NZ STANDARD RAIN GARDEN ECONOMICALLY SUSTAINABLE?

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ABSTRACT

One of the key devices in stormwater mitigation is the rain garden, it captures and treats run-off like nature planned it. Additionally rain gardens are aesthetic landscape features in residential and commercial areas. They present lower impacts to the environment and their importance is recognized by national regulations. Other countries have had success in lowering stormwater management costs by using rain gardens.

The document looks in detail at the hydraulic and hydrological parameters of the Auckland Regional Council (ARC) rain garden design (Technical Publication 10). It discusses the critical rain garden design parameters focusing on the coefficient of permeability (k-value) for filter soils and the driving head, therefore the depth above the filter bed. Stormwater run-off has to be captured, treated and assessed for Water Quality Volume (WQV), Extended Detention Volume (EDV) and for Peak flow attenuation volumes. The effectiveness of the rain garden will be discussed comparing WQV plus EDV with the post development 2-year storm peak detention volume.

The paper will explore the potentially significant economical impacts on stormwater projects. Improving the constructability of rain gardens and thereafter treating and capturing stormwater runoff “at source”, which may in turn decrease cost in storage devices further downstream, will be discussed.

KEYWORDS

Rain Garden, Bio Retention, Stormwater Management, Mitigation Device

1 INTRODUCTION

A rain garden captures and treats run-off just like nature planned it which makes it the attractive option for storm water treatment and retention.

During a recent project, with which I was involved, to select catchment wide stormwater mitigation and treatment devices, initial investigations showed that rain gardens designed within current guidelines would not be a feasible option. An analysis of the design parameters for rain gardens indicated several reasons why installation of rain gardens in New Zealand might not go further than the idea.

This paper has been prepared to discuss the economical impact of changing design parameters for a rain garden as a treatment option to make it attractive, efficient and affordable to use as a device in stormwater mitigation. This paper is not intended to consider the requirements for stormwater treatment, but rather to determine the factors that will impact the decision to use a rain garden ahead of other acceptable devices within the TP10 guidelines.

Trying to implement sustainable raingardens into a conceptual design and stumbling over some issues on the way was the incentive of this paper, and initiated the desktop research and hydraulic background study. The paper will explore the design of the raingarden hydraulically, hydrologically and process wise. Also, by way of an example, we will discuss the outcome of some of these guidelines, especially the possibility to treat and store EDV and WQV on site within residential and commercial areas.

2 RAIN GARDEN DESIGN

Rain gardens are small bioretention areas, with engineered soils and vegetation, used for passive filtration. They are designed to treat and manage small volumes of stormwater run-off. The first flush run-off is stored and infiltrated through the soil or evapotranspirated in the vegetated shallow depressions with plating material. The design area requires an overflow weir to allow the larger storm events to pass through the system to the detention areas as part of stormwater management plan. Depending on the soil permeability, an under drain could be installed but if the in-situ soil is suitable rain gardens can simply allowed to recharge ground water. The paper concentrates on the required surface area of a rain garden as a result of the following design parameters:

- Coefficient of permeability
- Live storage capacity
- Driving head

Note that the design area of a rain garden is dependant on permeability of the filter soil, live storage capacity and the driving head available. The area also depends on the amount of WQV for each site.

2.1 ARC DESIGN

The following paragraph provides an overview of the current ARC guideline for designing a rain garden and the parameters that will be discussed in the subsequent sections.

Figure 1 Rain Garden (adapted from TP10, Chapter 7, Figure 7-4)

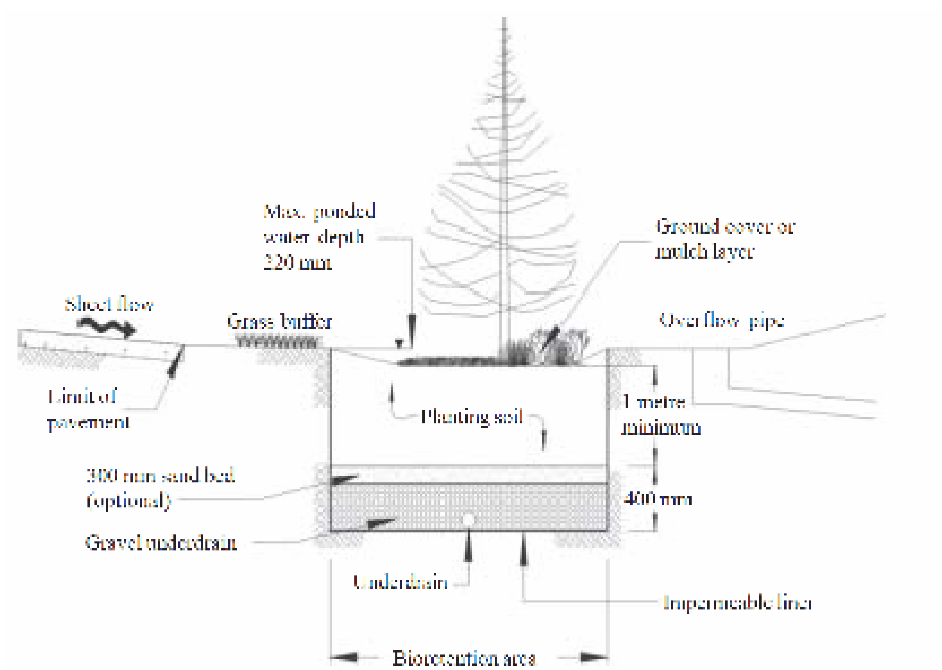


Figure 1 shows a schematic of the main design features of a rain garden. The ARC guideline specifies the following parameters for design:

- The water quality storage volume (WQV) should be one third of the 2 year-24 hour rainfall specified in TP108 for the design location.
- Minimum live storage volume shall be taken as 40% of the WQV to ensure the WQV passes through the filter.
- A maximum depth above filter bed should be 220mm.

The size of the bioretention area is a function of the runoff generated from the drainage catchment, the planting soil depth, the coefficient of permeability, the average height of water above the planting soil. The following equation is given for rain garden area calculation in TP10:

$$A_f = \frac{(WQV)(d_f)}{k(h + d_f)(t_f)} \qquad (1)$$

A_f = surface area (Rain Garden)(m^2)

WQV = treatment volume (m^3)

d_f = planting soil depth (m) - as per guideline 1 meter

k = coefficient of permeability (m/day) – as per guideline a minimum 0.3 m/day

h = average height of water (m) - as per guideline ½ max. depth which is 0.11meters

t_f = time to pass WQV through soil bed - as per guideline - use one day for residential and up to 1.5days for non-residential to be conservative

Chapter 7 of the TP10 guideline explains the design of rain gardens. The TP10 guideline is referenced through out NZ and impacts the selection of treatment devices in LID areas.

The main design parameters from TP10 considered in this paper are:

- minimum of:0.3m/day for coefficient of permeability,
- minimum driving head of 110mm, and
- live storage of 40 %.

The filter depth is 1m that shall ensure treatment of contaminates of the stormwater run-off. For a residential property the water should filter through the soil in 24h or less, commercial lots 36h or less. With a depth of 1m of filter bed and a *k* value of 0.3m/day, it takes a drop of water 3 days to pass through the filter.

2.2 VARIATION OF COEFFICENT OF PERMEABILITY

2.2.1 HYDRAULICS

The calculation of the rain garden area is based on Darcy's law; this equation is based on proportional relation between the flow through a filter medium, area horizontal to flow, pressure change per unit length and the coefficient of permeability. It has to be noted that this equation does not include effectiveness of treatment, but only the time the WQV will need to filter through the soil. This section will discuss the impact of the variation of the permeability coefficient. It also should be noted that the volume of WQ run-off assures that 75% of contaminates will be treated.

$Q = – kA\ (dh/dL)$ (2) Darcy's law

Q = Flow (m^3/s)

k = coefficient of permeability (m/day)

A = Area perpendicular to flow (m^3)

dh = head difference

dL = length of filter

First, a look at the effect of the permeability coefficient considered in terms of hydraulics and how this affects the required area of the rain garden.

Table 1 shows these calculations, based on treating 1m^3 WQV, planting soil depth of 1m, an average height of water above the bed of 0.11m and 1 day (24 hours) for the water to pass through the soil bed.

Table 1: Area of Rain garden required for different values for the coefficient of permeability k based on treatment of 1 m3 WQV:

k Value	Areq	Available live storage (0.11m depth)	% Reduction in Design Area
m/day	m^2	m^3	-
0.3	3.0	0.66	0%
0.4	2.3	0.50	25%
0.5	1.8	0.40	40%
0.6	1.5	0.33	50%
0.7	1.3	0.28	57%
0.8	1.1	0.25	63%
0.9	1.0	0.22	67%
1	0.9	0.20	70%

The table shows that by adjusting the design k value from the minimum of 0.3m/day up to 0.5m/day, 40 % less land is required for the installation of a rain garden. Increasing the k value to 1m/day would mean 70% less area compared to the stated value of 0.3 m/day. This little change could help the councils, developer and land owners to design more attractive and cost effective rain gardens without reducing the effectiveness, still the same amount of WQV will be treated.

It should be noted that in the guideline it does state that 0.3m/day is the minimum required permeability. However in the design phase most engineers would interpret this as a worst case scenario design approach as there is no indication in the example on how the rain garden is affected by varying this value.

2.2.2 LEACH FIELDS

A rain garden is not a new development, there are national and international examples, but we could take a step back and look at the parallels to leach fields used for wastewater disposal. Leach fields are accepted practices for wastewater treatment. Typical hydraulic design permeability is between 0.6-7.2 m/day (10 States Standard). Based on practical experience an engineered soil should be able to achieve in excess of 2.0m per day, and to be conservative, a factor of safety of 2 results in a rate of 1000mm (1.0m) per day. Converting this to an equivalent practice in rain garden design, this would reduce the required area by 70%, refer to Table 1.

If we look at a rate of 0.5m per day a reduction of rain garden area of 40 % is achievable. When considered against a standard leach field design parameter of 2.0m per day, a security factor of 4 is achieved.

It should be noted that the minimum of 0.6m/day for a leach field is set in order to achieve adequate water quality treatment.

The following section will discuss the consideration that the driving factor for rain garden design will be the live storage volume at a permeability coefficient k equal to 0.5m/s.

2.3 LIVE STORAGE

Section 2.2 discussed the hydraulics and the design influence of the k value. It becomes apparent that varying the *k* value can reduce the required rain garden area, therefore potentially reducing costs of excavation and engineered soil fill, making it a more cost effective solution for stormwater treatment.

ARC TP10, Chapter 7 recommends that a live storage of 40% WQV should be provided above the planting soil. Applying the maximum allowable depth of 0.22m would mean a surface area of 1.81m2 is necessary to store 0.4m3 for WQV of 1m3, equivalent to the area required for a permeability coefficient k equal to 0.5m/day, refer to Table 1. If the designer considers a *k* value greater than 0.5m/day, the live storage then becomes the driving factor for the rain garden design.

Therefore here it should be discussed if the minimum value of 40% is necessary to ensure that the WQV passes through the filter. Especially if the k value is higher the live storage value might be able to be reduced if it can be assured that the WQV can be filtered through the soil at the higher flow rate. This paper does not look further into this detail. However, the following section considers the change of the driving head and the maximum depth above the soil bed.

2.3.1 DRIVING HEAD

The average driving head is set as half of the maximum depth. Varying this value does not affect the required raingarden area significantly but would influence the total live storage, as found in the North Shore City guidelines as well as "Facility for Advancing Water Biofiltration, Monash University "(FAWB) guidelines in temperate regions. Up to 300mm head is acceptable in bioretention areas. That would increase the driving head to 150mm

Table 2: Area of Rain garden required for different values for the coefficient of permeability k based on treatment of 1 m3 WQV and an increased maximum head of 300mm and driving head of 150mm:

k Value m/day	Areq m^2	Available live storage (0.15m depth) m^3	% Reduction in Design Area -
0.3	2.9	0.87	3%
0.4	2.2	0.65	28%
0.5	1.7	0.52	42%
0.6	1.4	0.43	52%
0.65	1.3	0.40	55%
0.7	1.2	0.37	59%
0.8	1.1	0.33	64%
0.9	1.0	0.29	68%
1	0.9	0.26	71%

Table 2 indicates that by increasing the driving head from 0.11m to 0.15m the required rain garden area could be reduced by 55%.

2.4 FILTER DEPTH

Filter depth is the main parameter to assure the water has enough exposure to the filter medium for adequate treatment can take place. This parameter could be investigated further but would depend on contaminant loading and specific treatment parameters. This paper does not look further into this.

3 CREDITS FOR DETENTION

The current stormwater management guideline considers three areas: water quality treatment, extended detention and 2 year and 10 year storm peak post development detention.
The guideline suggests that the treatment of one third of a 2 year 24 hour storm event has to be treated as WQV. The basis of this is that with this volume it has been proven that 75% of total suspended solids will be removed on a long term average basis.
For the Auckland region a daily rainfall map can be found in TP108, Figure A1. For the 2 year 24hour storm event, a rainfall depth between 50mm to 130mm is expected. The following calculation will consider a rainfall depth of 80mm and 130mm, to use the maximum rainfall in the Auckland Region and a medium rainfall depth. These values will be used to calculate the required rain garden area under different scenarios, for example lots with 80 to 90% impervious area.

This example is a desktop study only and is intended to highlight the effect of the different area reductions resulting from the variation of factors described in section 2.
The example also discusses the different run-off volumes for WQV depending on the 2 year 24 hour storm event and the EDV. The first 34.5mm of a rain event has to be stored and released over a 24 hour period to prevent erosion in the downstream catchment.
When designing a wet pond as a suitable stormwater treatment option, the WQV and EDV are considered separately and there is a credit of ½ WQV if EDV storage is provided.
Does this apply to mitigation and treatment of EDV and WQV at the "source", for example with a rain garden?
A pond design WQV will mainly be treated by settling, and to a lesser extent by infiltration. Also the routing to the pond will require different consideration than for storage and treatment at "source".

3.1 RAIN EVENTS

For the purpose of modelling the volumes discussed above, four events were looked at for the 80mm and 130mm rainfall depths:

- WQ Event (one third of 2 year 24 hour storm)
- ED Event (34.5mm)
- 2 year 24 hour event (pre and post development)
- WQ + ED Event (for graphical presentation)

Figure 2 and 3 show the rain events, with profile from TP108, for 80mm and 130mm respectively.

Figure 2: Rain events for WQV and ED Volume modeling 80mm

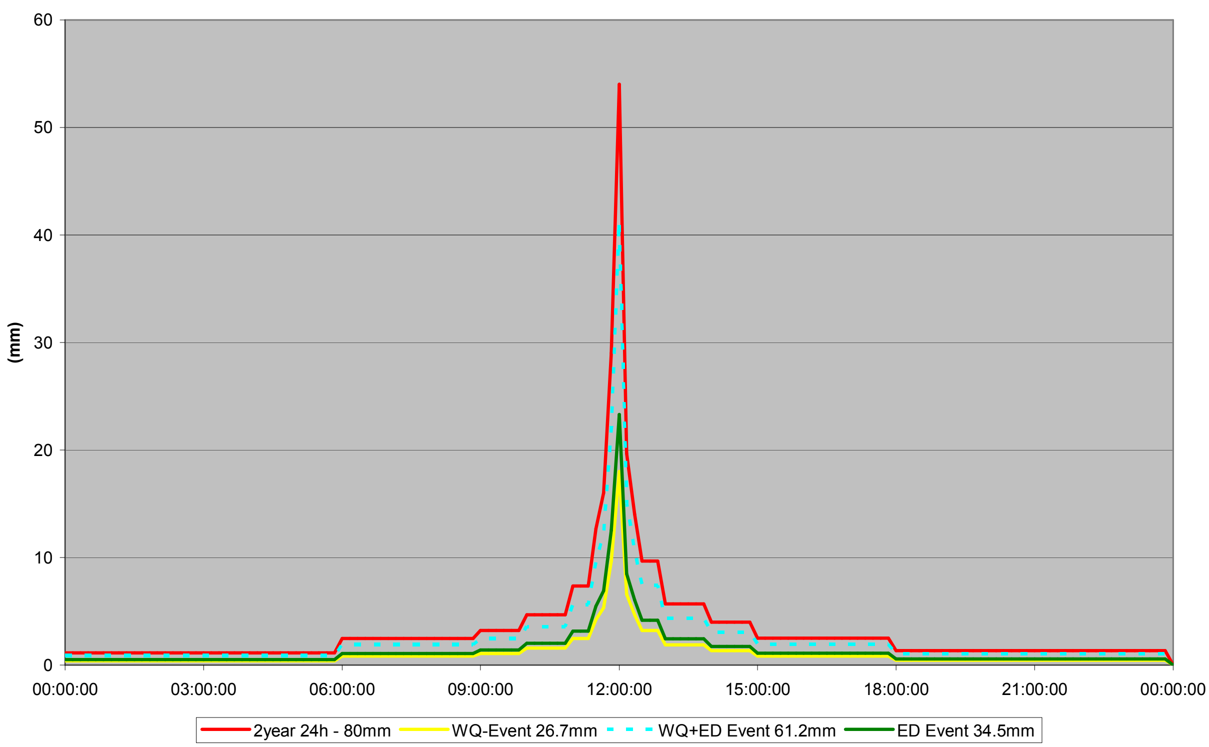
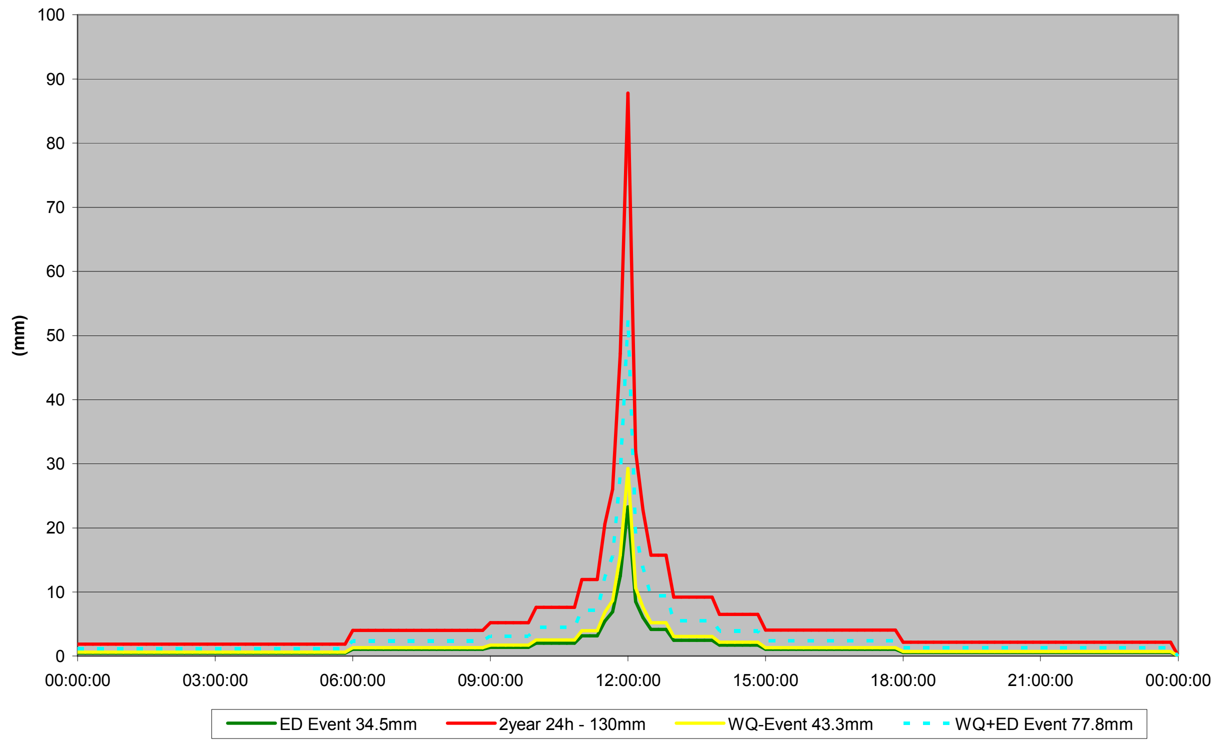


Figure 2: Rain events for WQV and detention Volume modeling 130mm



Depending on the depth of the 2 year event, the WQ event could be larger or smaller than the ED event. The ED plus WQ event has been included to visualise that by adding these two events for the 80mm rain event the volume underneath the graph is nearly as much as the 2 year 24 hour rain event itself.

It shows that the two events WQ and ED are very similar where ED is constant. Why are the two events and the run-off considered separately? The WQV is to assure that the water will be treated but not necessarily stored and the EDV only needs be detained and released and without treatment. Designing a stormwater pond with no upstream treatment or storage of WQV or EDV in the contributing catchments, the volume in the pond must include the WQV plus ½ EDV. We want to assure both treatment with the WQV and storage with ½ EDV . Let's assess the actual volumes in the next section.

3.2 WQV AND EDV

When designing storage for EDV and WQV in a wet pond you only can take a credit of ½ the EDV. As mentioned in earlier sections the WQV is for treating contaminants and EDV for erosion control. Both are actually most concerned about the first part of a rain event.

The preference of LID is to treat and store WQV and EDV at "source", directly at new residential or commercial lots. When considering a wet pond there are numerous risk factors associated with the stormwater getting to the pond before being appropriately stored and treated.

Let's take a step back; we want to treat the WQV and we need to store EDV. If we store the WQV in the process of treating it (such as in a rain garden design) we should get 100% credit of the EDV since the WQV is not generally required to be stored, and vice versa. This theory assumes that the upstream catchment sites in question all have installed rain gardens or similar treatment device.

As seen in Figure 2 and 3, the WQV can be lower or higher than the EDV, therefore we have to make sure that when designing a rain garden, the greater volume will be used to assure that water is treated and stored and not double counted., This has the potential to make the rain gardens about 1/3 smaller. Additionally the "at source" EDV storage and WQV treatment has the advantage that the pond design for the 2 year rain event and 10 year rain event could be dry ponds with lower volumes and could therefore have multiple uses.

3.2.1 EXAMPLE – 1000M^2 SITE

This section has been prepared to provide a simple example of the implications of design parameters on a residential and commercial lot. The commercial lot is assumed to be 90% impervious and the residential lot 80% impervious. Both examples will look at the volumes occurring on site with both the 80 mm and 130 mm 2year 24 hour events.

The CN for the pre-developed lot was assumed to be 74, the lot was assumed to be 50m long (catchment length) by 20m wide with an average slope of 5%. Refer to Table 3 for an overview of the input parameters. These lots are fictive for an installation of a rain garden and a thorough investigation of the terrain and other boundary conditions would be required prior to design. These examples have been prepared to visualize potential impact of changing the credits between EDV and WQV.

- Scenario 1 Residential 80% Impervious 2year 24h rain depth 80mm
- Scenario 2 Residential 80% Impervious 2year 24h rain depth 130mm
- Scenario 3 Commercial 90% Impervious 2year 24h rain depth 80mm
- Scenario 4 Commercial 90% Impervious 2year 24h rain depth 130mm

Table 3: Set up for modeling of example lots

Scenario	1	2	3	4
Catchment Details	***Residential***		***Commercial***	
Total Area (m^2)	1000.00	1000.00	1000.00	1000.00
Imperviousness (%)	80%	80%	90%	90%
Impervious Area (m^2)	800	800.00	900	900.00
Pervious Area (m^2)	200	200.00	100	100.00
Catchment Length (km)	0.05	0.05	0.05	0.05
Catchment slope	0.05	0.0500	0.05	0.0500
Rainfall				
ED depth (mm)	34.5	34.5	34.5	34.5
2yrs rainfall depth (mm)	80	130	80	130
WQ rainfall depth (mm)	26.7	43.3	26.7	43.3
ED+WQ (mm)	61.2	77.8	61.2	77.8
Pre-Developed details				
CN pre-developed	74	74	74	74
Post-Developed details				
CN pervious	74	74	74	74
CN impervious	98	98	98	98

Table 4 presents the run-off volumes modeled for the different scenarios. Since the ED event is constant and not dependant on the location of the investigation and therefore on the specific rainfall depth, WQV is lower than EDV up to a 2 year 24 hour event of 103.5mm. The WQV is greater than EDV for rainfall events over 103.5mm in this example.

Table 4 Modeled volumes for the different Scenarios

Scenario	***1***	***2***	***3***	***4***
RESULTS				
WQV (m^3)	20.7	36.2	19.0	33.7
EDV (m^3)	27.9	27.9	25.8	25.8
2yrs Pre peak ((m^3)	*34.2*	*72.9*	*34.2*	*72.9*
2yrs Post peak (m^3)	*71.4*	*120.2*	*67.5*	*115.3*
dV 2 year	37.1	47.2	33.3	42.3

Figure3: Run-off volumes for the different scenarios

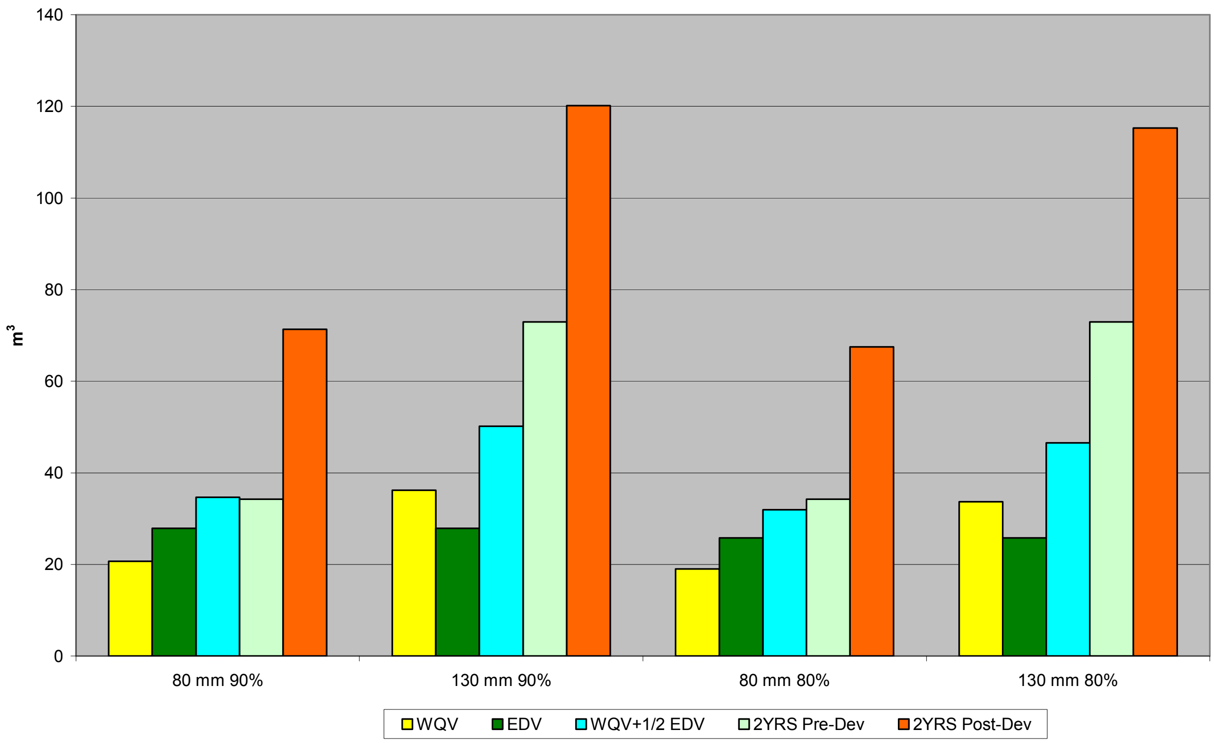


Figure 3 indicates that the volumes which must be detained when applying the pond credits of WQV and ½ EDV is approximately the same as the 2 year pre development volume for scenario 1 and 3 which are the 80mm rainfall events. When looking at the extreme event of 130mm rainfall the pre development flow volume is about 20m3 larger. So what does this tell us? That we are essentially removing the pre-development 2 year event from the system for the 80mm rainfall event.

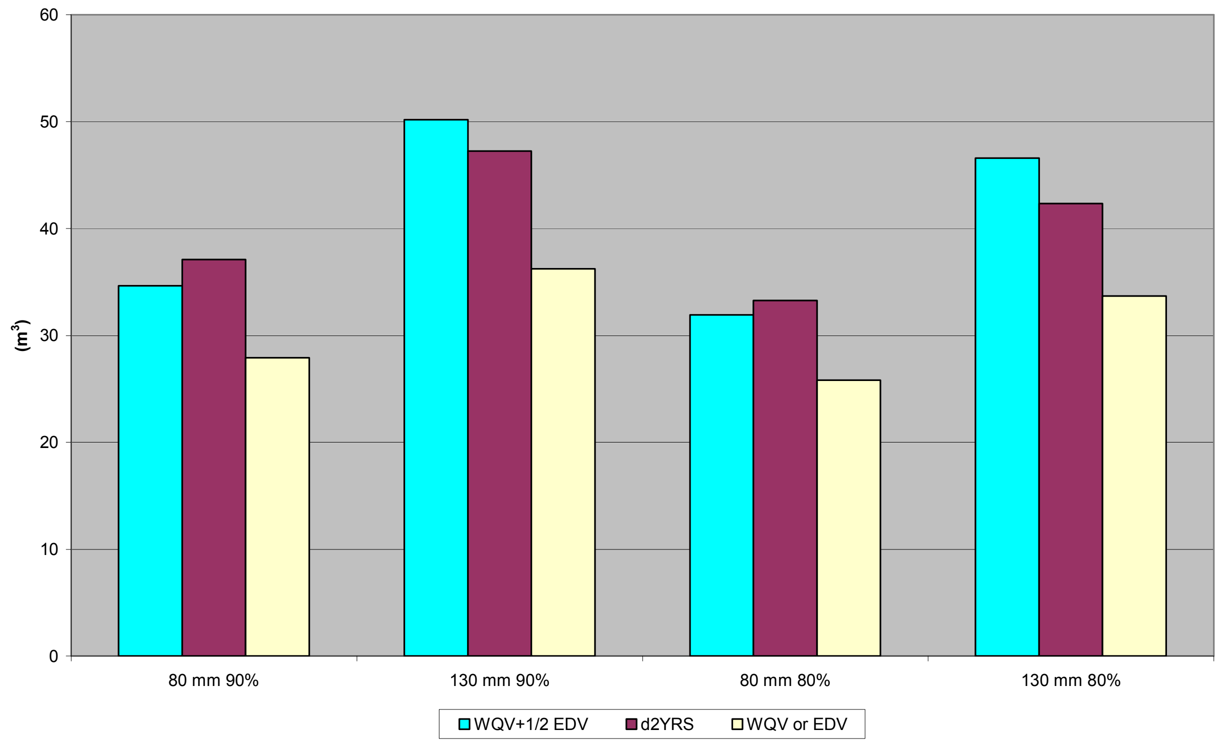
Looking at Figure 4 we can see that the delta of post and pre events is equivalent to the WQV plus ½ EDV. This means that by adding these volumes up we will need to store a total of a 2 year 24 hour event because we have considered the events separately.

Also it does not make sense to store the whole redevelopment event volume, this seems very conservative.

The idea is to provide ED storage and WQV treatment but if, as in case of the rain garden design, the treatment process includes detention then the greater of WQV or EDV should be considered, not both accumulatively. Therefore the design will fulfill both the erosion parameters and treatment.

We would still have to look at storage and release of the delta pre and post development 2 year 24 hour event and reduce the peak of the post 2 year 24 hour to match the pre development conditions. But this could now be undertaken using a dry pond. And this will still be conservative since we do not account for volumes stored by EDV.

Figure 4: Run-off volumes for the different scenarios



It is recommended that when we model rain gardens, especially if they filter into an under-drain that would return to the stormwater system, that we adjust the parameters of the rain garden design.

How does credit of EDV or WQV affect the size of the raingarden?

Table 5 shows the required area for a rain garden design based on the different scenarios using a required area of 3m2 for treating every 1m3 of water.

Table 5: Required rain garden area using 3.0m² for every 1m³ of WQV

Scenario	**1**		**2**		**3**		**4**	
	Area (m^2)		**Area (m^2)**		**Area (m^2)**		**Area (m^2)**	
WQV	62.1	31%	108.7	54%	57.0	57%	101.1	101%
EDV	83.8	42%	83.8	42%	77.5	77%	77.5	77%
WQV+1/2 EDV	104.0	52%	150.6	75%	95.8	96%	139.8	140%

If we analyze the values in Table 5, only treating the WQV in a rain garden, it would mean between 31 and 101% of the available pervious area is necessary. Treating and storing WQV plus ½ EDV would mean 52 to 140% of available pervious area is necessary. The obvious choice will therefore not be a rain garden to implement as a mitigation device. They are attractive but, for residential areas in particular, you would probably rather have some available open space in your garden.

Adapting the smaller required area of 1.4 m^2 for every 1m^3 of WQV, from Section 2, and allowing full credit for either EDV detention or WQV, Table 6 highlights the reduction in required area compared with available pervious area. Even Scenarios 2 and 4 (130mm event) would be able to install rain gardens just on the area basis.

Table 6: Required rain garden area using 1.4m2 for every 1m3 of WQV

Scenario	**1**		**2**		**3**		**4**	
	Area ***(m^2)***		***Area*** ***(m^2)***		***Area*** ***(m^2)***		***Area*** ***(m^2)***	
WQV	29.0	14%	50.7	25%	26.6	27%	47.2	47%
EDV	39.1	20%	39.1	20%	36.2	36%	36.2	36%
WQV+1/2 EDV	48.5	24%	70.3	35%	44.7	45%	65.2	65%

Table 7: Required rain garden area using 1.4m2 for every 1m3 of WQV, 100% credit for EDV or WQV

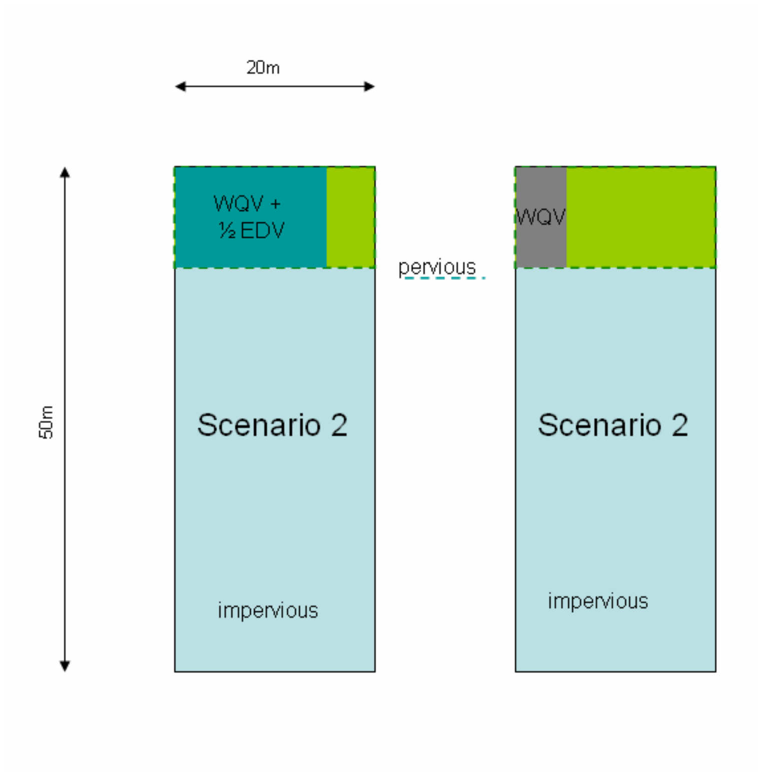
Scenario	**1**		**2**		**3**		**4**	
	Area ***(m^2)***		***Area*** ***(m^2)***		***Area*** ***(m^2)***		***Area*** ***(m^2)***	
WQV or EDV- new	39.1	62%	50.7	66%	36.2	62%	47.2	66%
WQV+1/2 EDV - old	104.0		150.6		95.8		139.8	

Table 7 represents the area which would be saved if the changes discussed in the previous sections were implemented through rain garden design.

Figure 5 shows uses the Scenario 2 example with the current guidelines and with the changes proposed in this paper.

- Coefficient of permeability 0.7 m/s
- Maximum depth above Filter soil 300mm
- Full credit of WQV or EDV

Figure 5: Sample Area showing the required area of rain garden within the pervious area of the residential lot.



3.2.2 BENEFITS OF TREATING AND STORING "AT SOURCE"

If the stormwater run-off is treated at source the land use area will decrease and the costs for detention must be lower. Areas which would previously have been constructed as wet ponds can now potentially be designed as dry ponds with multiple purposes, providing additional benefits to stakeholders.

4 CONCLUSIONS

It appears that the guidelines for rain gardens, whilst technically correct, are applied in an overly conservative manner potentially making rain gardens a cost prohibitive treatment option.

Research on leach fields and other filters used for wastewater treatment should be considered along with international lessons learned and other national pilot projects.

It is my view that the usage of the parameter EDV and WQV should be better defined and that more credits are allowed for different storage and treatment devices when treating "at source". The current guidelines should consider the dramatic effects of design parameters on the selection of rain gardens or other treatment devices and ensure that the designers are aware of the conservatism within the recommended minimum values provided.

As demonstrated in this paper, with minor engineering adjustments to design parameters, a reduction in rain garden area of up to 66% can be made on each site. I firmly believe this would have a great impact on the potential selection and installation costs of a rain garden. Stormwater managers would see many more of these effective biofiltration treatment devices installed as a result.

Additionally the collective benefits of reduced detention volumes and a dry pond would further reduce the costs of the overall development and improve the amenity value to the community.

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