UTILISING STORMWATER RUNOFF TO MEET NON-POTABLE WATER DEMANDS AT AUCKLAND ZOO: A QUANTITATIVE AND QUALITATIVE ASSESSMENT

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ABSTRACT

Auckland Zoological Park uses substantial quantities of water in their daily operation; for visitors and staff sanitary purposes, animal welfare and cleaning, through to irrigation in summer. Up to 2/3 of the demand is for non-potable quality water. The merits of stormwater runoff to meet this demand was evaluated at a desktop level for the period from 2010-2014.

Stormwater runoff was calculated using a simple event based model utilising historic daily rainfall statistics from NIWA's Cliflo database. The watershed was divided into sub-catchments and each was analysed based on Auckland Regional Council's TP108 methodology. Stormwater runoff for the 16.4 ha site was calculated to be 45ML to 86ML per annum for the study period.

Reservoir storage is required to bridge the periods between rainfall. A reservoir capacity of 14ML achieved 72% volumetric reliability over the study period whereas a volume of only 1.2ML still achieved 59% reliability. An uncharacteristically dry period in 2013 skewed the results and meant that large increases in reservoir volume resulted in only incremental improvement in volumetric and temporal reliability.

Water quality demands for the end user are high as a result of the potential to ingest pathogen or toxins by visitors, staff and animals. Heavy metal pollutants from vehicles in the carpark make this sub-catchment a poor quality option for stormwater harvest and levels of pathogens in runoff from exhibits means that stormwater requires a degree of filtration and sterilisation before re-use. Qualitatively, a 'one type fits all' approach for non-potable water use limits its viability as a potable water substitute.

The capture, filtration, storage and distribution of non-potable water for multiple end users is challenging. This study highlights some of the opportunities but also the difficulty in implementing stormwater re-use schemes and perhaps explains why the uptake of water re-use strategies is not prevalent.

Keywords

Stormwater re-use, sustainability, water quality, non-potable.

PRESENTER PROFILE

Andrew Steele has a background in ecology with a BSc from Auckland University and ten years in Marine Aquaculture R&D in New Zealand. This was followed by a career in hydraulic and biological design of marine and freshwater engineered ecosystems with Thorburn Consultants (NZ) Limited. He has a Masters in Engineering Studies from Auckland University with a focus on hydraulics, hydrology and sustainable engineering and currently works as a consulting Environmental and Civil Engineer.

1 INTRODUCTION

Auckland Zoological Park is one of the city’s major attractions with a visitation of around 800,000 per annum. It operates with a strong conservation message alongside its reputation as one of Auckland’s, and indeed New Zealand’s, premier attractions. Like many institutions it is focused on developing its environmental sustainability practices.

The Zoo is Council owned and operated, has been open since the 1920’s, and has seen considerable development and re-development over its years. As a result, the services and infrastructure are a mix of very old and new. Due to piecemeal development and a long history, there has never been a Zoo-wide approach to infrastructure, however of late there is a growing need to provide an integrated approach to the three waters and, in particular, to water supply.

The Zoo has considerable dependence on high volumes of municipal supply potable water; it suffers from frequent surface flooding in rainfall, has mild contaminant issues in its stormwater, and grapples with peak sanitary sewer flows to trade waste due to combined systems. In fact, the Zoo as a distinct catchment suffers from many of the same stormwater issues that affect aged suburban developments. Implementing sustainable water infrastructure often requires one to challenge traditional concepts of where water originates and where it ends up. The three waters are interconnected in more complicated ways than the traditional approach and to utilise these resources efficiently the interrelationships of these three waters needs to be explored and understood.

Water re-use, and in particular stormwater re-use, is widely accepted as a way to reduce reliance on municipal supply for residential, business and industry alike (Hatt et al., 2006, Zhang et al., 2014), however, the costs associated with initiation or upgrading are often a barrier (Makropoulos and Butler, 2010, Thompson, 2014). Zoos and amusement parks, like many businesses, have tapped into this resource in an effort to reduce costs by developing ‘green blue infrastructure’ solutions or sustainable practices. In Australia, both Sydney and Melbourne Zoos have adopted water re-use schemes (Hatt et al., 2006), as has Oregon and Jacksonville Zoos in the USA, and Artis Zoo in Amsterdam (Aeijelts Averink and Buijs, 2000). Kayseri amusement park in Turkey re-uses stormwater for its attractions (Karakoçak et al., 2013).

Hatt et al. (2006) suggested that an impediment to the adoption of stormwater recycling projects in Australia has been the “lack of practical and widely accepted methods for assessing the many financial, social, and ecological costs and benefits against traditional alternatives” and Makropoulos and Butler (2010) suggest that a distributed or de-centralised water supply is relatively untried and unproven.

This work sets out to quantitatively and qualitatively define the water requirements of the Zoo with a view to exploring the possibility of harvesting, treating, storing and distributing stormwater as per the “four core functions” (Hatt *et al.,* 2006) for re-use, in an effort to reduce reliance on potable water.

2 BACKGROUND

2.1 CATCHMENT GEOMORPHOLOGY

Auckland Zoo is a sprawling 16.4 ha site. It is intersected through the centre by Motions Creek which runs more or less northwest across the site. Motions Creek is a highly modified channelised stream that separates moderately contoured basalt geology to the south west, and steeply contoured Waitemata sandstone topography to the north east (GNS, 1992).

Photograph 1: Aerial image of Auckland Zoological Park with indicative boundary. Motions Creek in blue (Source: adapted from Google Earth)

The level of development within these two geologically distinct zones is influenced by the topography, with most of the Zoos attractions sitting on the moderately sloping volcanic portion to the south west. By contrast, the north east is predominantly heavily vegetated with secondary native bush covering the majority of the hillside. Whilst this bush has regenerated after clearing in the 1920's it has been so for a good portion of the last century, therefore hydrology in this area is as if it were virgin bush.

2.2 HYDROLOGY

The geomorphology and development of the Zoo has a profound influence on its hydrology and runoff characteristics. To the southwest is highly pervious underlying rock covered for the most part in impervious asphalt. The porosity of the basalt means that antecedent conditions have little effect on the soil moisture deficit, so storm events can be treated in solitude. The net result is that runoff occurs quickly and is not sustained.

Similarly, runoff also occurs quickly from the other side of motions creek due to the Waitemata tight clay and sandstones having minimal storage and soakage potential. The dense bush mitigates this to a degree however this mitigation is offset by the steep slopes.

The result of these geological characteristics is that runoff events from the Zoo catchments are short and flashy. Any runoff destined for re-use needs to be collected quickly, in multiple decentralised zones and stored in impervious structures.

2.2.1 UPPER CATCHMENT

Between these two zones is Motions Creek which carries water from upstream of Auckland Zoo. The catchment above the Zoo is almost entirely piped except for the section through Western Springs Park and the Zoo itself. Water quality is very poor and has influxes of industrial, traffic, and sanitary sewer runoff. Motions Creek is a highly degraded creek and therefore is not considered a good candidate for surface water harvest even though it has high base flow and is part of the greater watershed.

2.3 RE-USE OF STORMWATER

2.3.1 WATER QUALITY AND AVAILABILITY

The quality of water influences the degree to which it can be re-used on site. For this study, water was to be re-used where it will come into contact with people, i.e. staff operating wash-down hoses, maintaining equipment, or contact with aerosols from irrigation. Members of the public may incidentally come into contact through overspray from irrigation. Water contact with animals comes through the same mechanisms as for people, but in addition, water could be used for wash-down of animal back-of-house quarters, used as wash-down directly onto the animals, used in water features that they may drink from, bath in, and most critically, used in aquariums where animals swim and or permanently reside.

The quality of water and the level of contaminants influence where and how it can be re-used, but also the level of physical filtration, biological filtration and sterilisation that is required to render it fit for purpose. Poorer quality water has limited end-use opportunity but costs little or nothing in terms of filtration; whereas high quality water has considerable costs associated with filtration, but has a more ubiquitous scope for use. One filtration method does not necessarily fit all.

In Auckland we take water quality for granted and indeed we expect or assume that all reticulated water is of drinking water standard. We regard it as useful for almost any end use with little regard for chemical or biological constituents. As a result there is risk in providing alternative water that does not meet the conventional standard. The greatest risk is perceived to be health and the greatest health risk is seen to be pathogens such as *Botulism*, *Cryptosporidium*, *Giardia*, *E. coli* and *Camphylobacter*. Abbott *et al*. (2007) surveyed roof collected water from private dwellings and found that half of the samples exceeded the Drinking Water Standards for New Zealand maximum acceptable value for *E.coli.*

In addition there are risks of other non-biological contaminants such as excess nutrient or toxic heavy metals. Some of the contaminants such as metals and suspended solids may pose a nuisance such as iron staining or residual suspended solids once water evaporates.

Choosing the level of water treatment that best meets the needs of the end user is a difficult task made more difficult at the zoo because of complex interaction between (rare and intrinsically valuable) animals, public and staff. By providing potable quality water the one size fits all strategy is simple and effective if a little costly. However there is a clear and significant need for large volumes of water at the zoo that does not need to reach potable standards and stormwater would appear to be a candidate to fill that need.

3 METHODOLOGY

To quantitatively assess this stormwater re-use proposal, a continuous model was developed, tested and analysed for sensitivity. The model included a demand model: based on existing water usage compared to known parameters; a supply model: based on an accepted rainfall-runoff model for the Auckland region; a reservoir model; and in later work a financial model: based on operational and infrastructure costs. The model is depicted in Figure 1 and the methods by which each element of the model was derived are described below.

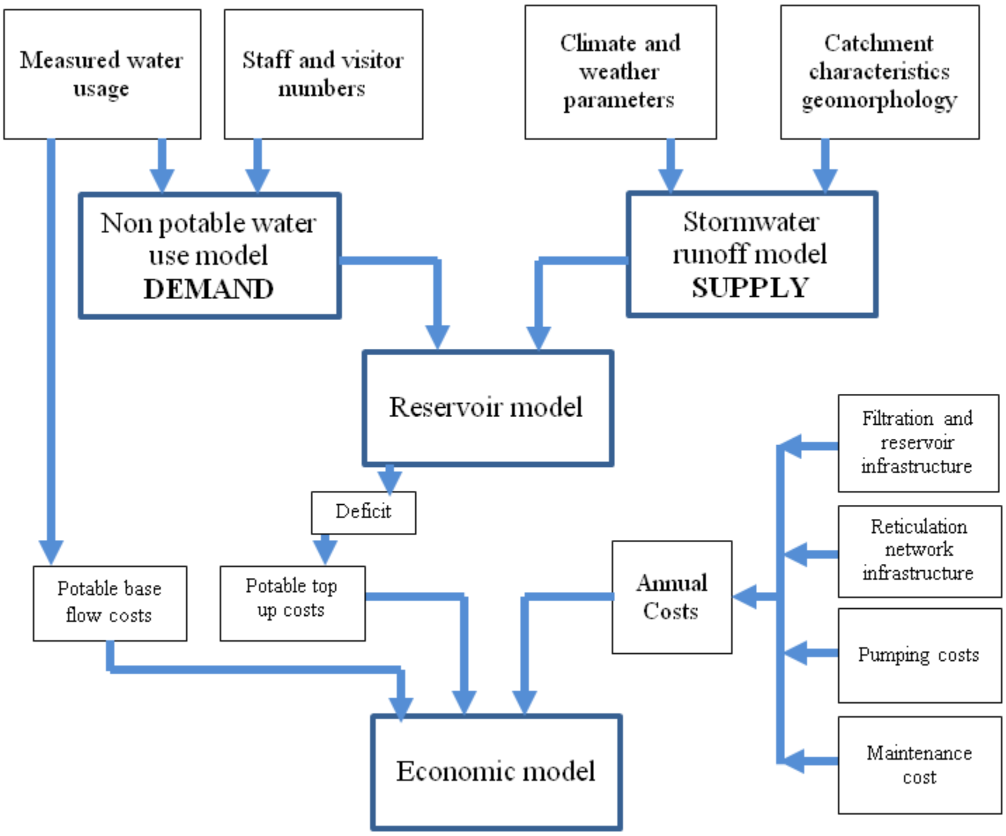

Figure 1: Towards development of the economic feasibility model.

3.1 WATER DEMAND

3.1.1 METERED TAKE

Records of potable water use on a monthly basis were obtained from Watercare invoices to Auckland Zoo from 2010 to 2014. The Zoo manages 9 Watercare meters feeding from different roadside connections around the site however only 6 meters covered 98% of the volume. The monthly readings from all of the six meters feeding this ring main were logged in Excel. Note an existing non-potable water system is in use at the Zoo however its use is not metered so its volume and end use are not considered in this work.

3.1.2 END USE

In order to determine the potential for stormwater re-use for non-potable purpose, the distinction between end-users at the Zoo needs to be considered. Determining where to draw the distinction between the two types of water is not clear and is based on qualitative criteria as discussed in section 3.4. However, for the purpose of this study a water demand must be satisfied by either municipal town supply (potable), or alternate supply (non-potable) and a clearly defined threshold is required between the two.

All demand from people, be they staff, volunteers or visitors, is to be met by the potable system, even where their actual usage only requires non-potable quality, such as toilet flushing. A fixed portion of potable water is required for animal husbandry purpose where the quality needs to be assuredly high: direct consumption, animal washing (where ingestion is possible), or where the optical properties need to be highest, such as the aquariums, require potable water.

By contrast, water for irrigation, waterfalls, stream features, and animal exhibit wash-down can be met by the alternative or non-potable supply.

Staff and visitor numbers were obtained from the Zoo. Daily water usage rates by staff and visitors to tourist attractions were researched from literature and applied to the Zoo and applied to the non-potable demand Equation 1.

$$Non\,potable\,demand\; = Potable\,supply - \begin{pmatrix} number\;of\;staff\;\times\;Lstaff^{-1} \\ +number\;of\;volunteers\;\times\;Lstaff^{-1} \\ +number\;of\;visitors\;\times\;Lvisitor^{-1} \\ +\;allowance\;for\;animal\;consumption \end{pmatrix} \tag{1}$$

Irrigation consumption was determined based on sprinkler head flow rates applied to weekly logs of sprinkler use at various sites around the Zoo. Determining a method to estimate manual sprinkler and hand watering proved difficult so no assessment was made. Meters were fixed to wash-down hoses and data collected for a number of the key wash-down sites.

3.2 WATER SUPPLY (RUNOFF)

3.2.1 SUB-CATCHMENT DELINEATION AND DESCRIPTION

The Auckland Zoo catchment was divided up into sub-catchments by delineation using DXF contour maps obtained from the Auckland Council GIS database (Auckland Council, 2014). The catchments were divided into pervious and impervious based on the GIS layers available and licenced from Auckland Council. Pervious consisted of grassed, bare yard, garden, or bush. Impervious consisted of asphalt or concrete and building roof area. The underlying soil classification was considered B for catchments west of Motions creek and C for eastern side of Motions Creek based on a Geological and Nuclear Science (GNS) map (1992).

3.2.2 RAINFALL RUNOFF

Rainfall data for the previous five years (2009-2014) were extracted from NIWA's Cliflo online database (NIWA, 2014) (weather station: Auckland, Mangere Ews 22719 C64972). The data were scanned for missing inputs and where necessary substitutes made by extrapolation between readings. Daily readings in mm per day were used and corresponding sunshine hours and evaporation data extracted at the same time for later analysis. By extracting daily rainfall, the infiltration component is relevant, whereas if a lumped month approach was used it would be difficult to determine the proportion infiltrated. I.e. a large discrete storm would produce greater runoff than an equivalent depth of rain over a long period of time.

Infiltration rates were considered to be 5 mm for pervious and 0 mm for impervious surfaces. Where impervious surfaces were integrated into pervious, but were not connected by pipe network, a lumped average infiltration rate was calculated as per the TP108 methodology (Auckland Regional Council, 1999), which is based on the SCS methodology.

The Cliflo rainfall data was applied to the TP108 modelled data for all 10 sub-catchments on a continuous but daily 'event' basis for the duration of the data period. The daily runoff volumes were then summed to give monthly runoff volumes.

3.3 MATCHING DEMAND WITH SUPPLY

The annual demand for non-potable water, having been derived from the methods outlined in 3.1.2, was matched to the annual runoff supply as calculated in 3.2.2 to determine if the supply and demand were in the same order of magnitude. Once this was established, a monthly reservoir simulation analysis model was developed in Excel. Equation 2 outlines the reservoir mass balance based on inputs and outputs and calculates the end of month volume stored. The model operates within the confines of the reservoir size, constrained to zero at the lower limit and reservoir capacity for the upper limit.

$$Z_{t+1} = Z_t + Q_t - D_t - \Delta E_t - L_t \qquad (2)$$

$$0 \leq Z_{t+1} \leq C.$$

Where:

Z_t = Reservoir Storage (time in months);
Q_t = Reservoir inflow (runoff);
D_t = Draft (monthly demand);
ΔE_t = Net evaporation loss;
L_t = Other losses;
C = Active storage capacity.

3.3.1 RESERVOIR SIZING

Rain water is currently stored and treated in the Zoo's central lake. The lake was measured using GIS and the volume determined by estimating depth. Additional storage would need to be met by proprietary tanks and was determined using the reservoir simulation model (Equation 2). Reservoir sizes were serially input into the model and the temporal and volumetric reliability calculated based on the number of months the desired draft was achieved and the required volume versus the target volume according to Equation 3.

$$R_v = \sum \frac{Actual\ Supply}{Target\ draft} \tag{3}$$

Where:

R_v = Volumetric Reliability.

The reservoir size was optimised taking into account the practicalities of reservoir size, spill (overflow), and the risk of failure. Where the required demand draft was not met for a particular month, the deficit would be met by potable mains water. The reservoir was assumed to be empty at the start of the sample period, simulating a worst-case scenario.

3.4 QUALITATIVE ASSESSMENT

3.4.1 QUALITY REQUIRED

Quality indicators and the scope for re-use of stormwater were discussed with Auckland Zoo's animal husbandry, horticulture, and veterinary teams to ascertain the qualitative requirements for end-users around the site. It is assumed that water will be used for gardens, ponds, aquaria, water features, and for exhibit wash-down. As such, water quality standards were researched in the literature for; horticulture, livestock, drinking water, bathing, and for aquatic ecosystems.

Parameters of interest that are vehicle-derived and are toxic to wildlife are: heavy metals (Fassman, 2012, Feng et al., 2012, Roinas et al., 2014) and petroleum hydrocarbons (LeFevre et al., 2012). These parameters are of most concern at the visitor carpark and to a lesser extent service roads within the zoo.

Parameters affecting the design of filtration and reticulation are: total suspended solids (TSS) and biological oxygen demand (BOD) (a measure of organic load), which affects fouling and filtration design, reticulation, irrigation nozzles blockages and deposition in pipes resulting in anoxic processes in pipework leading to odour issues.

Lastly nitrogen and the pathogens *E.coli* and coliforms are likely to be found in runoff of animal origin and are of concern to animal and human health alike. These pollutants are likely to be found in runoff from exhibits.

Stormwater treatment through LID treatment devices is the first line of filtration and would be used where practical however a second tier of filtration at the storage and distribution site would provide additional polish. Recirculating sand filtration has proved successful for the Zoo and is necessary prior to sterilization so fit as the second tier filter.

3.4.2 ESTIMATED STORMWATER QUALITY

Quality of stormwater runoff is difficult to assess in a study of this duration and scale. A literature search was carried out to identify the probable levels of a number of common stormwater contaminants of concern to the Zoo in lieu of a comprehensive testing regime. Values of stormwater quality prior to passing through treatment device and post treatment devices were mined from the literature to determine if low impact design (LID) stormwater filtration would be suitable. Ponds, swales, and raingardens were investigated to identify the best practicable option.

3.4.3 SAMPLED WATER QUALITY

The literature reviews was complemented by grab samples taken from Auckland Zoo's stormwater lake, a location downstream of this lake (the alligator pond) and from pre- and post-an existing non-potable filtration system at the Te Wao Nui exhibit constructed in 2011. These grab samples would provide a better understanding of Zoo-specific parameters because they represent stormwater that has come from animal exhibits or surface water that has been treated in a similar manner to the recirculating sand (second tier) filter design proposed in this work.

The lake is located at the outlet point of sub-catchments B and C (Figure 5). The alligator pond is located in catchment E and the Te Wao Nui filtration system is located at sub-catchment G. Samples were taken by Auckland Zoo and delivered to Watercare Services Ltd for analysis of BOD_5, TSS, nitrogen (TN), *E.coli* and coliforms. Testing methods were to Watercare standard and are outlined in Table 4. The quality of existing surface water sources, filtered water and literature data were compared with ANZECC quality standards (ANZECC and ARMCANZ, 2000).

4 RESULTS AND DISCUSSION

4.1 DEMAND

For the period from August 2010 to March 2014, potable, or municipal water, had a demand of between 156,000 $Lday^{-1}$ and 540,000 $Lday^{-1}$, with a mean usage of 309,000 $Lday^{-1}$. Auckland uses up to 425,000,000 $Lday^{-1}$ (Watercare Services Ltd., 2011). Clear seasonal trends (figure 2) are evident with peak usage in late summer, presumably the result of irrigation and increased evaporative losses from the ponds and moats required for containment of animals.

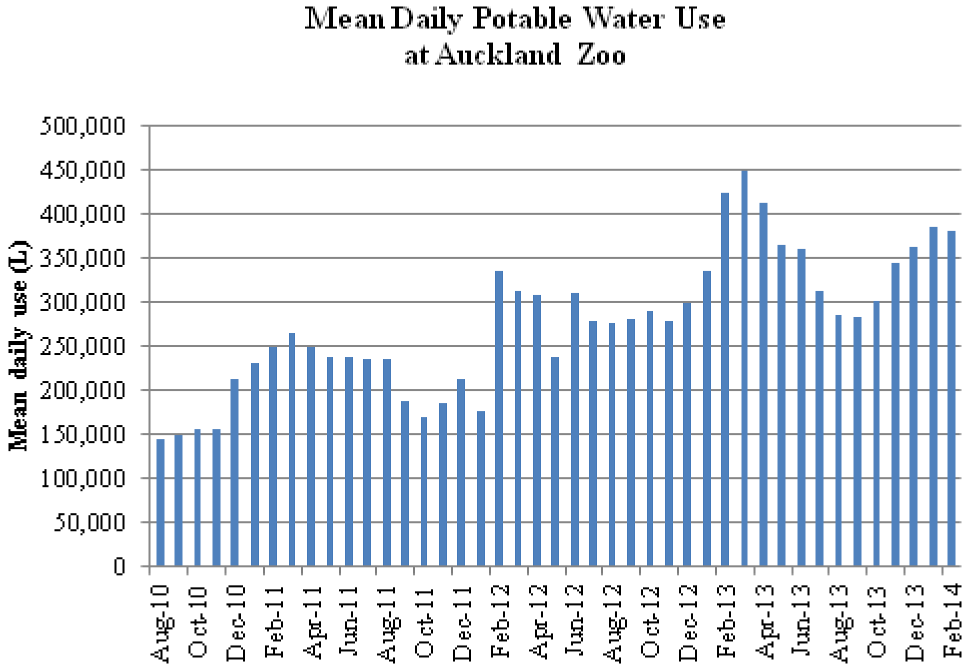

Figure 2: Water usage in average litres per day.

Also evident is a distinct upward trend in usage. Whilst 2013 and 2014 were uncharacteristically dry summers for Auckland, this upward trend is also evident in winter, and thus is driven by some variable other than weather alone. Visitor numbers increase over the study period, however, the direct impact of visitors on this volume of water is unlikely. Visitors to tourist attractions are reported to use around 40 Lday^{-1} each (Auckland Regional Council, 2004), which could account for a difference of only 50,000 Lday^{-1} between the least visited month and the most visited month in the record length. However, while the visitors may not directly use the unaccounted for water, it is reasonable to suggest that increased visitors leads to a more rigorous cleaning regime, which could account for the difference. Construction of new exhibits may be a factor in increased water consumption; however, the development that is of most significance in the study period is the Te Wao Nui exhibit, which for the most part derives its water from consented surface take from Western Springs so is unlikely to be the culprit. This Te Wao Nui water system is the site for water sampling and provides the basis for future secondary stormwater filtration design.

Whilst unseasonably dry summers and a customer driven focus may be primary drivers in this increase in water usage, the prospect of losses to ground are possible. Notwithstanding the above, whether or not the need to increase water usage is a real or perceived need, according to the Zoo, there is an opportunity to rationalise water use on the premises.

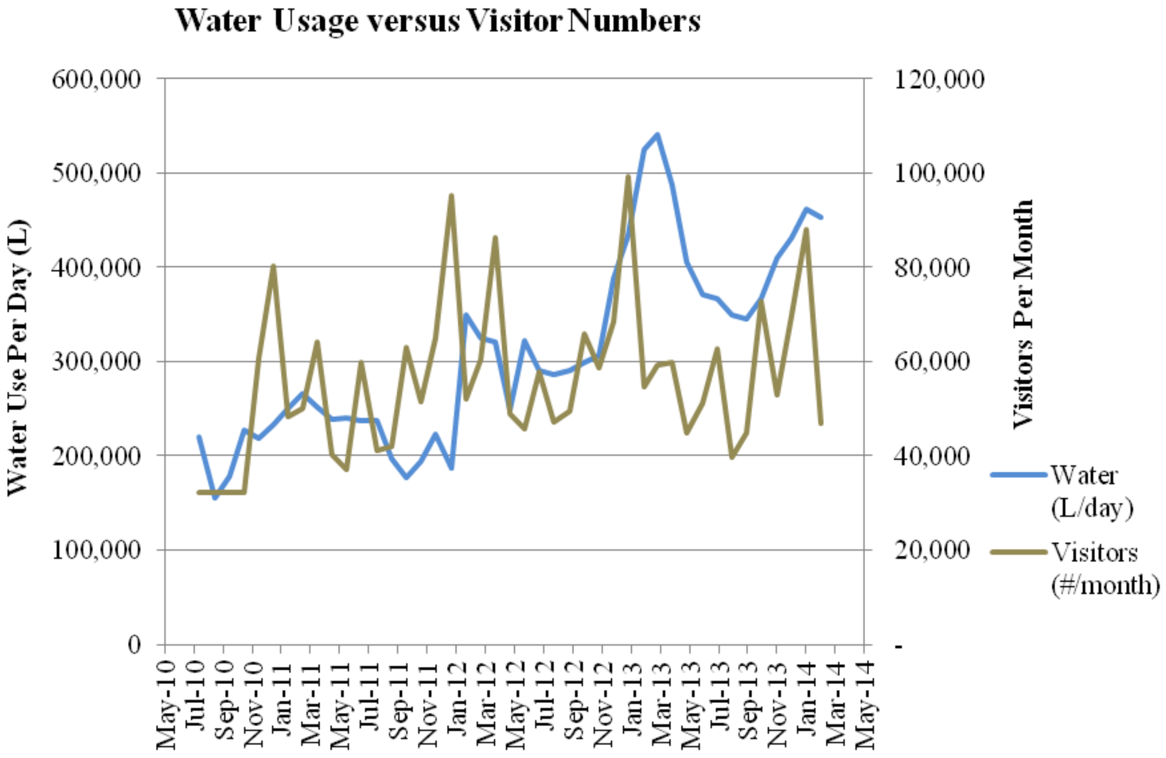

Figure 3: Water usage (in blue) compared with visitation numbers (Green).

4.1.1 END USE

Staff water use was set at 60 Lperson^{-1}day^{-1} while visitor water usage was set at 40 Lperson^{-1}day^{-1} (Auckland Regional Council, 2004). A budget allowance of 50,000 Lday^{-1} was factored into the potable quality demand for use in exhibits where direct ingestion or other health concerns might prohibit the use of non-potable water around animals. The sum of these three was determined to be the potable demand. The remainder on the other side of the threshold assumed to be non-potable as per equation 1. Figure 4 illustrates the proportional demand of potable versus non potable end use. While the split was determined to be near to 50% in 2010, the non-potable demand has increased resulting in a two thirds:one third split between non-potable and potable respectively. A slight increase in potable usage can be seen over the period and is the result of visitor number increase as determined by equation 1.

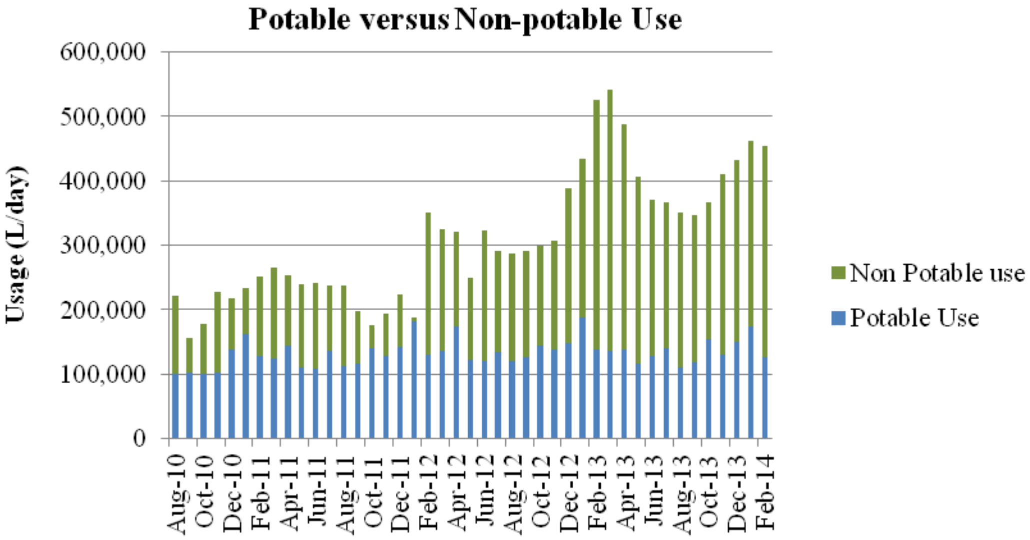

Figure 4: Monthly water usage calculated split between potable and non-potable.

Determining the volume of water used in wash-down and for irrigation was largely unsuccessful for this study. With respect to keeper wash-down, data was logged and on a given day there was up to 28,067 L used for hose-down; however, with no repetition to the data logging, nothing could be derived from the spot sample, other than usage as a rough order of magnitude. It is also possible that because data were being collected, the activity could be moderated either consciously or subconsciously by staff.

Likewise with irrigation, the sprinkler programming system was assessed on a one-off basis and a rate of only 21,676 Lmonth^{-1} was noted. This data was collected late in the irrigation season and is not representative of the irrigation quota. Furthermore, much of the irrigation around the Zoo is done by hand or using mobile sprinkler units that do not have programme functions and is, therefore, not easy to quantify.

Further work is required to identify where the large volume of water is actually going. This study highlights the importance of a well-designed reticulation network that can be monitored adequately and accurately for auditing purposes.

4.2 SUPPLY (STORMWATER RUNOFF)

4.2.1 CATCHMENTS

The Zoo site was divided into 10 sub-catchments ranging in size from 1.05 ha to 3.62 ha as shown in Figure 5. Table 1 outlines a summary of the TP108 (Auckland Regional Council, 1999) parameters for each sub-catchment.

Table 1: Summary of sub-catchment TP108 design characteristics (Curve number, impervious = 98).

Auckland Zoo sub-catchments						
	Name	**Size (ha)**	**Pervious (ha)**	**Impervious (ha)**	**Soil class**	**Curve # (Pervious)**
A	Carpark	1.48	0.888	0.592	B	64.67
B	Africa	3.62	2.353	1.267	B	72.62
C	Tigers	1.05	0.42	0.630	B	68.00
D	Australia	1.08	0.81	0.270	B	61.87
E	Lower Lake	1.06	0.795	0.265	B	60.27
F	Hippos	1.52	1.064	0.456	B	65.36
G	Elephants	1.43	1.001	0.429	B	69.50
H	Rainforest	2.47	1.927	0.543	C	71.08
I	Aviary Bush	1.95	1.560	0.390	C	70.33
J	Southern High Country	1.35	1.175	0.176	C	74.55

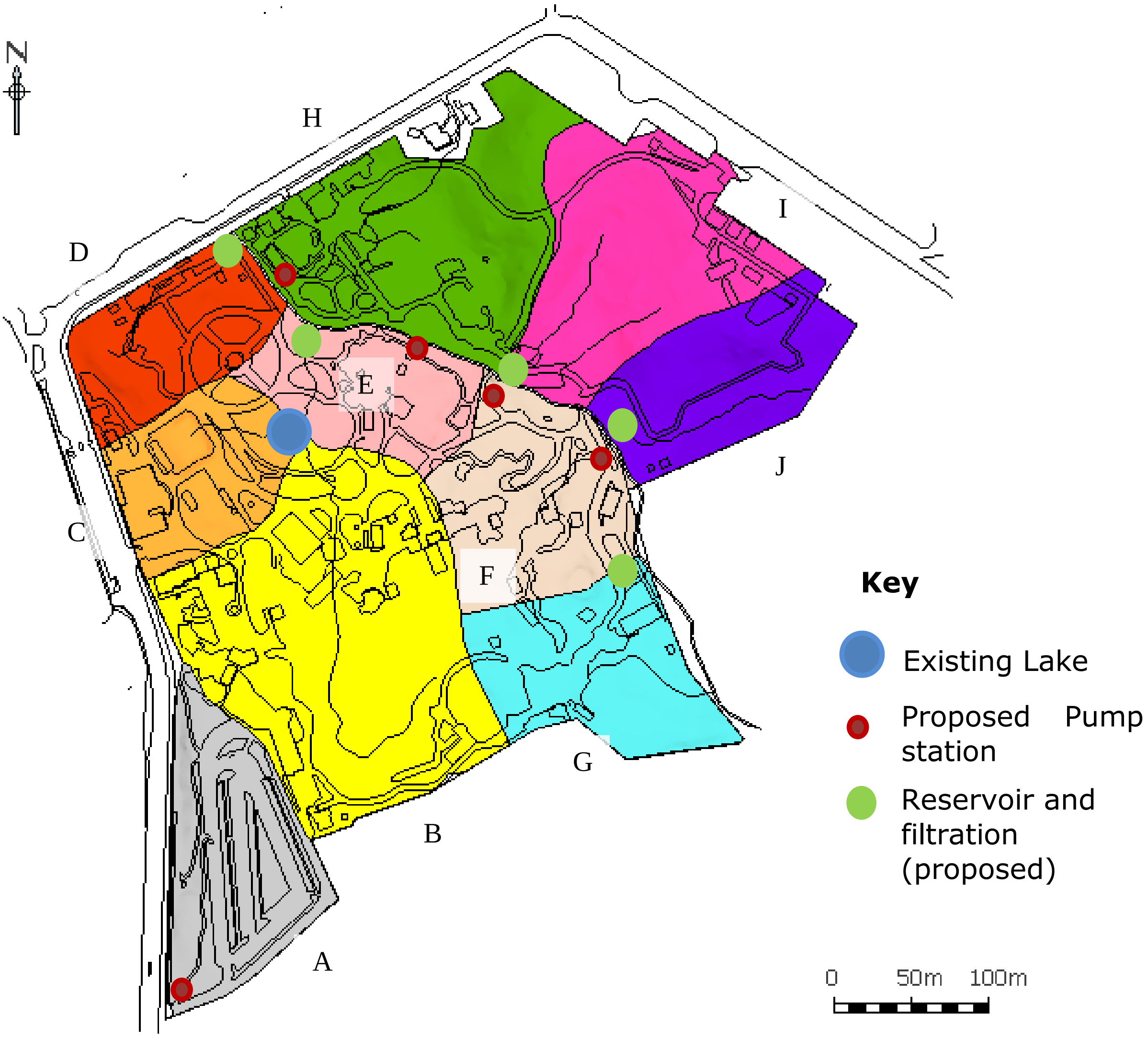

Figure 5: Auckland Zoo showing delineated sub-catchments. A-Carpark (grey), B-Africa (yellow), C-Tigers (orange), D-Australia (red), E-Lower Lake (pale pink), F-Orangutans (beige), G-Elephants (sky blue), H-Rainforest (green), I-Native Aviary (bright pink) and J-Southern High Country (purple.

4.2.2 RAINFALL RUNOFF

Rainfall in the study period (according to the Cliflo database measured at the Mangere Weather Station (NIWA, 2014)), was 1.62m, 1.02m and 1.15m for 2011, 2012, and 2013 respectively. While 2011 was a wet year, the latter two were drier than the mean Auckland rainfall of 1.27 m, as reported by Mahmood (2007). This rainfall translated to runoff volumes (from all of the sub-catchments) of 86,000 m^3, 45,000 m^3, and 56,000 m^3 for the same periods. The greatest portion of runoff came from the Africa sub-catchment contributing 25% of the runoff. Figure 6 outlines the percentage contribution of the 10 sub-catchments.

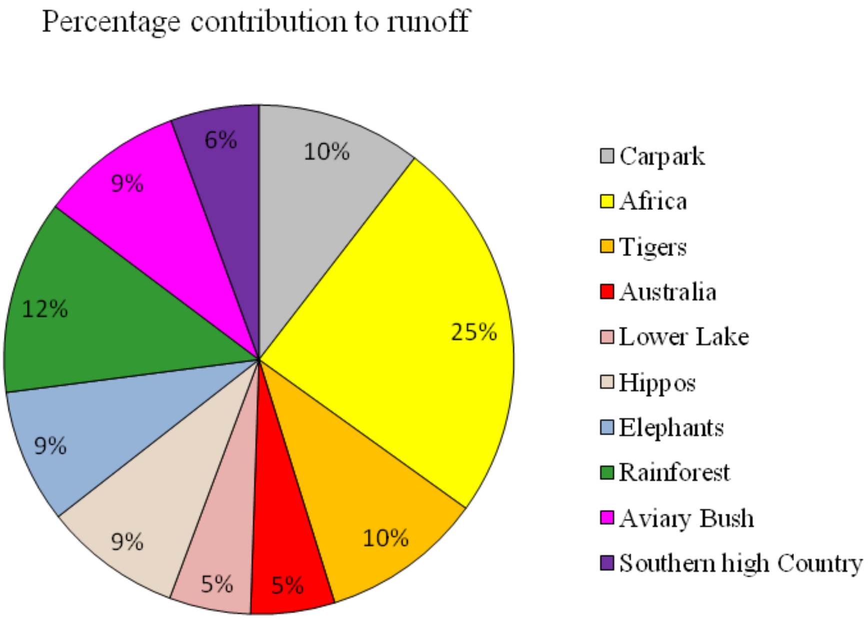

Figure 6: Contribution from sub-catchments to the total runoff volume.

The practicalities of collecting all of the runoff from all of the catchments on a developed site are not fully addressed, and in reality, only a portion of the runoff could possibly be intercepted. Nevertheless, for the purpose of this work it was assumed that all the runoff could be caught and transferred to storage. In an attempt to practically achieve this level of collection, and in lieu of storage at the design point for every watershed, pump stations would need to be designated at the design outfalls. The most immediate and practical areas that can be harvested with little or no infrastructure modification are the sub-catchments: Africa, Tigers, and the Lower Lake, which combined, contribute around 40% of the total runoff. These sub-catchments currently feed into the storage lake that is used to settle out suspended solids derived from the African plains area. This would be the most practical place to initiate a stormwater re-use scheme.

4.3 MATCHING NON-POTABLE DEMAND AND SUPPLY

Over the full period of this study (August 2010 – February 2014 inclusive), non-potable demand volume is matched well with runoff supply, being 230,000m^3 and 210,000m^3 respectively; a 20,000 m^3 or 10% deficit. A deficit when designing a supply and demand model with only one source of water would be problematic, but in this work, if stormwater does not meet the supply, then the municipal supply is available for backup so this deficit is not seen as a major concern. Except that infrastructure is not being utilised so in effect becomes a costly white elephant while not in use.

When looked at closer, it can be seen that supply meets demand early in the study period, but as demand increases over time, a corresponding decrease in supply is observed due to drier than average years. The observed mismatch becomes more evident over the study period as indicated by Figure 7 which shows the annual volumes to date. Note that 'annual-to-date' measures are of value in this work and are used extensively because they remove seasonal periodicity and thus underlying trends can be observed more clearly.

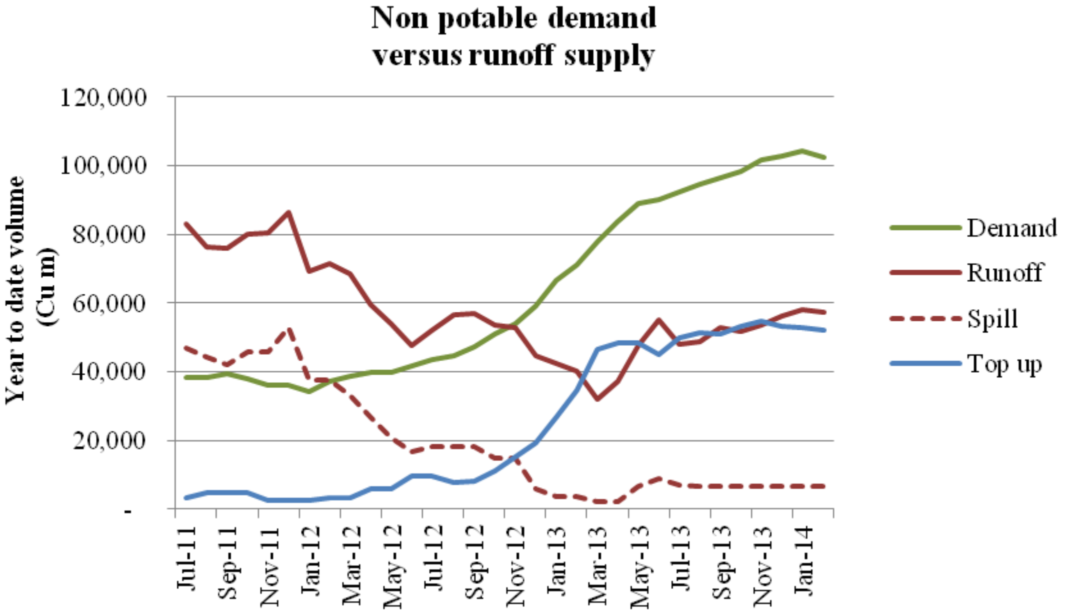

Figure 7: Demand for non-potable water versus supply from runoff, top up from potable system and spill. 12 months 'year-to-date'. Based on a reservoir volume of 1,276,000 L.

4.3.1 RESERVOIR STORAGE

In order to meet the daily demands when supply is intermittent, the reservoir provides buffer storage between runoff events. Achieving reservoir reliability was problematic in this work due to the massive shift in ratio between demand and supply part way through the study period and because of the variable nature of demand and supply at the Zoo. This meant that an excessively large reservoir is required in an attempt to prevent spill and provide the capacity to carry the winter surplus through into the drier seasons. That being said, with successive dry periods and increased demand even a very large reservoir of 15 million L does not produce the required security of supply to extend beyond a dry season, as can be seen in the behaviour diagram in Figure 8. I.e. if demand exceeds supply then no amount of storage will suffice.

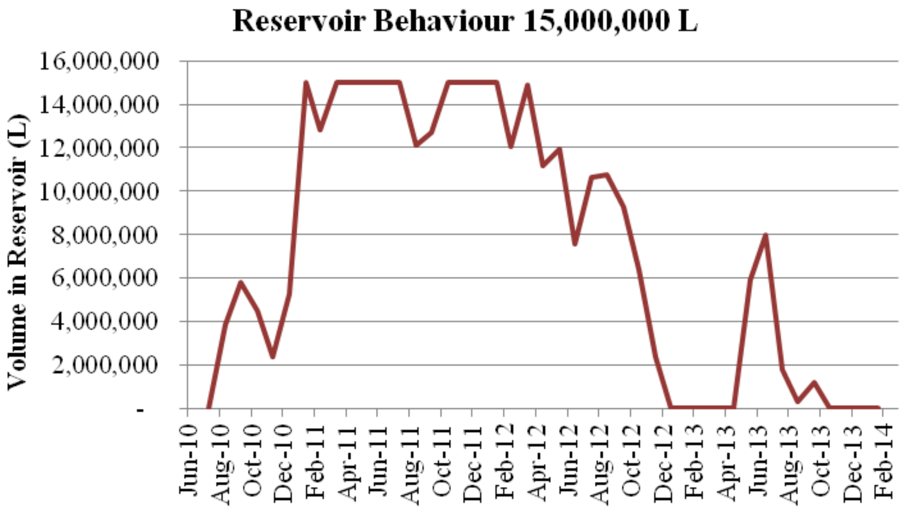

Figure 8: Behaviour diagram for 15 million litres of storage.

The practicalities and cost of a 15 ML reservoir are prohibitive and so a more modest 600,000 L tank supply plus the existing lake volume of 676,000 L was deemed to be the most practical. A total reservoir volume of approximately 1.2 million litres was arrived at and is shown in the behaviour diagram of Figure 9. This size reservoir results in a 49% temporal reliability and 60% volumetric reliability. Increasing the reservoir volume above this size only achieves incremental advantage in reservoir reliability. If demand consistently outstrips supply the reservoir is of little use other than short term storage.

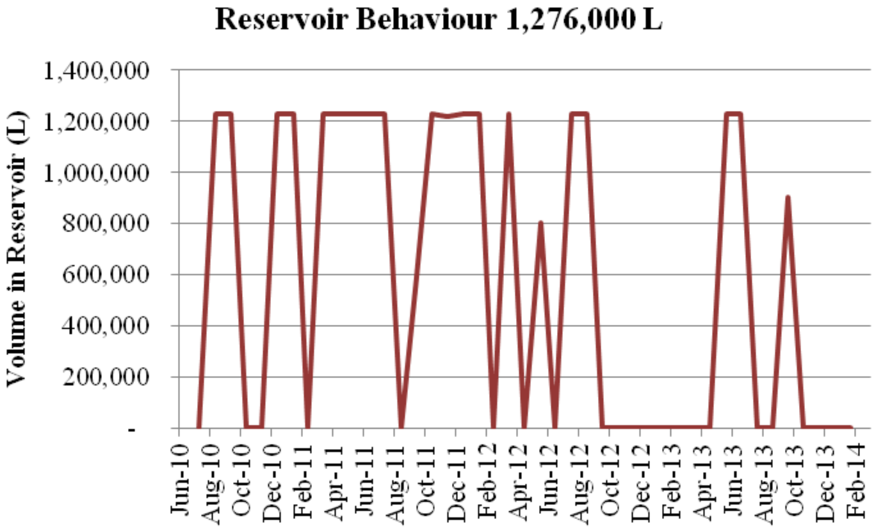

Figure 9: Behaviour diagram for 1.276 million litres of storage.

At twice this size, (2.6 million L), the reliability increases to 56% and 64% (Figure 10) for temporal and volumetric reliability, respectively, and is not sufficient to justify the extra expenditure and space, hence why the smaller size was settled upon.

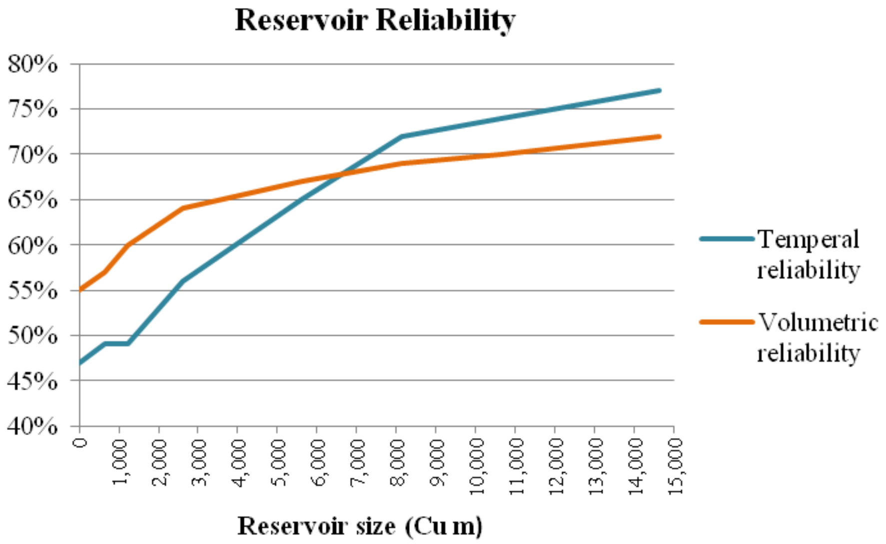

Figure 10: Temporal and volumetric reliability of reservoirs at differing capacities.

The 600,000 L tank storage would be divided into smaller proprietary tanks, giving a decentralised storage approach. In the short term, locating proprietary tanks on a heavily established site is considerably easier than bulk earthworks required for a dam or pond.

At this size the reservoir essentially becomes a mechanism to carry water between rainfall events rather than a means to get through dry years or even dry summers. Because of this small reservoir size, there is often an excess of runoff water in larger storms and, as such, water is regularly spilt and permanently lost from the balance. This inefficiency erodes the potential for rainfall runoff to fully match the demand even in years where supply and demand appear to be well matched. The exception to this is in the last portion of the study period, where demand consistently exceeded runoff and water is used almost immediately after it is captured 'hand to mouth'. In this instance there is no chance for spillage.

The use of reservoir model data has limitations in this study, and the results should be considered as indicative. By lumping data into monthly increments, the fact that storm, and thus runoff, events are measured in hours, or days, is lost. For the smaller reservoir sizes this would hide some level of spillage. Further investigation is required in order to optimise reservoir size.

Evaporation was applied to the reservoir model firstly at a blanket rate of 3 mm per day and then at the Cliflo data rates from Mangere Station. Evaporation over the surface of the lake had no real consequence with approximately 15 m^3 lost per day. As a percentage of the water budget this was not worthy of incorporation into the model.

Overall the water balance is met only in 2011 (Table 2), but when looked at more closely in Figure 7, the tipping point can be identified as late in 2012. Minor adjustments in reservoir size will have little influence on this and even an impossibly large reservoir size would only serve to delay the tipping point rather than avoid it altogether. Because of the dry period and heavy use of water in the latter years of the study period, the model parameters would need to be adjusted to better suit the long-term design of a supply-demand and reservoir model. I.e. the expectation of how much of the non-potable demand can really be met by stormwater should be reevaluated.

Table 2: Annual non-potable water balance for the study period.

Year	Runoff Supply (Million L)	Non-potable Demand (Million L)	Reservoir Spill (Million L)	Potable Top-up (Million L)
2011	86.4	36.2	52.8	2.6
2012	44.7	59.1	6.1	19.1
2013	56.3	102.9	6.8	53.3

Providing a base flow of water to the reservoirs would have a significant influence on the supply and demand dynamic at the Zoo. Motions Creek intersects the Zoo and is the obvious choice for such a baseflow source, however, quality is questionable with its upper reaches serving a densely trafficked urban watershed with reportedly frequent overflow of sewage from an aged combined waste and stormwater system, (Perry, 1998).

4.4 WATER QUALITY

4.4.1 QUALITY REQUIRED

Water quality standards for various end uses at the Zoo based on Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000) and based on Timmons et al. (2002) are summarised in Table 3.

Table 3: Summary of water quality guidelines relevant to Auckland Zoo stormwater recycling (ANZECC and ARMCANZ, 2000).

	Heavy Metals (mgL^{-1})			**Nitrogen (mgL^{-1})**	**TSS (mgL^{-1})**	**Biological (cfu 100mL^{-1})**	
	Cu	**Zn**	**Pb**			***E.coli***	**coliforms**
Irrigation	5	5	5	5 (25-100^{a})			100 (10^{b})
Livestock drinking water	0.4^{c} (5)^{d}	20	0.1	90^{e}	90^{ef}		100
Bathing	1000	5000	50			35	150
Aquatic Ecosystems	1 0.03^{f}	2.5 0.005^{f}	1 0.02^{f}		80^{f}		

a = Long term use, b = Food crops, c = sheep, d=pigs and poultry, e = all expressed as Nitrate-N
f =Timmonset al, (2002).

4.4.2 ESTIMATED STORMWATER QUALITY

Carpark runoff in Christchurch, New Zealand showed event mean concentrations (EMC's) of 16-30 mgL^{-1} for TSS, 7.7-16.8 mgL^{-1} for Cu, 1.9-10.2 mgL^{-1} for Pb and 35-121 mgL^{-1} for Zn (Wicke et al., 2009). With removal efficiencies of 80% (Feng 2012) and up to 90% using stormwater best management practice (BMP) of bioretention cell (Fassman, 2012) these figures are likely to be in the order of 10 mgL^{-1} for Cu, 5 mgL^{-1} for Pb and 66 mgL^{-1} for Zn based on the mean runoff multiplied by the average of the removal efficiencies mentioned previously. It is noteworthy that the New Zealand Centre for Conservation Medicine (NZCCM) has an architectural copper cladding which potentially contributes to the deterioration of stormwater according to Davis et al., (2010) but this roof catchment feeds to the central lake where it is treated. TSS figures are already below the guidelines so the effect of filtration was not considered for this contaminant.

Napthalene concentrations were reduced from inflow 17 μgL^{-1} to EMC of 2 μgL^{-1} (88% removal) in Zhang et al., (2014) and LeFevre (2012) recorded similar removal efficiencies of 93% for this contaminant. Naphthalene is one of the simplest polyaromatic hydrocarbons (PAH's) and is representative of this family of contaminants likely to be discharged to the carpark from vehicles (LeFevre et al., 2012).

The results of heavy metal removal by stormwater BMP device are not sufficient to render carpark water fit for most of the end uses as outlined in Table 3. However, stormwater from the carpark could conceivably and practically be pumped to the central lake where it would achieve dilution with other stormwater runoff, as well as additional treatment train reduction factors. As such, it has been included in the stormwater runoff model but in practice the marginal results, topographical separation of the catchment and stigma attached to vehicle runoff would mean the carpark would not be considered as a practicable source of stormwater. The service roads within the Zoo site are however critical to the water balance due to the expanse and could not be considered for removal. These service roads are generally trafficked by low volumes of service vehicles, which are mainly electric powered and are unlikely to produce contaminants to the same levels as road vehicles. For both the carpark and service roads, the Zoo would need to monitor for spills of oil's to deal with any acute point source loads of contaminants.

4.4.3 SAMPLED WATER QUALITY

Water quality results obtained from the grab samples (Table 4) showed results that met or exceeded the required quality for all but the biological indicators of *E.coli* and coliforms. Water in the lake was especially high for *E.coli* and can be attributed to the high level of runoff coming from the lions and the Africa region where much of the animal faecal matter is defecated in the yards and paddocks as opposed to controlled impervious areas where animal waste is directed to the sanitary sewer.

BOD and TN were manageable and TSS figures were sufficiently low to not warrant filtration, however, given the high biological counts, a sterilisation system was deemed necessary. For UV sterilisation to be effective, solids must be removed to prevent shadowing in the treatment chamber and so a simple sand filter arrangement has been proposed for the satellite treatment systems situated in 5 of the sub-catchments. Filtered water in the Te Wao Nui system show marked reduction factors for all constituents indicating that the filtration design would be appropriate for replication elsewhere at the Zoo to treat stormwater prior to distribution.

Table 4: Summary of water samples taken from Auckland Zoo on 15 April 2014, processed by Watercare Laboratory Services, Auckland and reported on 21 April 2014.

Water Quality Parameter	**Western Springs surface water (gravity line)**	**Filtered Springs surface water (Te Wao Nui)**	**Central Lake (stormwater pond)**	**Post Lake (alligator pond)**
$CBOD_5$ (mgL^{-1})	2.5	<0.5	1.1	1.5
TN (mgL^{-1})	2.6	1.4	0.96	1.6
TSS (mgL^{-1})	7.6	<0.8	3.8	4.4
E. Coli ($cfu100mL^{-1}$)	250	<9.0	>550[1]	>550[1]
Coliforms ($cfu100mL^{-1}$)	280	<9.0	>550[1]	>550[1]

$CBOD_5$ = Biochemical Oxygen Demand APHA (2005) 5210 B
TN = Total Nitrogen (as N) APHA (2012) 4500-P J, 4500-NO3 F (Modified)
TSS = Total Suspended Solids APHA (2012) 2540 D
E. coli = *Esterichia coli* by membrane filtration USEPA Method 1603 (2002)
Coliforms = Total coliforms by membrane filtration SPHA (2012) 9222 B
1= CFU/100mm exceeds Ministry for the Environment and Ministry of Health 'microbiological water quality guidelines for marine and freshwater recreational areas.

5 CONCLUSIONS

Implementing a stormwater re-use scheme is a complicated task and carries many risks for Auckland Zoo. However, the considerable reliance on potable water to carry out tasks that require only lower grade water makes investigation of such a scheme attractive.

Auckland Zoo appears from the outset to be a good candidate for stormwater harvest due to its high proportional use of non-potable versus potable water around the park. The zoos demand for this lesser quality water, whilst having a degree of seasonality, also extends through the winter meaning a dedicated non-potable system would not lie redundant in winter. In summer however potable top up is required.

Analyisng water usage for a non-potable scheme enables a better understanding of water use and can lead to savings even before a re-use scheme is implemented simply because of the scrutiny that a system is put under and the rationalising that goes with this. Establishing where water goes at the Zoo was difficult due to its complicated aged reticulation system and lack of established record taking. As a result, establishing a threshold for classification of non-potable versus potable was in this case an arbitrary one simplified as; general domestic use (plus a nominal volume for high spec animal use), being potable and all the rest being lumped as non-potable. In reality the decision on where to draw this threshold needs to be based on cost of filtration versus volume output.

The demand for non-potable water was determined to be between 50,000 Lday^{-1} and 400,000 Lday^{-1} or 40 million L to 100 million L per annum. Based on the stormwater runoff calculated, supply from all the catchments was from 45 million L to 86 million L per annum. Based on these figures and on the level of increased demand for non- potable water, it is likely that the Zoos sub-catchments combined would not entirely meet this demand. In addition, the practicalities of catching and storing all of the runoff from site would be prohibitive and a closer inspection of what can really be caught needs to be carried out. Impervious piped areas and the upper western catchments that feed the central lake are the obvious starting points for a stormwater harvest scheme with the Africa sub-catchment accounting for a quarter of the total runoff from the Zoo. Harvesting water from the heavily vegetated slopes on the north east and harvesting rainwater from the carpark will be problematic.

Reservoir design was challenging to derive in this study due to the non-stationary demand data set and the extremes of rainfall that fell in the defined study period. Decentralised small tank storage is seen as the only option for increased storage due to the heavily developed site. A baseflow from another source would assist in minimisation of reservoir size.

Water quality from the majority of the Zoo sites is suitable for recycling and re-use with the exception of biological contamination found in the lake, and heavy metals from the heavily traffic areas. Heavy metals from the carpark are of the greatest concern and only treatment that uses a sequential chain approach such as a raingarden followed by a treatment pond, would render it fit for re-use. All re-used water would need to be sterilised to limit the possibility of pathogenic cross contamination between and with species at the Zoo. The Te Wao Nui filtration system suggests that control of this *E.coli* and coliforms is practical and feasible with existing ultra violet (UV) sterilisation technology, albeit costly. In this study it was demonstrated that a nominally light level of stormwater filtration renders the majority of water useful for most of the non-potable purpose however a one size fits all approach is not always appropriate and so additional secondary filtration is also required.

In all, stormwater alone would not provide for the extensive non-potable needs of the zoo. Even with reservoir storage, much of the water that is able to be collected would be re-used in a hand to mouth manner. Basic stormwater device treatment is unlikely to render all the stormwater fit for purpose on its own but with some additional sterilisation or treatment chain approach, stormwater is a viable substitute for municipal water. Matching demand with supply requires a holistic view of quantitative, qualitative, temporal and economic aspects. Creating a stormwater re-use model that captures all of these elements adequately for a site such as the zoo is a difficult task and further investigation is required. Whether the installation of a 'third pipe' reticulation system is economic is for further investigation.

ACKNOWLEDGEMENTS

The author would like to thank Auckland Zoo's staff who provided background and detailed information, Thorburn Consultants (NZ) Ltd for time and resources and Associate Professor Dr Carol Boyle for supervision and guidance.

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