noted that increasing the pond volume had a significant positive effect on the sedimentation efficiency. A 50 % increase in pond volume was required to the 1:1 ratio pond to achieve the same sedimentation efficiency as the 4:1 pond. The 2:1 pond required a 20% increase in pond volume to achieve the same sedimentation efficiency as the 4:1 pond.

In terms of different pond shapes, the modelling results indicated that the circular pond performed poorly, even when considering different outlet orientations. The circular pond required a 100% increase in volume to meet the rectangular 4:1 pond sedimentation efficiency.

The trapezoidal pond required a 25% increase in volume to meet the 4:1 rectangular pond sedimentation efficiency.

Performance of the L-shaped pond was similar to the rectangular pond; requiring only a 12% increase in volume to meet the 4:1 rectangular pond sedimentation efficiency.

5.1.2 PERSSON

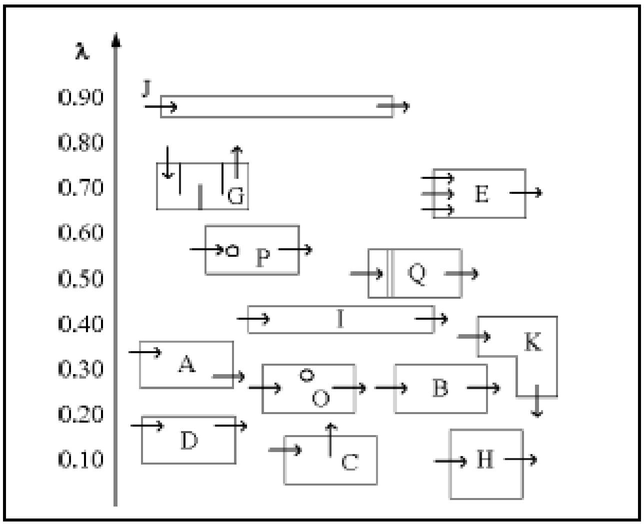
Modelling studies by Persson (1999a) and Persson *et al* (1999b) analysed 13 different pond shapes and configurations through 2-D simulation. The purpose of the studies was to determine the hydraulic efficiencies ("how well the incoming water distributes within the pond") for the different pond shapes.

The hydraulic efficiency, λ, was determined as a function of effective volume, which is derived from the residence time of the water within the pond, and a turbulence or mixing parameter.

A graphical summary of the hydraulic efficiencies for the different pond shapes and arrangements, as presented in Persson *et al* (2003) is provided in Figure 2 below and summarised in

Table 3.

Figure 2: Hydraulic efficiency, λ, of various pond layouts from Persson (1999b) as presented in Persson et al *(2003).*



Note: the higher λ the better the hydraulic performance of the pond

Table 3: Hydraulic efficiency, λ, of various pond layouts (Persson et al *1999b)*

Pond layout (refer to Figure 2)	Hydraulic efficiency, λ
A	0.30
B	0.26
C	0.11
D	0.18
E	0.76
G	0.76
H	0.11
I	0.41
J	0.90
K	0.36
O	0.26
P	0.61
Q	0.59

All ponds simulated within Figure 2 had a constant volume of 2,700m^3 and depth of 1.5m. The "basic" rectangular ponds (A to G, O to Q) have a length to width ratio of 2:1. Pond G has 3 baffles. The "0" in ponds O and P represent an island. The double line in Q represents a subsurface baffle.

The study by Persson (1999a) concluded the following:

- Length to width ratio: as the length to width ratio increases pond performance increases. This is the also the case in Pond G where the flow path is increased though the use of bunds. Persson *et al* (1999b), included a qualifying statement that "care needs to be applied in designing elongated shapes to ensure that the increase in flow velocity associated with the narrower cross section would not lead to resuspension and remobilisation of settled material", which corresponds with the ARC (2007) research outlined above

- Islands: the island placed on the side of the pond (pond O) did not alter the short-circuiting compared to a basic pond (pond B), although mixing decreased. The island placed near the inlet (pond P) improved the pond performance

- L-shaped: the hydraulic performance of the L-shaped pond (pond K) did not differ much from the basic shape" (rectangular), which suggests that the pond can be curved for aesthetic purposes without compromising hydraulic performance

- Inlets and outlets: the arrangement of the outlets in relation to the inlets affects the hydraulic performance of the pond. Refer to Section 6 below for more details

- Subsurface baffles: a subsurface baffle placed near the inlet (pond Q) improves the hydraulic efficiency significantly. Ponds that include a forebay with a forebay bund set below the permanent water level would likely fall under this category.

The South East Queensland (WSUD, 2006) design manual has incorporated the hydraulic efficiency values, λ, into their pond design; refer to Section 7.1.2 below.

5.2 RECOMMENDATION

In most cases the shape of the pond will be restricted by land availability and topography within a development site. Therefore, the following pond layout recommendations are made:

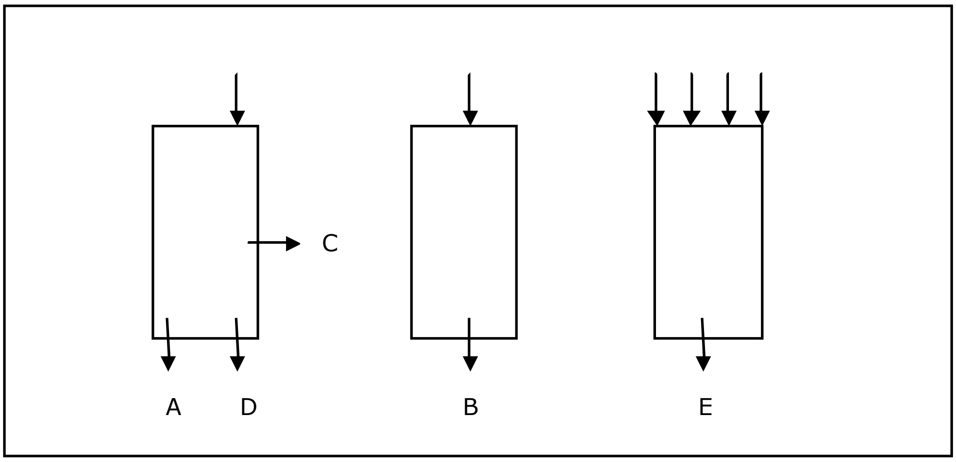
- The current TP10 2003 recommendation that the pond shape should tie in to the site topography and look as natural as possible should be retained
- The current minimum pond length to width ratio of 3:1 be retained. An optimal pond length to width ratio of between 3:1 and 4:1 is recommended
- The Persson *et al* (1999a, 1999b and 2003) hydraulic efficiency figure (Figure 2) and associated discussion be adopted to provide guidance when considering pond shape. If an alternative settling velocity approach to pond design is included (as discussed in Section 7.2) this figure will also form part of the design method
- The top of the forebay bund be located 150 to 300mm below the permanent storage water level, unless porous bunds are used. The purpose of the forebay bund is to allow for more flow dispersion across the top of the bund into the main pond.

6 INLET AND OUTLET ARRANGEMENT

6.1 REVIEW

The pond study by Persson (1999a), as outlined in Section 5.1.2, considered a number of inlet and outlet arrangements of rectangular ponds with a length to width ratio of 2:1 (ponds A, B, C, D and E), as regenerated in Figure 3.

Figure 3: Pond inlet and outlet arrangements (Persson, 1999a)

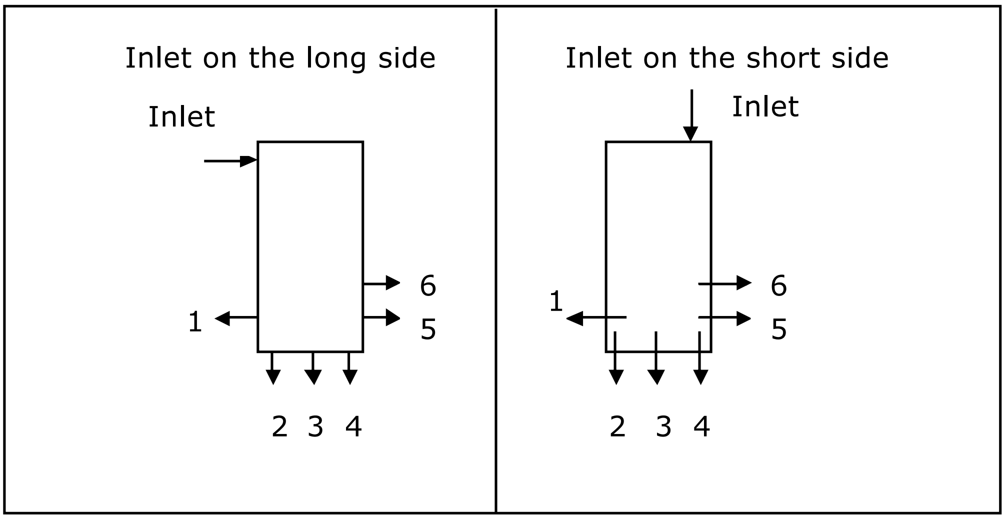


The order of performance, from the least to most amount of short-circuiting, from the Persson (1999a) study was arrangement E, A, B, D, C. Pond E included an inlet spread along the entire width of the pond, which resulted in much less short-circuiting and much better hydraulic efficiency. Ponds A and B provided similar hydraulic performance. Cases C and D produced more short-circuiting and were, therefore, less hydraulically efficient.

Glenn and Bartell (2008) completed a modelling study that considered a number of different inlet and outlet arrangements of rectangular ponds with a length to width ratio of 2:1 (refer to Figure 4). The purpose of the study was to determine which arrangement had the greatest impact on preventing short-circuiting. Performance was measured as a function of the travel time through the pond, where the longer the travel time the less short-circuiting and therefore the better the performance.

The study did not provide any discussion on the reasons for the performance results.

Figure 4: Pond Inlet and outlet arrangements (Glenn and Bartell, 2008)



The order of performance, from the least to most amount of short-circuiting, from the study for the inlet on the long side scenario was arrangement 5, 1, 2, 3, 4, while 6 was the worst performing. Travel times varied from 7.6 hours in arrangement 5 to 2.8 hours in arrangement 6.

In terms of the inlet on the short side scenario the order of performance, from the least to most amount of short-circuiting was 5, 3, 4, 1, 2, and 6. Travel times varied from 6.8 hours in arrangement 5 to 3.2 hours in arrangement 6.

It should be noted that two inlet and outlet arrangements are common to both the Persson (1999a) and Glenn and Bartell (2008) studies. Persson (1999a) arrangements A and D correspond to Glenn and Bartell (2008) "inlet on the short side" arrangements 2 and 4. However, for Glenn and Bartell (2008) arrangement 4 performed better than arrangement 2, although not significantly; the opposite result was obtained by Persson (1999a).

In this case, given Persson has carried out numerous research studies on pond configurations including inlet and outlet arrangements, it is considered that the Persson results are more reliable.

6.2 RECOMMENDATION

The inlet and outlet have an effect on the performance qualities of the pond, in terms of flow path length and short-circuiting. In reality the inlet and outlet locations are likely to be restricted by site constraints. For example the pond outlet may need to be in a certain location within the pond for access purposes, or because of its locality relative to the receiving water body.

However, during the design process consideration should be given to the both the inlet and outlet arrangements when designing the layout of the pond to maximise the flow path length and reduce short-circuiting. In particular the effectiveness of spreading the flow across the width of the pond at the inlet is noted (Persson (1999a) arrangement E) and should be encouraged as a simple design measure to increase the treatment performance of ponds.

It is recommended that guidance on the inlet and outlet arrangements and their relative effects on pond containment removal performance should be included within GD01.

7 SETTLING VELOCITY DISTRIBUTION

7.1 REVIEW

The design manuals reviewed used three main methods for sizing the pond to meet of water quality requirements:

1. The pond is sized to capture a certain volume of stormwater runoff
2. The pond surface area is sized as a portion of the catchment area
3. The pond area is sized based on the contributing flow and the settling velocity of the predicted sediments entering the pond.

The more common volume and area based methods are described first, with the settling velocity based method then described.

7.1.1 VOLUME AND AREA BASED METHODS

The volumetric and area based designs are outlined in Table 4 below. Both methods define a volume to be treated. The volume methods base this on a volume of runoff, whereas the area methods base this on a portion of the catchment area.

Table 4: Volume and area based design summary

Design manual	WQV design approach	Method
TP10 2003	Capture one third of 24 hour 2 year ARI (80% annual runoff)	Volume
NZTA (2010)	Capture 90th percentile rainfall event	Volume
Portland (2008)	Capture 90% average annual runoff	Volume
Western Washington (2005)	Capture 6 month rainfall event (91% percentile event)	Volume
Seattle (2009)	Capture daily runoff volume at or below 91 percentile of the total runoff volume	Volume
New York (2003)	WQV = $(P \times R_v \times A)/12$ Where P = 90% rainfall event $R_v = 0.05+0.009 \times I$ I = impervious area A =area (acres)	Volume
Maryland (2000/2009)	WQV = $(0.05+0.008 \times I) \times A/12$ Where I = percentage of impervious area, A = area (acres)	Area

The water quality storage requirements are commonly determined as a percentage of the WQV. However, a comparison between the different design approaches with respect to that specified within TP10 2003 has not been undertaken, as the WQV design approach is being reviewed separately by Auckland Council (AC).

Barrett (2004) analysed pond performance using the BMP Database. The analysis found a relationship between permanent pond volume (V_b) and mean annual event runoff volume (V_r). The analysis concluded that "larger permanent pool volumes result in less variability of discharge concentrations and produce lower discharge concentrations for events with greater volumes." Barrett (2004) also noted that "TSS removal is not correlated to pond surface area", which reinforces the idea that volume is a more significant factor in contaminant removal within ponds.

Further analysis by Barrett (2008) again recognised the relationship between pond volume and runoff volume, whereby ponds with a V_b/V_r ratio of greater than 1.0 produce significantly lower effluent TSS concentrations compared to ponds with a ratio of less than 1.0.

However, Barrett (2008) includes the caveat that the BMP Database contains data from ponds that have not necessarily been well designed, but from ponds "whose monitoring programmes have been well documented".

7.1.2 SETTLING VELOCITY BASED METHOD

The main treatment process in a pond is sedimentation. TSS removal efficiency can be determined based on the settling velocity of the sediments entering the pond. However, calculating the removal efficiency this way requires a good understanding of the particle size distribution (PSD) and accurate settling velocity information for a given pond and catchment.

Auckland Council have completed a study and is preparing a TR, *Particle size and settling velocity distributions for the design of stormwater treatment devices in the Auckland region.* The TR provides PSD and settling velocity distribution (SVD) information for urban networks, urban streams and construction sites within the Auckland region.

The TR suggests that in designing devices based on settling "PSD is superfluous; it is the SS settling velocity distribution (SVD) that is required". However, SVD is derived from the PSD; therefore, PSD is relevant in that respect. The SVD was calculated from the particle sizes by assuming particle and fluid densities, shape and flocculation and compared against international data. SVD was determined using Stokes or Weber's Law, depending on the flow regime (laminar, transitional and turbulent). (Laboratory testing of the settling velocities may provide more direct measure of SVD values than calculated values).

The South East Queensland (WSUD, 2006) design manual incorporates settling velocities into their sedimentation basin design. The following equation (1) is used to determine the pond area:

$$R = 1 - \left[1 + \frac{1}{n} \frac{v_s}{Q/A} \right]^{-n} \quad (1)$$

R = the fraction of target sediment size band removed for a given settling velocity

v_s = settling velocity of the target sediment (m/s)

Q = applied flow rate (m^3/s) based on contributing area and land type

A = pond surface area (m^2)

n = turbulence or short-circuiting parameter

The settling velocities, v_s, for different particle sizes found in South East Queensland "under ideal conditions" are provided in a table for use in equation (1).

WSUD (2006) derives the turbulence or mixing parameter, n, from the hydraulic efficiencies, λ, as determined by Persson *et al* (1999b) and detailed in Section 5.1.2, which are detailed in Figure 2, from the following equation (2):

$$n = \frac{1}{(1-\lambda)} \quad (2)$$

WSUD (2006) outlines that where $\lambda > 0.7$ ($n > 3.3$) hydraulic efficiency is good, and where $\lambda < 0.5$ ($n < 2$) hydraulic efficiency is poor.

USEPA (2004) provides different procedures ranging in complexity for sediment routing in ponds for both quiescent and dynamic scenarios that utilises settling velocity. The document also sets out equation (1) within its text. The document states that site specific settling data is preferable. USEPA (1986) also references equation (1) for determining sediment removal under dynamic conditions.

A study by Persson and Pettersson (2009), which considered settling velocities in evaluating long term removal efficiency of ponds within Sweden, also utilised equation (1).

7.2 RECOMMENDATION

The current volumetric pond sizing approach used in TP10 2003 is consistent with numerous other design manuals. This approach is generally widely accepted within New Zealand, and is a familiar method to operators, regulators and designers. Therefore, it is recommended that the current approach to pond sizing be retained.

However, an alternative approach to pond design utilising settling velocity information should also be further investigated as an option in GD01. The design method set out in WSUD (2006), and also outlined in USEPA (2004) and Persson *et al* (2009), could be adapted and adopted.

It is recommended that a modelling investigation, which is currently underway, of the settling velocity design method be undertaken to consider its suitability for use as an alternative method for sizing ponds within the Auckland region. Calibration of the settling velocity methodology through modelling is required to adapt the design methodology to Auckland conditions and determine if:

- The SVD prepared by ARC is suitable for regional pond design, or if the variability of Auckland's geology and landuse require the use of site specific data
- The settling velocity method produces similar or different results to the volume based method
- The method is suitable to the design of all types of treatment device.

Adopting a settling velocity method as an alternative approach to pond design may also provide a method of estimating the performance of ponds that do not meet the design guidelines, and also act as a good design check. The method may also allow GD01 to be used in other applications, such as outside of the Auckland region and for situations with non-standard sediment types, for which it is currently used.

8 PONDS SMALLER THAN TP10 2003 RECOMMENDATIONS

8.1 REVIEW

It is often necessary to assess the effectiveness of ponds that do not detain the full WQV as defined by TP10 2003. This may occur due to site restrictions or other factors that limit the pond volume, or where the performance of a pre-TP10 pond needs to be assessed for an increase in catchment area or change in landuse.

TP10 2003 currently includes a table (replicated in Table 5), which provides a general guide to the expected level of treatment that can be achieved for different percentages of WQV. The values are not specific to a pond; they apply to all stormwater devices. Therefore, it provides an approximate guide only, which the author of TP10 2003, among others, consider may be misleading (pers.comms Earl Shaver, June 2010) as it is not device specific, so the removal efficiencies may vary between devices.

Table 5: Relative levels of removal efficiency (TP10 2003, Table 3-1)

Practice Volume	Efficiency
150% of WQV	82%
100% of WQV	75%
75% of WQV	70%
50% of WQV	60%
25% of WQV	50%
10% of WQV	40%
5% of WQV	30%

The first edition TP10 1992 also includes the same table (as Table 2.2) and provides a simple calculation example, where the achievable pond size is divided by the required pond size to give the percentage of the WQV that can be achieved. The expected efficiency is then interpolated from the table.

There is minimal other information on the performance of ponds that are not sized according to specifications. The pond performance data from the CWP Database, in Section 5.2, does not relate to pond size.

8.2 RECOMMENDATION

It is recommended that ponds that do not meet the design guidelines be investigated as part of the settling velocity modelling investigations set out in Section 7.2 above, with the aim of producing a sizing table specific to ponds. The outcomes from the review may not be available for GD01; however, could be included in updated revisions.

Therefore, in the interim it is recommended that the “relative levels of removal efficiency” table currently within TP10 2003 be retained, as no other documented information is currently available.

9 DESIGN PARAMETERS AND METHODOLOGY

A step-by-step review of the parameters and design methodologies behind all of the pond components was undertaken as part of the review. Factors that have an influence on the design approach to ponds was also reviewed, which included:

- Landscaping considerations (reviewed as a separate project)
- Construction, and operation and maintenance considerations (reviewed as a separate project)
- Effects of climate change.

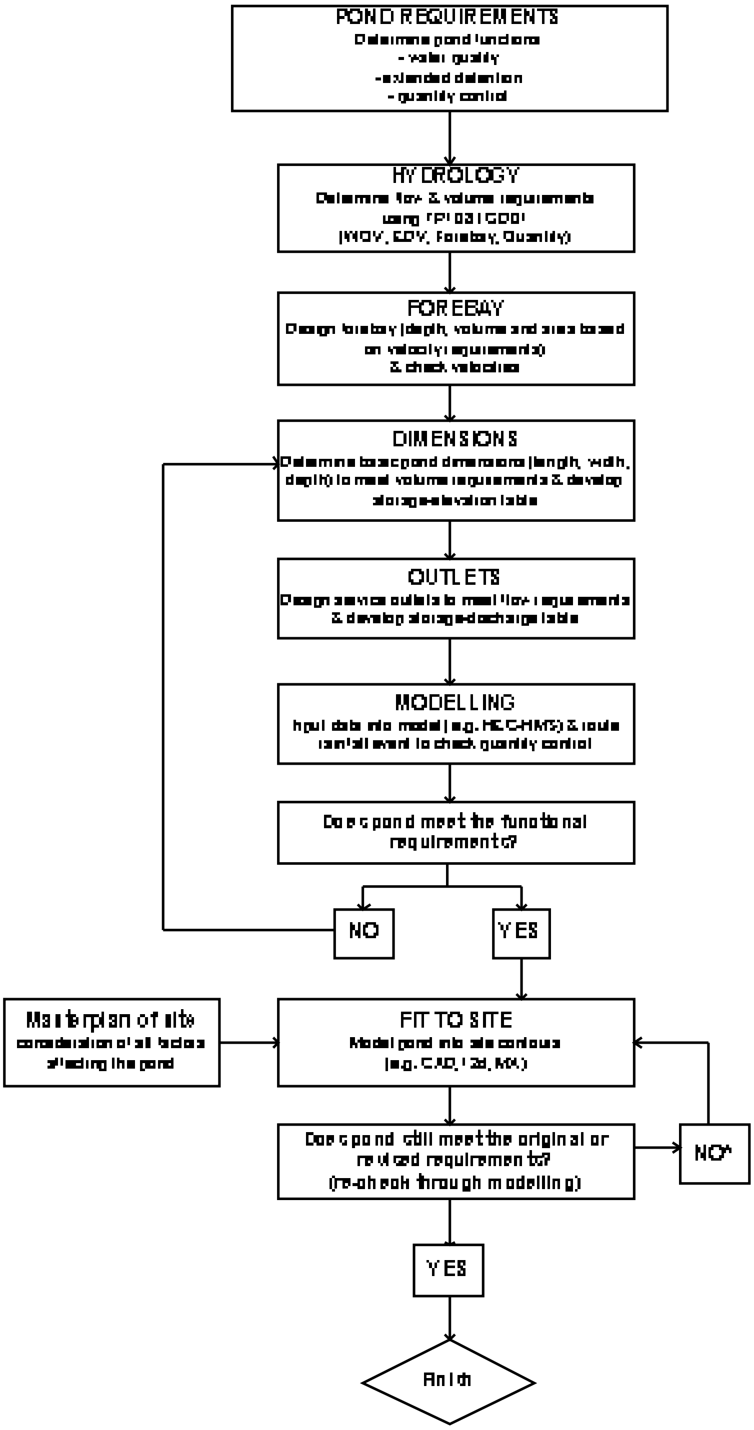
As outlined in the introduction this paper focuses on the issues identified in the gap analysis. Therefore, the step-by-step review and recommendations are not presented in this paper.

However, overall the review concluded that the design of stormwater ponds, as provided in TP10 2003, does not require major revision. The design methodology presented in

Figure 5 does not differ significantly to that within TP10 2003. Although, some design steps have been revised, while others have been added, and where appropriate more (or less) detail has been added. An updated case study example was also prepared and included in the pond TR.

At the completion of the recommended modelling investigations into SVD, which are currently underway, this methodology will be revaluated.

Figure 5: Pond design methodology flow chart



* If the pond does not meet the functional requirements, the achievable WQV should be determined and an assessment of the pond capabilities completed.

10 CONCLUSION

Stormwater management pond performance and design methodologies have been reviewed as part of the TP10 2003 revision process. A step-by-step review of the design methodology of the various pond components was carried out. Specific focus was placed on the pond design issues identified in a gap analysis of TP10 2003, which included:

1. A need to update the performance data with consideration to bands, or ranges, of performance
2. Consideration of the benefits of different pond shapes and layouts
3. Inclusion of particle size distribution (PSD) and settling velocity distribution (SVD) information for Auckland soils
4. Provision for guidance on the performance of ponds which are not designed to the recommended size in accordance with the design guidelines.

Based on the published literature, the review found that globally the general approach to pond design is similar and has not significantly altered to the approach that is currently outlined in TP10 2003. Therefore, the volumetric approach to pond design, as provided in TP10 2003, does not require major revision within GD01.

However, it is recommended that further modelling investigation is carried out to consider:

- An alternative approach to pond design utilising sediment settling velocities
- Evaluate the performance of ponds designed smaller than TP10 2003 recommendations.

It is also recommended that GD01 include updated contaminant removal performance data, and provide guidance on the influence difference pond shapes and inlet and outlet arrangements have on pond performance.

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