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Detainment Bund hydrology review

Introduction

Clarke (2013) recently completed a MSc study on the use of Detainment Bunds (DBs) to attenuate phosphorus (P) from storm flows. Because storms are extremely variable in nature, specific quantification of the DB catchment water balance was not attained in his study. My study aimed to use historic data along with field measurements to develop a quantification of the storm loads that may be attenuated by DBs. Understanding the volumes that DBs handle in these storm events can progress the development of guidelines for future DB dimensions.

Clarke (2013) focused on three main DBs in separate catchments on the western/ north-western side of the Lake Rotorua catchment. These DBs were subsequently named Waitetī, Awahou and Hauraki, following the sub-catchment names. Each DB had different dimensions, as indicated by DB storage capacity and storage capacity: catchment area ratios (Table 1). By quantifying the volumes of water moving through these structures we can examine how they handle storm events.

Methods

Calculating total runoff from DB catchments was investigated using two methods; water balance and the rational method. The water balance method required field testing of infiltration rates in the DB catchments, and ponding areas. Very low infiltration rates were obtained, likely from the binding of clays when dry and formation of thin impermeable pans within or below the root layer. Other studies that have examined infiltration rates in the Mamaku plateau found highly variable results that could not be applied to the water balance method (MacLeod, *pers comm.* 2014). As a result it was concluded that the rational method would be more applicable to this study.

The Rational method is widely used to calculate peak discharges in urban environments, yet it of practical use for small rural catchments given that land use is relatively homogenous. Instead of using peak discharge I applied a formula based on average discharge according to the method of Christchurch City Council (2011):

Q= 2.78C I A

Where:

Q=Average discharge (L/s)

C=Runoff Coefficient

I= Average Rainfall intensity during storm period (mm/hr)

A=Catchment Area (ha)

Then value of **Q** was multiplied by the storm duration, with a unit's conversion to express the volume (V) with results in m³.

C is influenced by infiltration rate, slope, evapotranspiration, storage, etc.. Runoff coefficients were taken from Mark & Marek (2011) and Queensland Government (2004) and gave a value of 0.50 for Waitetī and Hauraki catchments while Awahou was increased to 0.55 due to its slightly steeper topography.

I was retrieved from monitoring site rainfall data (BOPRC, 2012) whereby a storm event was determined from when the rainfall consistently exceeded 1.5 mm h^{-1}.

A was defined using ArcGIS watershed analysis (see Clarke, 2013).

Results

This study analysed historical hydrological data from BOPRC monitoring and uses Clarke's (2013) data from the sampling period in 2012. Using the rational runoff method (Mark & Marek, 2011; Christchurch City Council, 2011) the total storm volumes were calculated for each DB. The storm runoff volumes from the catchment were compared with the storage capacity of each of the DBs (to the riser) and defined as the storage exceedance, i.e., how many times the storm volume exceeded the DB capacity. Table 1 displays these results and shows that the largest storm in the 2012 sampling period was one named July #2. In this event the Waitetī DB had a storage exceedance of 13.9.The exceedance ratio, in this case, suggests that only 1/14th of the total storm load was held in the DB for the desired 3 days of settling (the last water remaining in the DB. In comparison, the Awahou DB had a larger storage: catchment ratio (157:1; table 1) and the same event produced a storage exceedance of only 6.5 suggesting a larger proportion of the storm load can be treated for the 3 days of desired ponding.

Table 1: Storm volume summaries and ratios against DB storage capacity for storms during sampling period March- September 2012. Qin is the total volume of the storm load that enters the DB over the storm, whilst storage exceedance ratio is how many times Qin exceeds the DB storage capacity.

Storm	**Qin (m^3)**			**Storage exceedance ratio**		
	Waitetī	***Hauraki***	***Awahou***	***Waitetī***	***Hauraki***	***Awahou***
March	21442	16780	7178	4.7	3.1	2.2
May	27484	25833	9201	6.0	3.9	2.8
July #1	39810	31156	13328	8.7	5.7	4.0
July #2	63911	50017	21396	13.9	9.1	6.5
July #3	46302	36236	15501	10.1	6.6	4.7
Sept #1	14812	11592	4959	3.2	2.1	1.5
Sept #2	11221	47585	3757	2.4	1.6	1.1
DB Volume: Catchment area	67	101	157	**DB Spillway storage (m^3)**		
				4589.0	5469.0	3298.0

Discussion

Clearly, large volumes of the water in storm events are not likely to be treated to any great extent assuming that 3 days represents a period of sufficient settling to achieve some degree of treatment. It has been identified in Table 1 that large proportions of water are not being thoroughly treated and instead bypassing the DB. Theoretically, this water would act as plug flow whereby water going in is the same composition as that of the out flowing water, therefore it would be the last water to go into the DB that is treated. This would not be the case in DBs. Instead the water that is treated for the desired time will be a mixture of the overall storm load rather than the last portion of the storm. There is the potential for thermal stratification from changes in incoming water temperature but this is expected to be relatively insignificant but could be a point of future research.

Storm water which rapidly passes through a DB during large rainfall events will still be exposed to some level of treatment as large particles will fall from suspension when the ephemeral stream flow encounters still water in the DB pond and velocity is arrested (Stokes law; Hsu, 2004; Clarke, 2013).Fine particles will remain in suspension and the attenuation of these requires as much ponding time as possible. Fine particles pose a challenge for total P attenuation in DBs, especially given that the ponding time is limited to 3 days (in most cases) as DBs have been constructed on pastoral farmland. Also the size of DBs are restricted to bund wall heights of up to 2.5m unless resource consent is sought for a larger structure.

It is not feasible to store all storm water runoff in DBs as there will always be larger storms which exceed a structure’s storage capacity. The design of DBs should be placed in the context of how many times the idealised 3 days is exceeded in each storm represented as the storage exceedance ratio in these storms. A DB with the storage: catchment ratio of 160:1 treats up to 1/7th of a large storm volume. P in storm loads will certainly not all be captured (Clarke, 2013) and this study reinforces that, apart from initial treatment from entering a stagnant water body, relatively large proportions of the water is leaving the DBs untreated. Maximising V will help to increase the proportion of storm water that is treated for the desirable time.

Further work should quantify total nutrient and sediment loads by setting up auto-samplers and automatic flow gauges on the ephemeral inflow and on the DB outflow. Although this is logistically challenging, it will allow observations of the behaviour of nutrients at high temporal resolution over an entire event. By defining the P attenuation efficiency of different sized DBs then accurate assumptions can be made for the ‘optimal’ DB dimensions. An understanding of the variations in concentrations of nutrients over the storm such as the ‘first flush’ and towards the end of the storm would be very useful. According to this study the ‘first flush’ of ephemeral stream flow will fill the DB but then be mixed and flushed with incoming water, compromising efficiency with which the first flush nutrients are attenuated.

Conclusion

This study suggests that the storage to catchment ratios need to be as high as possible as considerable volumes of water is not being treated to the desired extent. There are potential opportunities: maximise V without going through consent process for > 2.5 m DB, and maybe consider multiple DBs within a catchment. The current ‘fit for purpose’ storage to catchment ‘rule of thumb’ ratio, 120:1 (to the spillway), is going to be compromised considerably by typical storm loads. There is little quantitative data to calculate a specific ‘optimal’ ratio and therefore attaining quantitative data should be the focus of further DB research.

References

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