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Why best practice is destroying our waterways

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This study explores the genuine desire to protect and enhance urban waterways through whole of water cycle measures having wide ranging benefits to community health and climate change resilience. Controls that recognise the value of enhancing the local waterways and imitating a more natural regime, namely recovery, re-use, infiltration and runoff control were investigated. The options investigated were assessed against 'Levels of Service' (LoS) that represent the protection of local ecology, preservation of geomorphology and enhanced amenity for the community.

The LoS were derived based on discussions with DELWP and Melbourne Water (MW), and supported by a previous site specific study conducted by industry academia. The LoS were achievement of a 60% stormwater volume reduction, representing moderate protection of waterways, and 90% volume reduction, being optimum protection.

The Base Cases 1) Business-as-Usual; 2) introducing local stormwater harvesting; and 3) regional stormwater harvesting capturing a large catchment.

The study found that the base cases were inadequate in achieving these LoS. Storm therefore optimised these options to demonstrate the requirements that would need to be implemented to achieve the targets. The options were further tested against a range of Waterway Health Metrics to determine if the LoS truly represent ecological and geomorphological protection.

A range of options were investigated with the most effective distributed measures included porous roads, in combination with infiltration trenches along encumbered waterway zones. Alternative measures to these distributed systems were stormwater injection connections to the non-potable network.

The appropriateness of using the LoS were assessed against common waterway health metrics (low flow duration, Tqmean, R-B index, and creek mobilisation metrics). The modelling tools RORB and HECRAS were used in this assessment to complement the MUSIC study. The post-development scenarios were required to reach the pre-development level to be considered achieving waterway protection.

Only Base Case 3 met 60% LoS volume reduction. LoS can be achieved with major catchment changes (end-of line, road scale WSUD) plus porous roads. Base Case 2 also required permeable driveways for 90% LoS. Alternative to porous roads, stormwater injection was equally effective in achieving LoS. Porous roads were the most expensive option. This is likely due to the unavailability of technology in Australia.

Assessing the options further against creek protection indicated that 90% LoS generally achieved many of the pre-development levels for each of the health metrics but not all parameters were satisfied.

The key outcomes of this study were:

- *Large assets alone cannot achieve the LoS;*
- *The 90% volume reduction LoS generally achieves health metrics (specific to this case study catchment only and with some exceptions);*
- *Technological advancement in the industry should be encouraged to drive prices down;*
- *An alternative scenario, compared to porous roads, could be to extend local stormwater harvesting to allow injection of stormwater to supplement non-potable demands. This is likely to be a more cost effective option.*

The study also how waterway health metrics do not discriminate between options that protect the 'whole' creek. It is evident that 'best practice' falls dramatic short of effective waterway protection.

1. INTRODUCTION

1.1. Preamble

This paper is based on a study undertaken on behalf of the Department of Environment, Land, Water and Planning (DELWP). DELWP commissioned Storm Consulting Pty Ltd (Storm) to assess a case study investigating Whole-of-Water Cycle Management (WWCM) options for future development within Precinct Structure Plans (PSPs). The options considered lot scale, street, subdivision and precinct scale measures with the primary objective enhancing waterway protection. Findings of the investigation will be used to inform / shape building and planning controls and opportunities to integrate water management into new developments.

A case study was then undertaken on one of the Developer Services Schemes (DSS) within the PCPs to explore the optimization of stormwater management to enable appropriate protection of the high value waterway and how it relates to the integration of the water cycle management. This study is called Whole of Water Cycle Optimisation – Olive Grove Case Study (Storm 2015b) and is therefore the primary reference material for this paper.

1.2. Background

This Study aims to identify effective stormwater management measures to be implemented to reach pre-defined target criteria in relation to protecting the waterways. The investigation is to be a holistic appraisal seeking to enhance waterway health and encompasses the values of key stakeholders. Specifically, the objectives of this study are to:

- Understand and critically appraise current building and planning controls, and how WWCM opportunities may impact on these;
- Investigate stormwater management measures that protect waterways by reducing urban runoff volumes;
- Identify the WWCM options that achieve pre-determined target criteria (Levels of Service) with respect to volume reduction by optimising preferred Base Case opportunities provided by DELWP;
- Assess and compare the cost effectiveness of preferred opportunities; and
- Compare the achieved Levels of Service against selected waterway health metrics. The metrics express the ecological and geomorphological performance of the options.

The Olive Grove catchment has been identified as the case study of choice as it has an external (farmland) catchment and a combination of residential and commercial areas. The catchment composition of Olive Grove is varied, but consistent with that of a typical urban growth area lacking only industrial surfaces.

The overall assessment approach aims to identify integrated water management opportunities that build on the Business as Usual (BAU) case, referred herein as a Base Case Opportunity. This Base Case reflects development that complies with current best practice environmental management (BPEM) requirements. Two other Base Case Opportunities have also been put forward by DELWP that will be further investigated. These have been identified in consultation with Melbourne Water through a separate study, the Melton WoWCA, and will be further optimised under this study.

1.3. Site overview and Regional Context

The Olive Grove DSS extends from farming area to the north of the Melton Highway, through both the Plumpton and Kororoit PSP's to Kororoit Creek. The catchment is approximately 469 Ha (predominantly in the Plumpton PSP) comprising 130 Ha of agricultural land external to the development to the north. The location and extent of the catchment is shown in Figure 1.

The area has been predominantly used for grazing and cropping, which has likely degraded the natural regime including the ephemeral waterways. The main natural water feature of Olive Grove is an ephemeral waterway that flows south, dissecting the proposed main commercial area within the Plumpton PSP and diverted around a heritage dam in the Kororoit PSP. The length of waterway within the PSPs is approximately 4.3 km, and has been sized to allow a 60 m wide reserve for the length of the alignment by Melbourne Water. The land has a slight fall (approximately 1%) towards Kororoit Creek.

Kororoit Creek is a major waterway in Western Melbourne, running in an easterly direction through the central section of the Kororoit PSP (as shown in Figure 1) and is the receiving waterway of stormwater from the Olive Grove DSS. The corridor has been identified as a key Growling Grass Frog (GGF) habitat which has been identified in the approved Biodiversity Conservation Strategy (BCS) for Melbourne's Growth Corridors (DELWP, 2013).

The area is situated in one of the lowest rainfall zones in greater Melbourne. On top of this, are the identified high geomorphic1 values of the Olive Grove waterway (Alluvium, 2014), making local waterway management and appropriate design in the early stages of planning all the more important. Controls that recognise the value of enhancing the local waterways and imitating a more natural regime, through recovery, re-use, infiltration and runoff control will ensure the protection of local ecology, preserve geomorphology and enhance amenity for the community.

The LoS assessment was based on a study conducted in the area by the Melbourne Waterway Research-Practice Partnership (Duncan et al, 20142), which suggests approximately 90% of flow reduction is required to maintain Kororoit Creek in it's current geomorphological and ecological form. This aims to mimic a more natural condition with runoff frequency and contribution to baseflow maintained as per pre-development.

For clarity, the flow target refers to the reduction of total stormwater volume as a result of development, not the reduction of excess stormwater additional to existing conditions.

It should also be made clear that the 90% flow reduction LoS is specific to the Melton area only, and can not therefore necessarily be replicated in other zones with potentially varying imperviousness, soil parameters and catchment characteristics.

[1] High geomorphic value is defined in Alluvium (2014) as reaches that '...have an intact, remnant form that is representative of the waterways that were prevalent in the area prior to European settlement and land development'.

[2] Duncan, HP, Fletcher, TD, Vietz, G & Urrutiaguer, M (2014), *The feasibility of maintaining ecologically and geomorphically important elements of the natural flow regime in the context of a superabundance of flow – Stage 1 Kororoit Creek study*. September 2014. Melbourne Waterway Research-Practice Partnership Technical Report. 14.5.

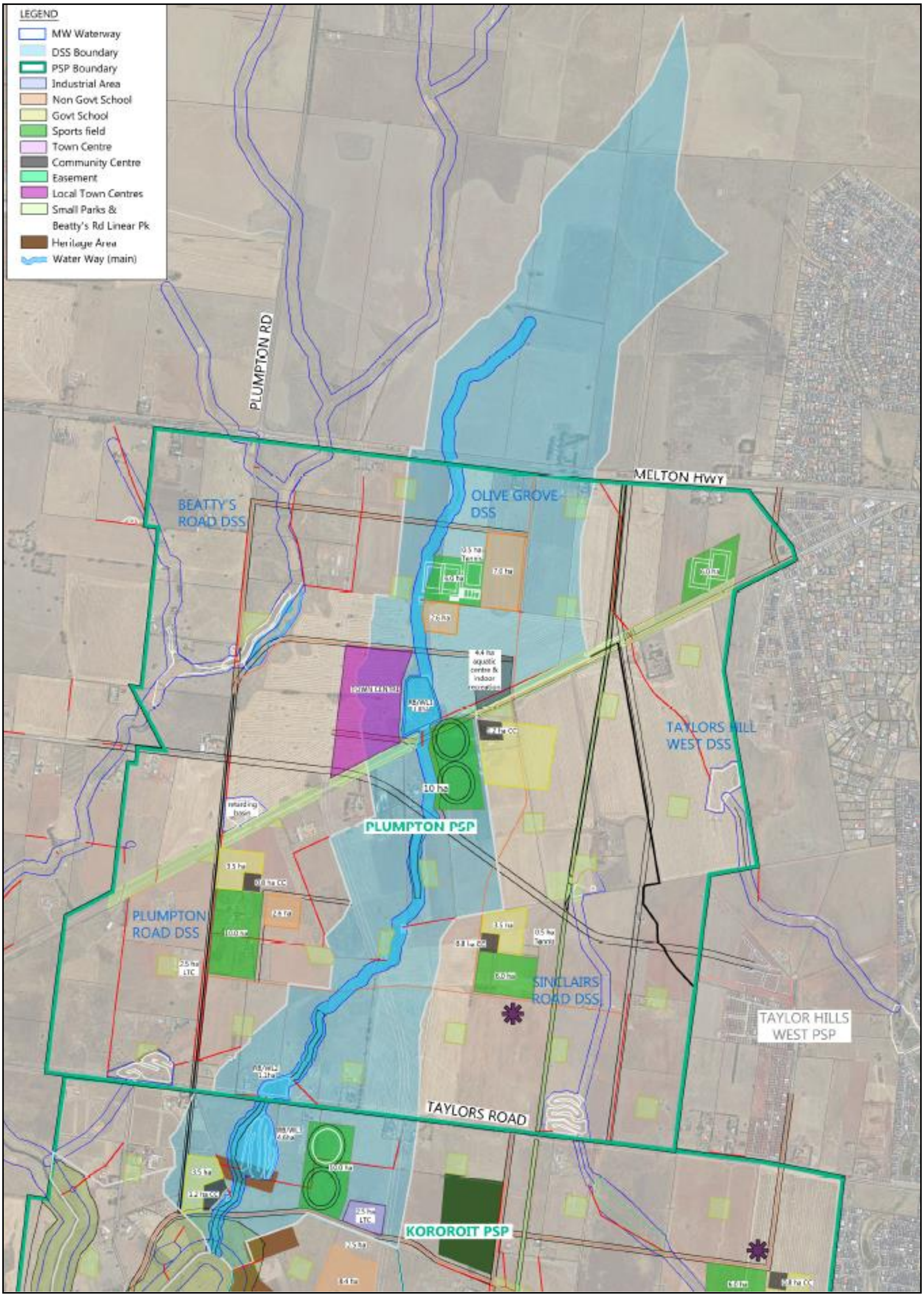

Figure 1 - Olive Grove DSS

2. OPTIONS DEVELOPMENT

2.1. Overview

The options to be explored under this study are to build on identified Base Cases to achieve certain flow reduction criteria, referred herein as Levels of Service (LoS), focussing on the protection of waterways. The Base Case options to be investigated have been identified by DELWP, as informed by the Melton WoWCA. Where these Base Cases have not achieved the LoS, options to improve performance from a flow reduction point of view are introduced.

2.2. Levels of Service Targets

The Levels of Service to be achieved focus on waterway protection as follows:

- BPEM (water quality only)
- 60% flow reduction
- 90% flow reduction

Flow reduction target refers to the total volume of stormwater generated as a result of development. The 90% target has been identified through the Melton WoWCA, based on work undertaken within the Kororoit Creek catchment (Duncan et al, 2014). The study suggests that the degradation of the waterway can be prevented by matching a 90% reduced flow regime. Since Olive Grove falls within the same catchment of this study, these target criteria have been adopted for the Olive Grove waterway case study.

2.3. Base Case Options

The Base Cases have been identified by DELWP in consultation with Melbourne Water, based on the outcomes of the Melton WoWCA as follows:

- *Base Case 1 - Business as Usual*
  This base case option reflects the implementation of water management based on meeting current best practice.
    - Class A recycled water.
    - Centralised water quality treatment and flood protection assets sized to meet regulatory requirements under Clause 56 (excluding the 1.5 year ARI discharge requirement).
- *Base Case 2 – Melton WOWC Option 1*
  This option builds on the BAU by introducing local stormwater diversion from wetlands to supply the irrigation needs of green and open space.
    - Class A recycled water.
    - No uptake of rainwater tanks.
    - Centralised water quality treatment and flood protection assets sized to meet regulatory requirements under Clause 56 (excluding the 1.5 year ARI requirement)
    - Stormwater diversion from online wetlands for storage and treatment to be used for irrigation needs of active and passive open space (non-potable reuse, supplementing Class A water)
- *Base Case 3 – Melton WOWC Option 3*
  This represents a focus on harvesting and using stormwater at a larger scale as an alternative supply option to the greater Melton area. This incorporates:
    - No Class A recycled water use.
    - Large scale stormwater diversion from northern portion of Olive Grove to be centrally treated and distributed via 3rd pipe for non-potable water supply with potable water only as a backup.
    - No uptake of rainwater tanks.
    - Centralised water quality treatment and flood protection assets sized to meet regulatory requirements under Clause 56 (excluding the 1.5 year ARI discharge requirement).

2.4. Optimisation Opportunities

To achieve the identified Levels of Service, urban development design would need to incorporate measures that retain most of the rainfall excess. This would be via as many forms of the hydrological cycle as possible, predominantly evapotranspiration, reuse and infiltration.

DELWP notes that on-lot rainwater tanks will not form part of the assessment. Council also prefers that swales are not used in streetscapes for residential areas. The opportunities to pursue the focus on maximising volume reduction are as shown below:

Lot and Residential

- Raingardens – treating road catchments only as the lots will likely drain directly to the stormwater network, not to the kerb. This has been the norm in new developments in the area (Storm has also recently conducted a site visit on another new development project in the area, noting that only roll over curb is present where roof and lot connection is inappropriate given the small rise of these kerbs)
- Porous Road – replacing residential roads only
- Permeable pavement – on lots to reduce urban hardstand area
- Neighbourhood scale roofwater harvesting and reuse

Street and Major Road Scale

- Raingardens and other WSUD infiltration (along major roads and commercial precinct only)
- Localised stormwater harvesting – meeting irrigation demands of sports fields (large and small distributed) and green space

Precinct Scale

- Distributed offline wetlands strategically co-located within green and open space areas. Co-location reduces impact on developable land and maximises re-use and amenity benefits
- Increased centralised asset size – maximising use of encumbered land within the waterway
- Unlined centralised assets allowing infiltration. This will need to be well considered given the impact this may have on the functionality, aesthetics and ecology of wetlands.
- Infiltration trenches in encumbered waterway buffer zone
- Stormwater harvesting for re-use in the commercial precinct
- Stormwater harvesting for injection to recycled water line for treatment and non-potable re-use

3. OPTIONS ASSESSMENT

3.1. Objectives

The options assessment aims to quantify the benefits of implementing a range of measures to minimise runoff volumes, building on the preferred Base Case Options. The approach will use modelling to compare the available measures, to provide the most optimised outcomes.

3.2. Base Case Conditions

Overall details of the Olive Grove case study site are as follows:

- Approximately 469 ha catchment predominantly in the Plumpton PSP
- Comprises residential, commercial, schools and parklands (no industrial)
- External agricultural catchment enters from the north (~130 Ha)
- Centralised assets in the Base Cases include 2 retarding basins and 3 wetlands

Under base case conditions, three wetlands perform the main water quality treatment functions through the catchment. The northernmost wetland (WL1) is combined with a retarding basin and located to the north of Beatty's Road adjacent the planned commercial centre for Plumpton. WL1 has a total footprint of 4.4 Ha (3.8 Ha wetland).

The second wetland (WL2), north of Taylors Road, is also combined with a retarding basin. This wetland is 1.1 Ha and the retarding basin has a footprint of 1.6 Ha. The southernmost wetland (WL3) has an area of 1.4 Ha. Four sediment basins (total footprint 0.1 Ha each including associated drying areas) also provide treatment along the length of the waterway.

3.3. Methodology

The investigation into options has been primarily conducted based on a quantitative modelling approach to determine the benefits to the waterway related to stormwater volume reductions. This will also be accompanied by a costs assessment (provided in subsequent sections). For the purposes of this study, the benefits to the waterway (achieving the Levels of Service) have been investigated irrespective of expense, with cost being a secondary consideration.

Modelling to determine volume reductions has been conducted in MUSIC (Model for Urban Stormwater Improvement Conceptualisation v6.0.1), a conceptual design tool that is used to predict the performance of water management systems and assist in designing strategies to tackle urban stormwater hydrology and pollutant impacts.

3.4. Base Case 1 Assessment

The BAU case, representing predominantly end of line treatment of stormwater to achieve current BPEM targets was modelled in MUSIC. The model results are as follows:

Table 1 – Base Case 1 MUSIC Results

Base Case 1	In	Out	% Reduction
Flow (ML/yr)	847	769	9.2
Total Suspended Solids (kg/yr)	179,000	38,300	78.6
Total Phosphorus (kg/yr)	377	129	65.8
Total Nitrogen (kg/yr)	2,530	1,400	44.6

As can be seen from Table 1, Base Case 1 achieves BPEM targets, however, reaches only 9% volume reduction. Considering the 130 Ha agricultural land to the north is in pre-development conditions, treatment to a certain % reduction does not apply. The volume generated from this node (51.7 ML), although still forming part of the model, can be subtracted from the final outflow volume. The volume reduction for the BAU becomes 15 %. This method has subsequently been applied to all the models. The stormwater breakdown for the Olive Grove BAU is shown on Figure 2.

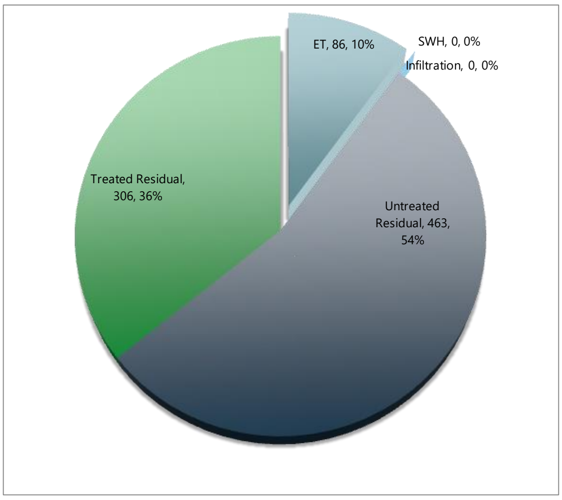

Figure 2 – Base Case 1 Volume Breakdown

3.5. Base Case 2 Assessment

Base Case 2 introduces localised stormwater harvesting. The model was adapted from the BAU case with harvesting tanks positioned in the catchments of the major fields – offtaking from the centralised wetlands. These were sized based on achieving an 80% demand met target for the irrigation of the fields. Two locations were considered ideal based on positioning near fields which were sized as shown in Table 2.

Table 2 – Stormwater Harvesting Tank Sizing

Sizing Parameters	SWH1	SWH2
Size (ML)	5.50	0.80
Demand (ML)	96.4 (20 Ha of green space)	53.2 (11 Ha green space)
Demand Met (%)	81 %	81 %
Re-use Supplied (ML)	78.1	43.1

This indicates the stormwater harvesting systems can supply the surrounding fields at a total of 121.7 ML, reducing potable demand requirements. Based on introducing the above tanks the following results were obtained for Base Case 2.

Table 3 – Base Case 2 MUSIC Results

Base Case 2	In	Out	% Reduction
Flow (ML/yr)	847	651	23.2
Total Suspended Solids (kg/yr)	177,000	36,800	79.2
Total Phosphorus (kg/yr)	369	122	67
Total Nitrogen (kg/yr)	2,560	1,270	50.3

Subtracting the agricultural volume, the reduction becomes 29%.

3.5.1. Base Case 2 – Option 1 (60 % Reduction)

To determine the measures that need to be implemented to bring Base Case 2 up from 29% to 60% reduction, the approach was to first address potential major changes in the catchment (precinct and major road scale). These were introduced in the modelling in the following order:

- Distributed offline wetlands located at suitable parks applied as 5% of park area
- WSUD applied to commercial area at 2% of the catchment
- WSUD and infiltration applied to the main roads (determined to be 8.49Ha of total area) at 2% of catchment

This brought stormwater runoff to 547ML with the volume reduction becoming 35%.
On lot solutions were then investigated to determine how Base Case 2 could achieve 60% reduction. The focus turned to residential solutions as these areas form the larger portion of the whole catchment. The following scenarios were investigated:

- Raingardens applied to 1% road catchment (RG 1%)
- Raingardens applied to 2% road catchment (point at which further increase results in no added benefit to stormwater reduction) (RG 2%)
- Raingardens applied to 1% road catchment and permeable driveways on lots (RG 1% + PD)
- Porous Road on residential roads (PR).

As can be seen from Figure 3, Porous Road is the most effective in reducing stormwater volumes, bringing Base Case 2 above 60%.

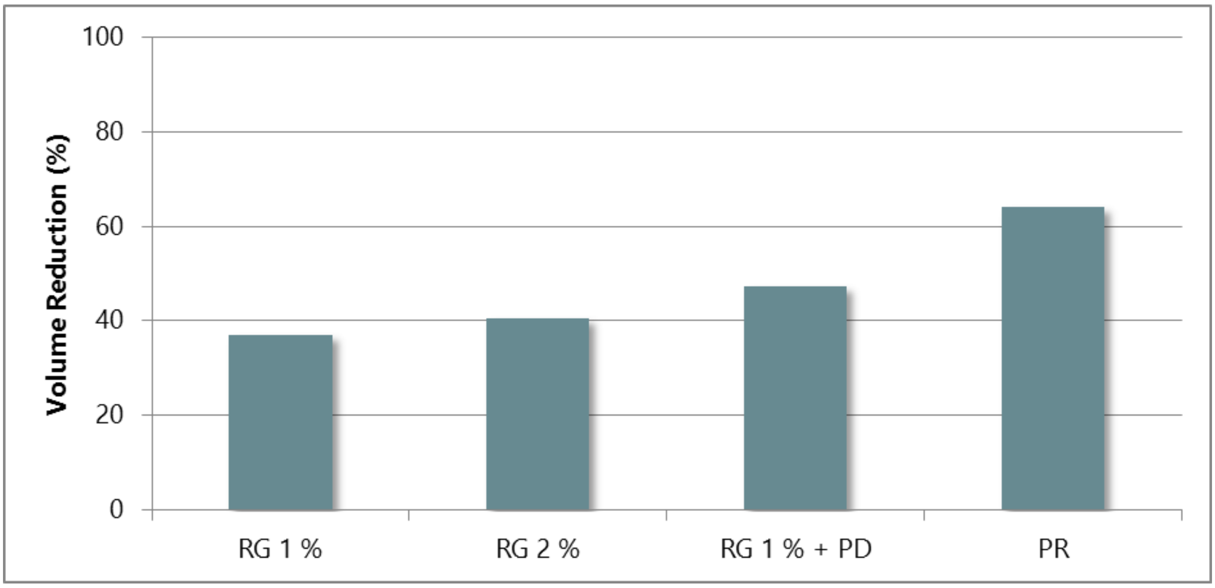

Figure 3 – Base Case 2 Option 1 Residential Measures

The whole of catchment measures and Porous Road has been adopted as Base Case 2 Option 1. The stormwater volume breakdown for Base Case 2 (Option 1 - 60% reduction) is shown in Figure 4.

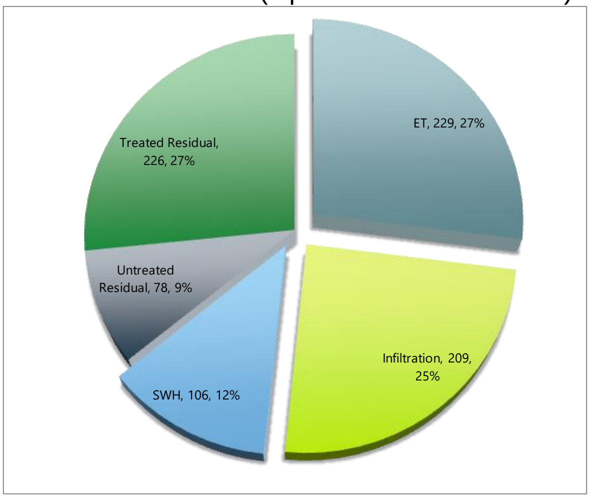

Figure 4 – Base Case 2 Option 1 Volume Breakdown

Further to this, the introduction of Porous Road into the catchment reduces the stormwater harvesting reliability to 69% and 74% for SWH 1 and SWH2 respectively. To maintain 80% reliability for the stormwater harvesting tanks the sizes were required to be increased to 13ML and 1.5ML respectively. This would increase the volume reduction to 66%. A summary of infrastructure incorporated for Base Case 2 Option 1 to achieve 60% volume reduction is shown as follows:

Lot and Residential	Porous roads on residential streets
Street and Major Road Scale	WSUD applied to commercial area at 2% of the catchment WSUD applied to the main roads at 2% of catchment Local stormwater harvesting (SWH 1 – 5.5 ML, SWH 2 – 0.8 ML)
Precinct Scale	Online wetlands (WL1, WL2, WL3 sized as per Base Case 1) Distributed offline wetlands located at suitable parks applied as 5% of park area

3.5.2. Base Case 2 – Option 2 (90% Reduction)

To determine the measures that need to be implemented to further treat the catchment to the 90% reduction LoS, the major changes in the catchment proceeded as follows:

- Distributed offline wetlands located at suitable parks applied as 10% of park area
- Stormwater harvesting for commercial area (~25 ML demand)
- WSUD applied to commercial area at 2% of the catchment
- WSUD and infiltration applied to the main roads (determined to be 8.49 Ha of total area) at 2% of catchment
- Centralised assets increased to 150% of BAU size
- Infiltration trenches applied along the waterway length

These measures reduced stormwater volume down to 417 ML from the original Base Case 2 model with the percentage reduction becoming 51%.
Other measures that were investigated in the modelling at the major scale were:

- Leaky wetlands and leaky stormwater harvesting systems and pipes (for supply of street trees) were also investigated, and these were shown to be very effective in reducing volumes (> 60%). However, this assessment has prioritised residential (catchment) solutions over this option as:
    - wetlands are typically lined. Introducing seepage could impact on functionality as wetlands are sensitive to water levels, and are designed to maintain a 'normal water level' to ensure treatment capability. The lowered water levels also affect the aesthetics of the wetland which is of increasing importance in areas of high community use;
    - leaky stormwater harvesting systems are not ideal as one of the main functions of stormwater harvesting storages is to supply water (eg to sports fields). Leaky systems reduce how much water will be available when it is needed.
- Neighbourhood scale roofwater harvesting systems were also investigated. The systems would comprise approximately 20 dwellings draining to a common storage for reuse back into the same or similar dwellings. The neighbourhood scale systems were input in the model as a replacement to the large offline wetlands. The reasons these wetlands may not be practical and an alternative has been investigated are:
    - wetlands proposed at 10% of open space would be relatively impractical. These take up a large footprint and consume space that could be otherwise used for active recreation.
    - the aesthetic value of the open space may be impacted as wetlands can be unseemly looking on a large scale;
    - grading to the wetland and surcharging from the stormwater network can be difficult in a flat area.

  In the modelling the neighbourhood scale tanks were applied to only 30% of residential areas. The volume reduction incorporating the neighbourhood scale systems was found to be 52%, showing that this can be an alternative to the larger evaporative systems (at 51% shown above). Nonetheless, rainwater harvesting has been identified to be a low preference in this study, as advised by DELWP, with the larger wetlands adopted for subsequent modelling.

Subsequently, residential solutions were input to determine how Base Case 2 could achieve 90% reduction. The following scenarios were investigated:

- Porous Road on residential roads (PR). A blockage factor of 50% was applied to this node to ensure conservatism.
- Porous Road on residential roads and permeable driveways (PR + PD)
- Porous Road on residential roads and permeable driveways and diversion of 15% of the lots to the curb and raingardens (instead of directly to stormwater network) (PR + PD + RG)

As can be seen from Figure 5, all three measures in combination were required to bring this Base Case above 90% reduction.

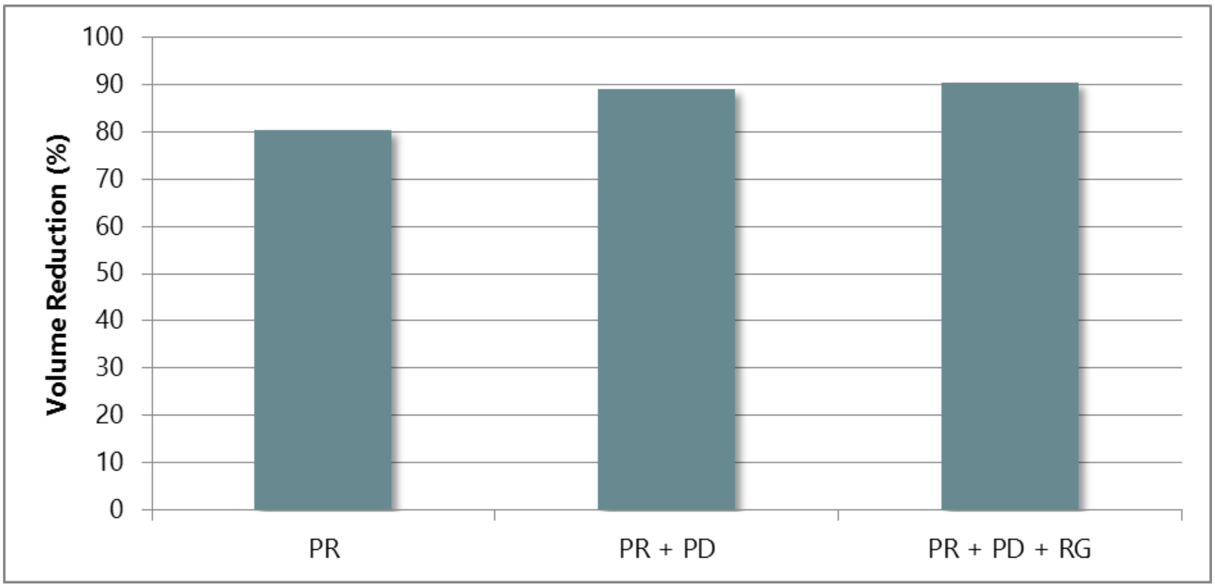

Figure 5 – Base Case 2 Option 2 Residential Measures

The last scenario shown in Figure 5 has been adopted as the Base Case 2 Option 2. The stormwater volume breakdown for the Olive Grove Base Case 2 Option 2 (90% reduction) is shown in Figure 6.

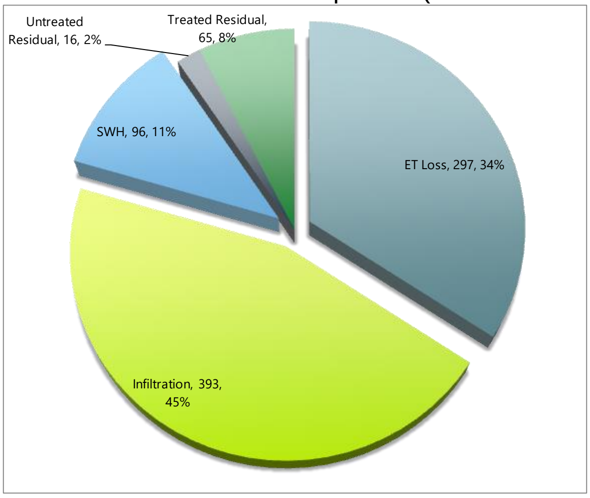

Figure 6 – Base Case 2 Option 2 (90% Reduction) Volume Breakdown

The introduction of measures into the residential catchment reduces the stormwater harvesting reliability to 51% and 46% for SWH 1 and SWH2 respectively. To maintain 80% reliability for each the sizes were required to be further increased to 22ML and 8ML respectively. This would increase the volume reduction to 95%. A summary of infrastructure incorporated for Base Case 2 Option 2 to achieve 60% volume reduction is shown as follows:

Lot and Residential	Porous roads on residential streets
Street and Major Road Scale	WSUD applied to commercial area at 2% of the catchment WSUD applied to the main roads at 2% of catchment Local stormwater harvesting (SWH 1 – 5.5 ML, SWH 2 – 0.8 ML) Stormwater harvesting for commercial area
Precinct Scale	Online wetlands (WL1, WL2, WL3 increased in size by 150% from Base Case 1) Distributed offline wetlands located at suitable parks applied as 10% of park area Infiltration trenches applied along the length of waterway

3.6. Base Case 3 Assessment

Base Case 3 increases the capacity of the system to recover and store stormwater by directing a large proportion of the Olive Grove catchment to a regional stormwater harvesting tank. The tank has been proposed under the Melton WoWCA as 25 ML with recovered stormwater pumped to a treatment plant located near the Holden Tank. The stormwater tank is augmented by potable water.

The total demand required to replace Class A water within the Holden Zone is 3,063ML/year. As the Olive Grove catchment forms only part of the input (less than half of the total catchment) the demand has been scaled down for this assessment to 1,348ML. The tank size was adjusted to represent the portion of the total 25ML that the Olive Grove catchment retains reserved for storage.

Based on introducing the above changes to the MUSIC model the following results were obtained for Base Case 3.

Table 4 – Base Case 3 MUSIC Results

Base Case 3	In	Out	% Reduction
Flow (ML/yr)	847	370	56.3
Total Suspended Solids (kg/yr)	178,000	24,600	86.2
Total Phosphorus (kg/yr)	372	71	80.9
Total Nitrogen (kg/yr)	2,550	717	71.9

Subtracting the agricultural volume, the reduction becomes 62%, which brings Base Case 3 up to the 60% reduction Level of Service. The stormwater breakdown for the Olive Grove Base Case 3 is shown on Figure 7 below.

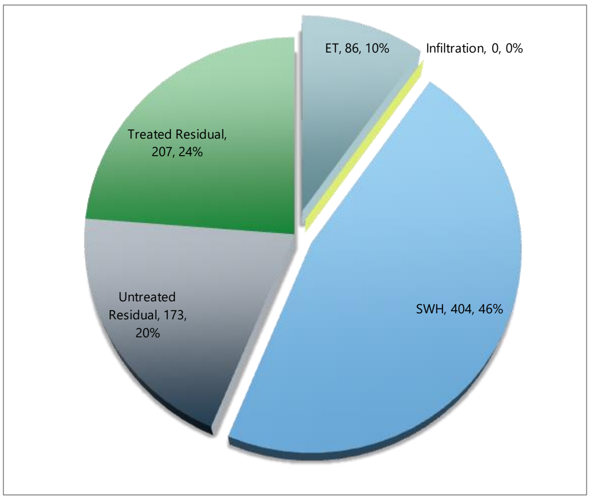

Figure 7 – Base Case 3 Volume Breakdown

3.6.1. Base Case 3 – 90 % Reduction

Similarly to the previous Base Case assessment, the approach to determine the measures that need to be implemented to bring Base Case 3 up to the 90% reduction Level of Service, was to first look to potential major changes in the catchment (precinct and major road scale). Localised stormwater in the upper part of the catchment (draining to the regional tank) was left as a last resort in this assessment, to minimise impact on the downstream regional harvesting system. The major catchment assets were introduced in the modelling as follows:

- Distributed offline wetlands located at suitable parks applied as 5% of park area

- Localised stormwater harvesting (lower catchment)[3]. This was set at a 3ML tank to achieve 80% reliability.
- WSUD applied to commercial area at 2% of the catchment
- WSUD and infiltration applied to the main roads (determined to be 8.49 Ha of total area) at 2% of catchment

This brought stormwater excess to 305 ML with the percentage reduction becoming ~70%. Residential solutions were then investigated to determine how Base Case 3 could achieve 90% reduction. Similarly to the Base Case 2 Assessment, Porous Road was the most effective measure in achieving the Level of Service as shown in Figure 8.

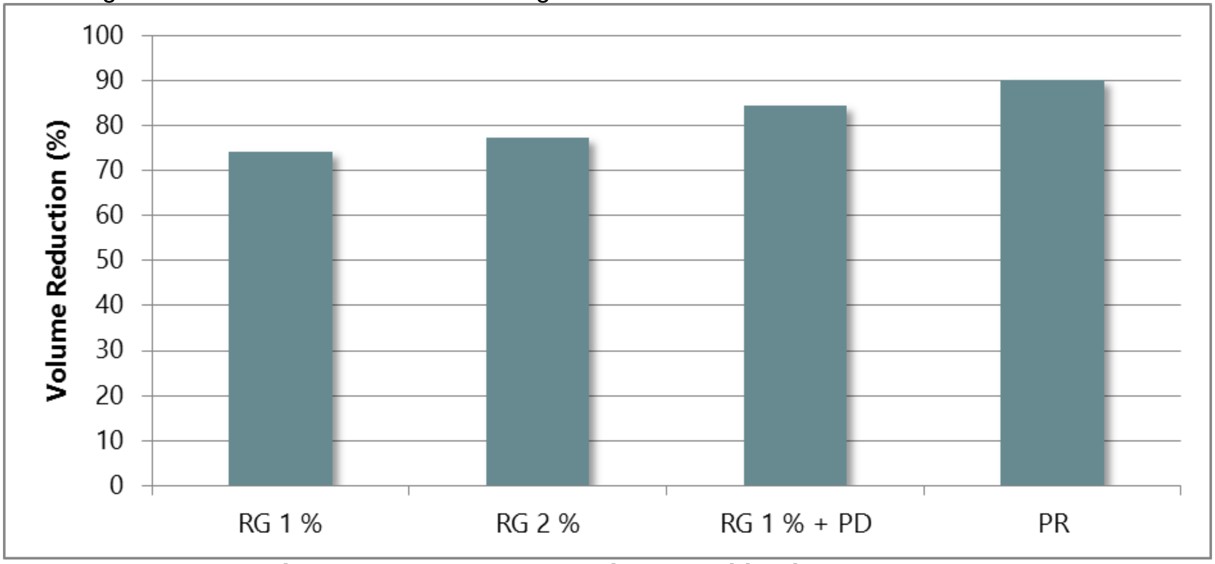

Figure 8 – Base Case 3 Option 1 Residential Measures

The major changes in the catchment and Porous Road scenario has been adopted for Base Case 3 Option 1. The stormwater breakdown for the Olive Grove Base Case 2 Option 1 (90% reduction) is shown on Figure 9.

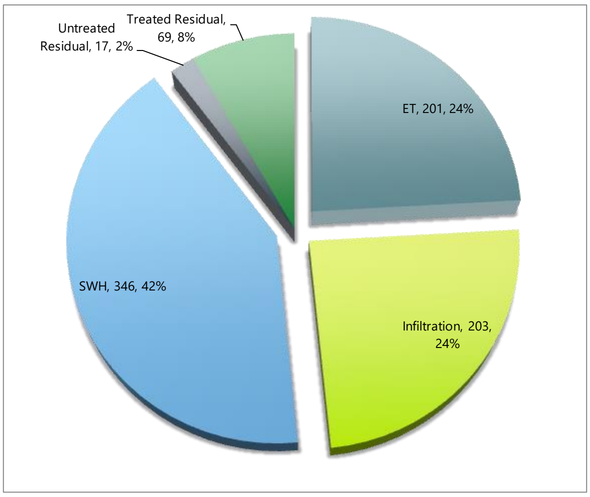

Figure 9 – Base Case 3 Option 1 (90% Reduction) Volume Breakdown

A summary of infrastructure incorporated for Base Case 2 Option 1 to achieve 60% volume reduction is shown as follows:

Lot and Residential Porous roads on residential streets

[3] The lower catchment is defined as the area that does not drain to the regional harvesting system (southern most portion). The upper portion was not subject to harvesting to ensure minimal impact to the regional harvesting system's ability to supply water for distribution in place of Class A water.

Street and Major Road Scale	WSUD applied to commercial area at 2% of the catchment WSUD applied to the main roads at 2% of catchment Local stormwater harvesting in lower catchment
Precinct Scale	Online wetlands (WL1, WL2, WL3 sized as per Base Case 1) Distributed offline wetlands located at suitable parks applied as 5% of park area Regional stormwater harvesting tank

3.7. Stormwater Injection Alternative

Delivering high water volumes to local stormwater harvesting storages is an opportunity to extend harvesting systems to allow injection of excess stormwater into the recycled water line during the cooler months. This will treat a much higher volume of stormwater compared to the typical local system that would only service sports fields and recreation areas. The excess water would augment the recycled water supply and is a potentially less expensive option to intensive residential measures. Stormwater injection would be a localised connection at the stormwater harvesting locations (with each location requiring a separate treatment plant to disinfect the water to Class A water).

Stormwater injection has been modelled in MUSIC for each of the options under the Base Cases as discussed in the below table. The Class A demand of 437ML was applied to SWH1 and SWH2, divided evenly between the systems (218.5 ML each).

Base Case 2 Option 1 (60 % reduction)	The model revealed porous road was not required with this option. Raingardens applied at 2% of the road catchment was found to be sufficient in combination with injection to bring Base Case 2 up to the LoS. The model showed the reliability of supply for each of the systems to be approximately 60% (given a Class A demand of 437ML, this equates to 260ML supply).
Base Case 2 Option 2 (90% reduction)	Porous road in combination with SW injection was found to result in 88% volume reduction. This doesn't quite reach the LoS, however, the next option considered (adding permeable driveway) resulted in 97% reduction. Therefore, it is likely that only a small percentage of the residential areas would require permeable driveways to bring the volume reduction to the 90% requirement. The reliability of supply dropped to ~30% (given a Class A demand of 437 ML, this equates to ~131 ML supply)
Base Case 3 (90% reduction)	Stormwater harvesting and injection was investigated (lower catchment only). Results indicate that stormwater injection results in 90% reduction without the need for porous road, however, raingardens for 1% of the road catchment and permeable driveways would be required. The model showed approximately 60% of demand could be achieved. The demand was applied as 218.5ML (half of Class A demand) which indicates 131ML of stormwater could be supplied in place of Class A water.

3.8. Results Summary

Figure 10 shows the performance of the initial Base Cases against the identified Levels of Service. Base Case 1 and 2 were shown to be inadequate in achieving the 60% and 90% volume reduction. Base Case 3 meets the 60% reduction target, however, falls short of the waterway protection target of 90% reduction.

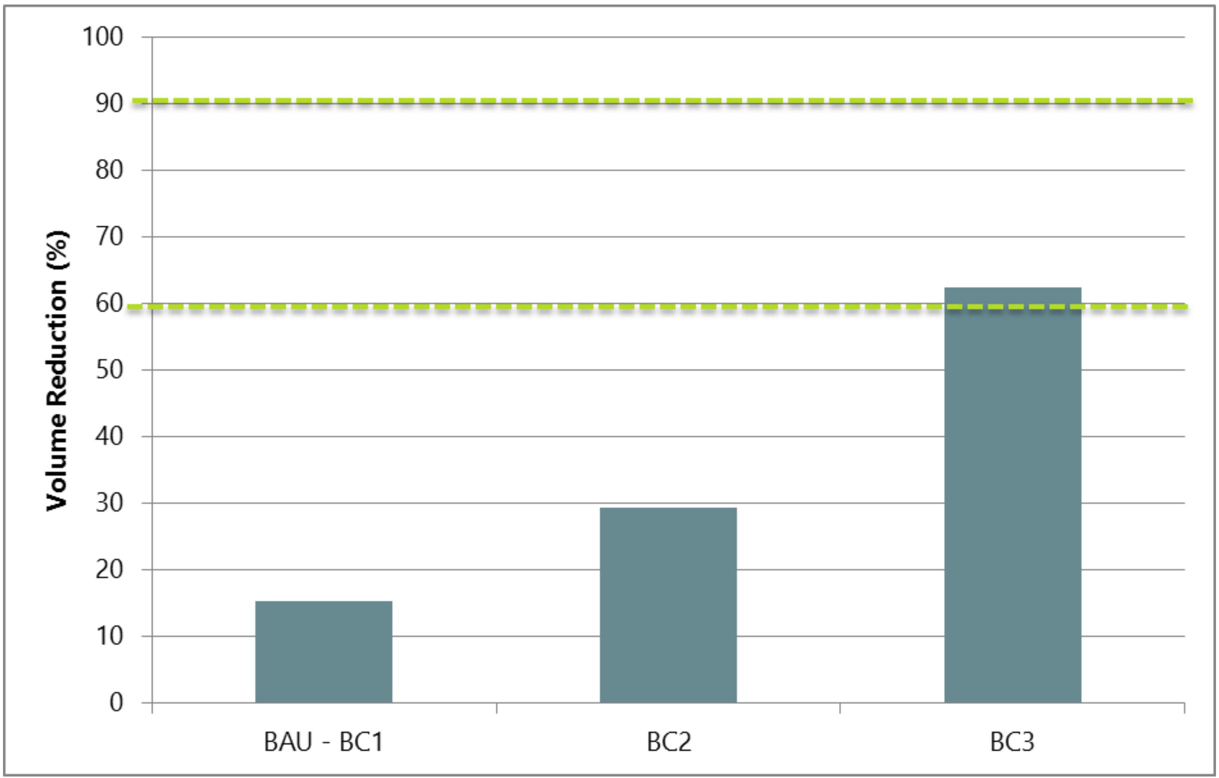

Figure 10 – Performance of Base Cases against Levels of Service

The assessment has found that the targets can be achieved by introducing the major catchment changes and porous roads to the options. Base Case 2 also required permeable driveways and diversion of 15% of the lots to the curb (to raingardens instead of directly to stormwater network) to achieve 90% volume reduction.

A summary of the results, showing a comparison of the stormwater volume breakdown for each option, is depicted on Figure 11. Base Case 2 Option 2 and Base Case 3 Option 1 produce the least residual flow and the highest ET, infiltration and re-use losses.

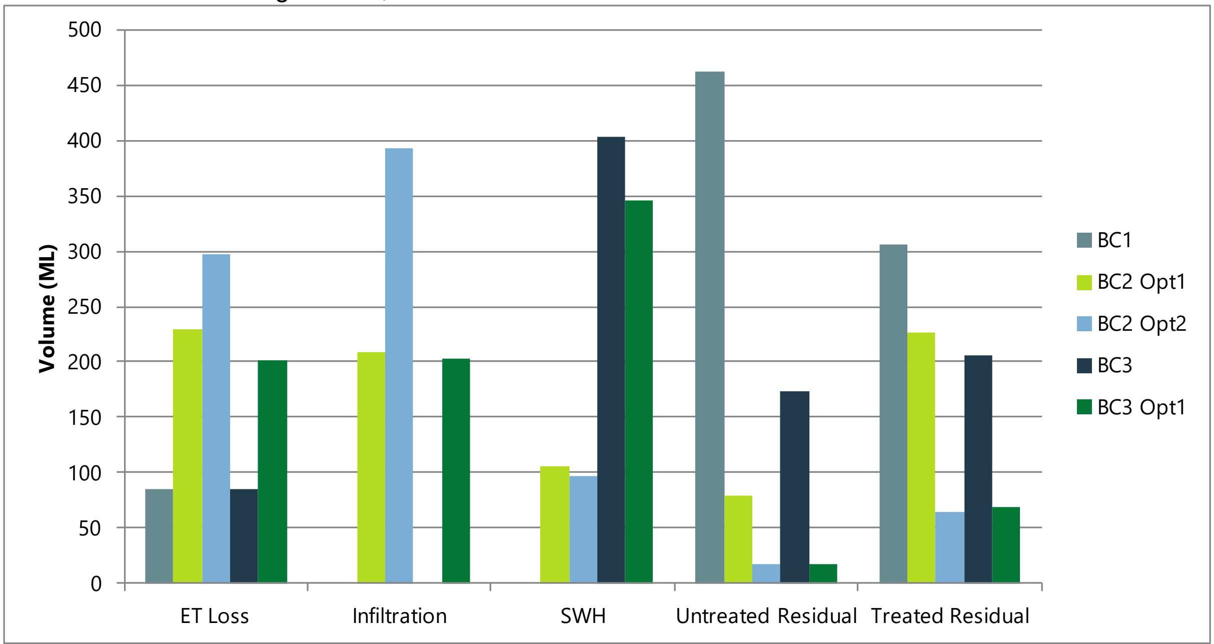

Figure 11 – Comparison of Stormwater Budget for each option

The assets required for each of the options is shown in Table 5. Also shown is the treatment area requirements, illustrating the impact the different options have on land use.

Table 5 – Treatment Assets Required for Each Options

Option	Retarding Basins (Ha)	Centralised Wetlands (Ha)	Offline Wetlands (Ha)	Residential Measures (Ha)	Street scale (Ha)	SWH (ML)	Treatment Area Required (Ha)[1]
BC1	6	9.5					9.5
BC2	6	9.5				6.3	9.5
BC2 Opt1	6	9.5	3.85	83	0.39	6.3	14
BC2 Opt2[†]	6	14.3	7.7	106	0.39	6.3	46
BC3	6	9.5				25	9.5
BC3 Opt1	6	9.5	3.85	83	0.39	28	14

[1]Treatment area required excludes the 83 Ha of Porous Road for BC2 Opt1, BC2 Opt2 and BC3 Opt1 as these are encumbered by residential roads.

[†]BC2 Opt 2 also includes ~5.5 km of infiltration trenches. This has not been included in the treatment area required as it is assumed to be installed in the encumbered waterway buffer.
The option comprising the largest land take is Base Case 2 Option 2 as this includes on lot permeable pavement and increased wetland sizes.

4. COST ESTIMATES

Costs estimates for each of the options have been estimated by building on Base Case 1 (BAU). Stormwater treatment costs were based on previous experience and supplier information. The cost estimates were then compared to the Levels of Service by producing 'cost curves' as directed by DELWP.

Base Case 2 Option 2 comprises the largest cost, as the level of treatment is driven by residential measures such as porous roads and driveways. Land acquisition costs are also highest for this option. It should be noted this is a "worst case" cost estimate for the porous road.

Base Case 3 Option 1 comprises the highest operational cost. This is driven by the higher cost associated with the regional stormwater harvesting system, as well as the cost of maintaining stormwater treatment assets.

The cost of waterway works has also been included. This cost decreases with increasing Levels of Service. The waterway works for Base Case 1 are significant. The proportion of avoided cost is assumed to correlate to the volume reduction achieved.

The cost curves relate capital cost to the Levels of Service achieved as shown on Figure 12.

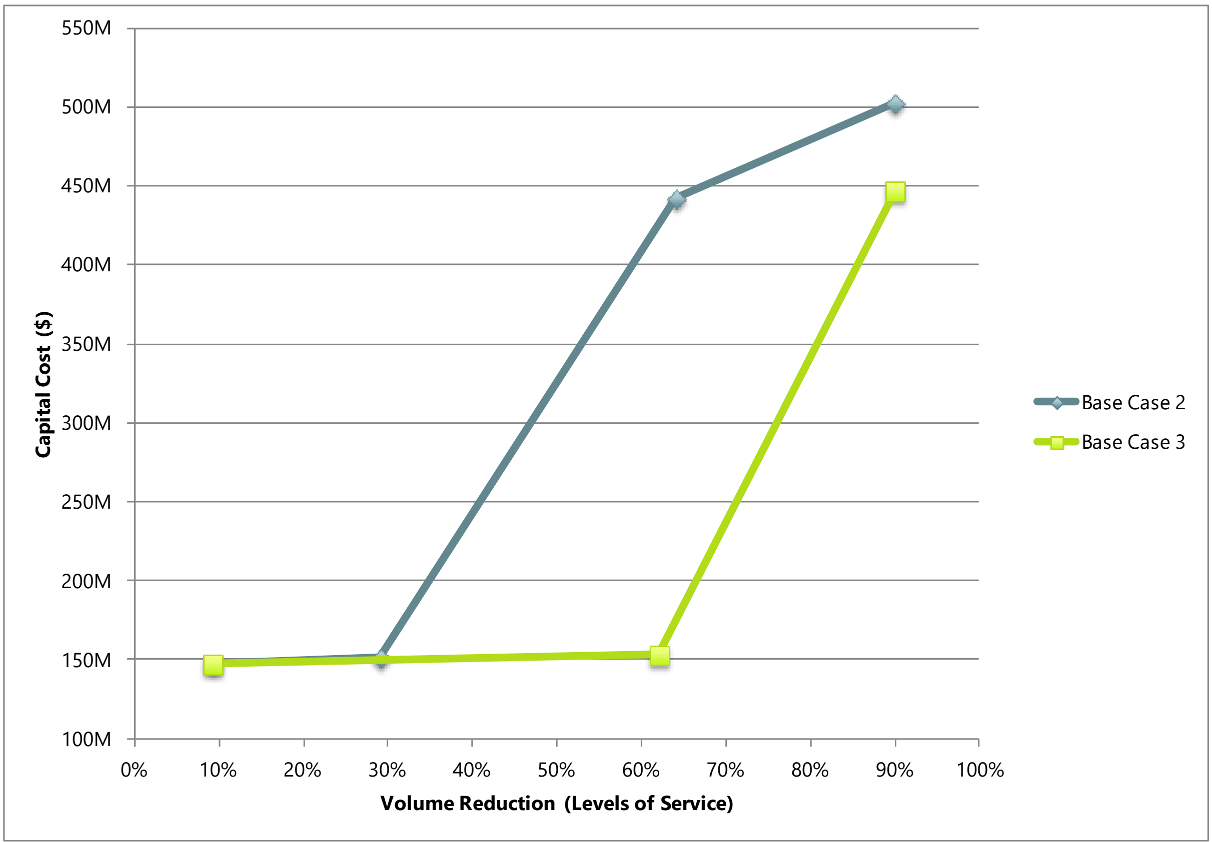

Figure 12 – Capital Cost Curve

Achieving the 60% Level of Service for Base Case 3 is a relatively flat line compared to the sharp rise to then achieve 90%. This is due to the high cost of implementing street and residential scale measures (over a large area). It should be noted, the sharpness of this rise may be skewed due to the high cost of porous roads and technological advancement in Australia is likely to reduce that capital cost overtime.

Cost curves for maintenance/operational cost were also developed including and excluding waterway avoidance cost as shown in Figure 13. This shows the avoided waterway costs incurred under the base case have a minor impact on maintenance costs.

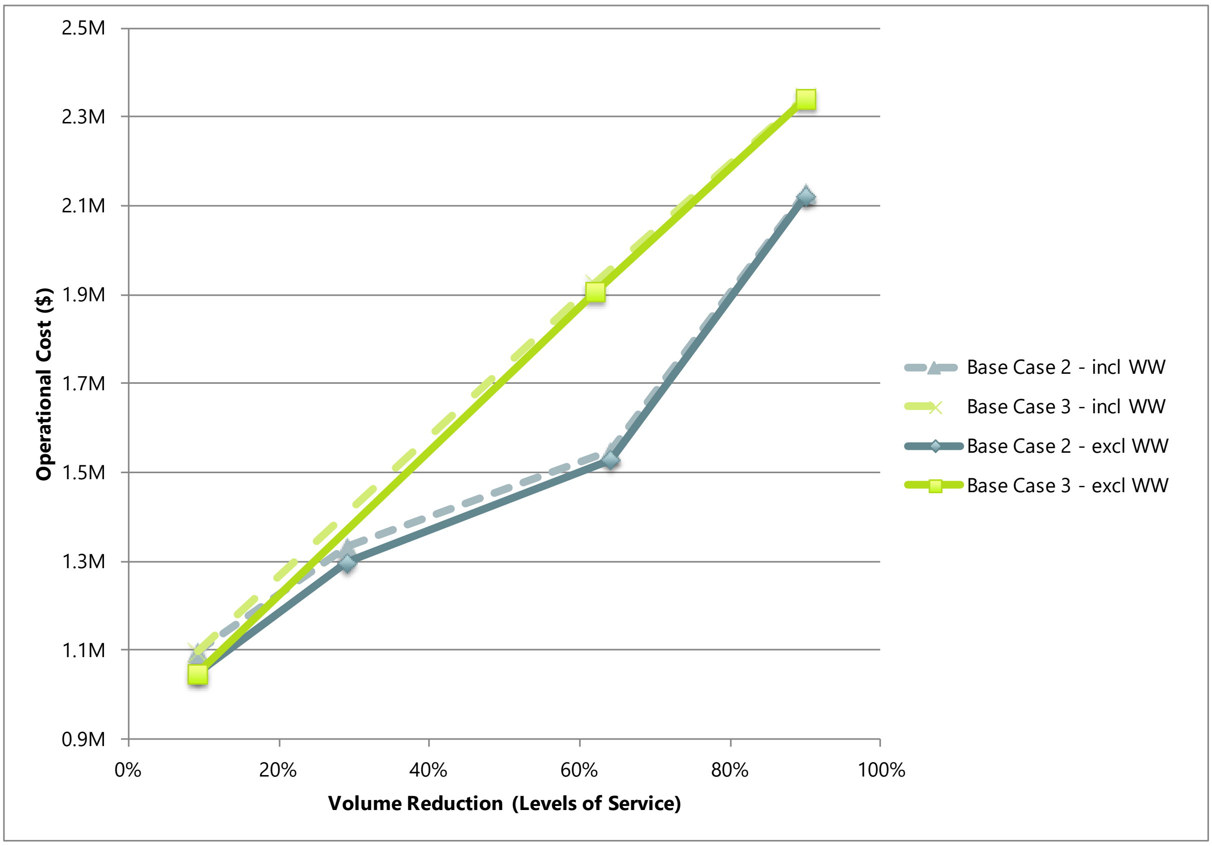

Figure 13 – Operational Cost Curve (Including and Excluding Waterway Costs)

As mentioned earlier in the report, alternative options and sensitivities exist in achieving the Levels of Service. The cost sensitivity investigates the lower bound estimates for porous roads and the potential to replace porous roads with injection of stormwater into the recycled water line (along with raingardens treating 2% of road catchment) to achieve the Levels of Service. Stormwater injection would be a localised connection at the stormwater harvesting systems (SWH1 and SWH2). These would each need a treatment plant and connect to the recycled water line (locally).

The capital cost curves for these two scenarios are shown in Figures 14 and 15. The costs are significantly lower, particularly for the stormwater injection scenario (Figure 15). It should be noted this sensitivity has addressed capital cost only and that maintenance and operating costs need to be considered when investigating stormwater injection with respect to treating this to Class A level.

This assessment has targeted catchment changes compared to end of line treatment. This is due to the damage that stormwater incurs once it has already entered the creek with end of line (stormwater harvesting) treatment. The LoS may be achieved quite effectively by the stormwater harvesting and injection option, however, this is often treated after the water has entered the creek, and only the downstream sections remain unaffected.

To mitigate this, trunk stormwater drainage could be installed along the length of the waterway (on both sides) to intercept stormwater and deliver this water straight to the stormwater harvesting systems.

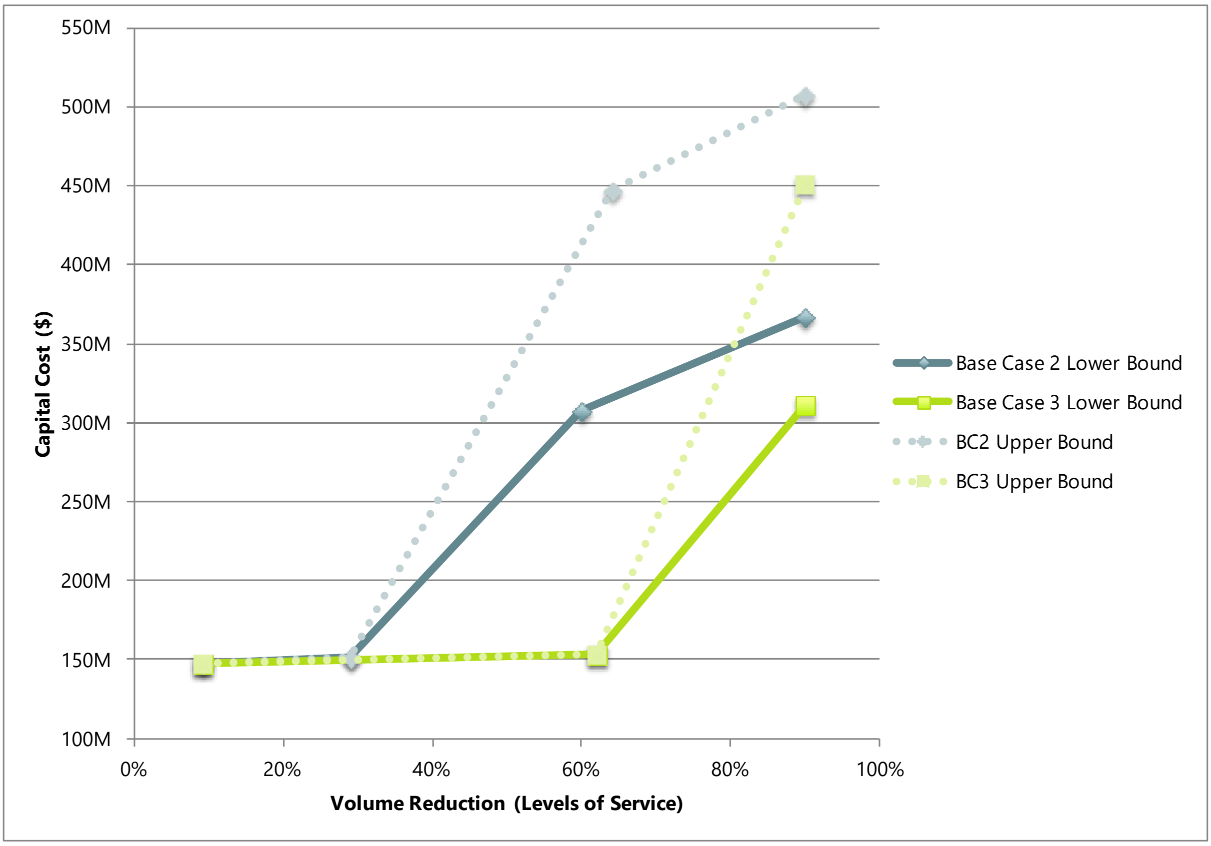

Figure 14 – Capital Cost Curve (upper and lower bound porous road)

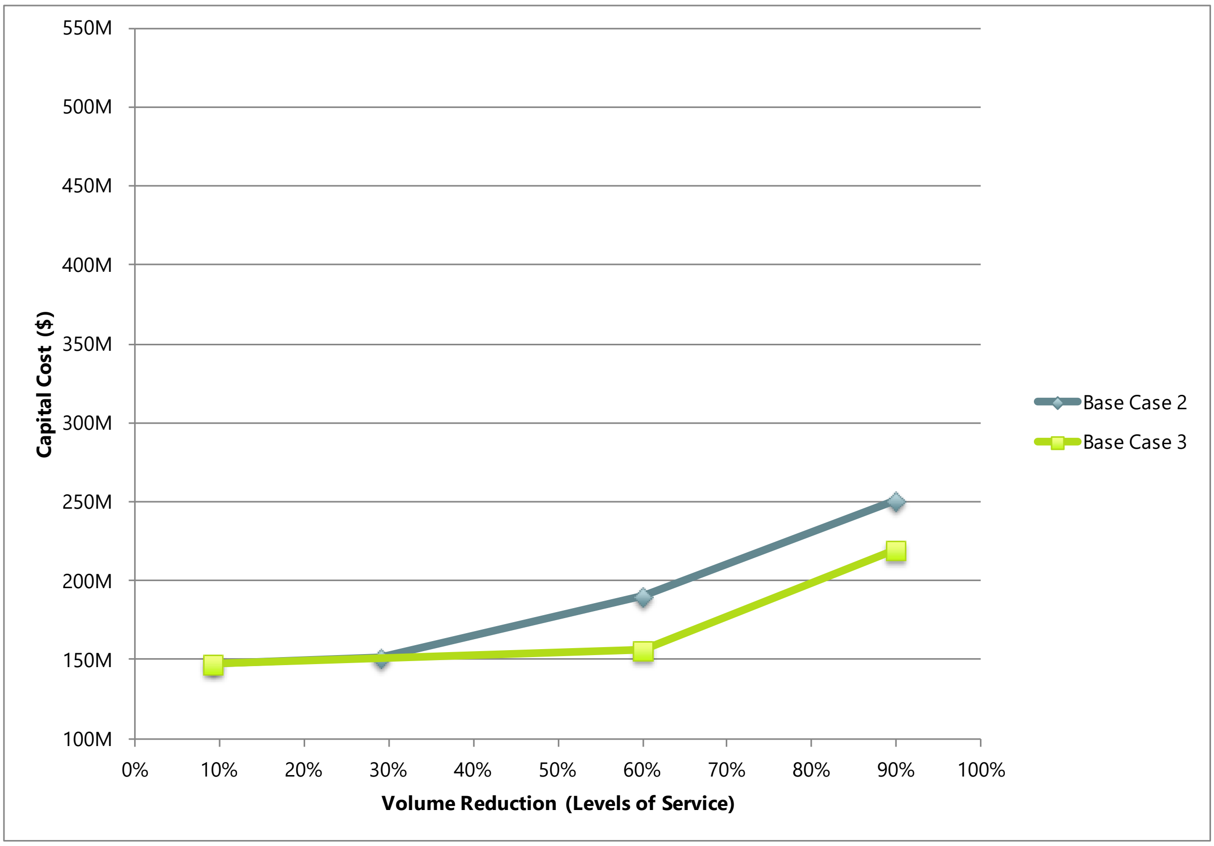

Figure 15 – Capital Cost Curve (SW injection – no porous road)

5. WATERWAY HEALTH ASSESSMENT

5.1. Objectives

Aside from cost, how do the Levels of Service perform with respect to other objectives? The waterway health assessment aims to examine the performance of the options based on a range of metrics expressing the ecological and geomorphological preservation of the waterway.

Several reaches along the Olive Grove waterway were identified as containing high values in a geomorphic and ecological study of the site (Alluvium, 2013). These are reaches that retain remnant features that have remained in good condition since European settlement and were recommended to 'maintain current form if feasible'.

It is likely that many waterways in similar rural areas would retain similar features, due to comparatively minimal anthropogenic impact. To determine whether the Levels of Service targeted can provide protection of the Creek's high values, several waterway health indicators have been investigated.

5.2. Waterway Health Indicators

The waterway health metrics/indicators to be investigated have been selected based on Duncan et al, 2014[4] reproduced as shown in Table 6. This table also describes the significance of the indicators to creek health.

As mentioned previously, the Duncan et al (2014) study indicates that a range between 70% - 90% volume reduction is required to maintain Kororoit Creek's current geomorphological and ecological form. This depends on the specific metric being evaluated. It should also be noted, the study found that not all indicators achieved the pre-development values, despite being in this volume reduction range.

[4] Duncan, HP, Fletcher, TD, Vietz, G & Urrutiaguer, M (2014), *The feasibility of maintaining ecologically and geomorphically important elements of the natural flow regime in the context of a superabundance of flow – Stage 1 Kororoit Creek study*.

Table 6 – Metrics chosen for the Kororoit Creek Catchment

Flow aspect	Metric selected	Definition and comments on calculation	Ecological or geomorphic significance
Low flow duration	Days per year of zero flow. Mean duration of zero flow periods	Zero flow days in full record divided by number of years. Zero flow days in full record divided by zero flow periods in full record.	Low flow periods affect habitat availability, as well as facilitating presence of species adapted to ephemeral conditions.
Low flow frequency	*Not used for Kororoit Ck, due to ephemeral nature*	Published metrics are unsuitable for highly ephemeral stream. Geomorphic metrics (see below) cover this aspect better.	-
Duration	Tqmean	Fraction of days with daily mean flow greater than annual mean flow.	Duration of peak flows is an indicator of the duration of 'disturbance events' (both water quality and hydraulic)
Rate of change	R-B Index	Sum of the absolute values of change in mean daily flows divided by the sum of the mean daily flows.	Variability of flows is an indicator of the duration of 'disturbance events'
Timing	Month of minimum monthly flow	Take mean of all flows in period of record in Jan, Feb, etc., and find minimum of these mean monthly flows.	Seasonality of minimum flows important for alignment with seasonal biological events.
Bed mobilisation	Fraction of time > $Q_{1.5yrARI}/2$	Empirically derived based on analysis of sediments in study catchment and critical shear stress needed to mobilise them, combined with 1D hydraulic model.	Bed erosion influences habitat availability
Bank mobilisation	Fraction of time > $Q_{2yrARI}/2$	Based on commonly-used threshold for bank mobilisation	Bank mobilisation affects sediment transport, habitat availability, riparian vegetation, etc.

5.3. Methodology

The MUSIC models developed for each of the options described in Section 3 were adapted for this assessment. While the Options Assessment (refer Section 3) uses a one year time period (to enable extensive sensitivity analysis of options), a longer time period of 5 years was adopted for the Creek Health Assessment as this is considered more suitable for the average outputs required. For example, output considers daily values against yearly averages. The rainfall period 1984 – 1988 was used as this is consistent with average rainfall for the area and also comprised variable yearly rainfall. A pre-development MUSIC model was also adapted.

Low flow duration, Tqmean, R-B index and timing were assessed on daily timesteps with bed and bank mobilisation based on 6 minute analysis. The more discrete timestep was used for the latter parameters due to the requirement to compare to peak flows.

With respect to bed and bank mobilisation indicators, the respective peak flows required were obtained from RORB modelling. Peak flow outputs were converted to a 6 minute period to compare to the MUSIC model output.

RORB output (Q1.5 / 2) also formed input to the 1D hydraulic modelling which was conducted in HECRAS (related to the bed mobilisation parameter).

The bed mobilisation metric required the determination of critical shear stress. This is the threshold that dictates the mobilisation of sediments specific to the site. Duncan et al (2014) defined 2 N/m^2 as the adopted lower limit, applying to gravel-sized sediments characteristic of Kororoit Creek.

Alluvium (2014), a study of the feasibility of protecting the Olive Grove waterway, indicates the subsurface comprises basalt which is resistant to weathering and observed 'scattered basalt stones and boulders, which generally become more concentrated along drainage lines'.

This is relatively consistent with the greater Kororoit Creek assessment (Duncan et al, 2014). USGS (2008) indicates 2 N/m^2 applies to fine gravel. This implies sediment sizing less than a fine gravel may be mobilised.

Average shear stress for the waterway was determined using HECRAS modelling for various peak flows beginning with Q1.5 / 2. The flow was varied to correlate to the critical shear stress.

A summary of the approach to assessing the parameters is shown in Table 7.

Table 7 – Summary of Creek Health Assessment Modelling Approach

Metric	Modelling Approach
Low flow duration (days = zero flow & mean duration of zero flow	MUSIC - daily timestep with a 5 year model period
Duration (Tqmean) = mean days > annual mean	
Rate of Change (R-B index) = sum daily change / mean daily flow	
Bed mobilisation (time > Qshear stress threshold / 2)	RORB (start with Q1.5) – convert to 6 min value HECRAS – vary Q to shear stress output (~2 N/m2) MUSIC – 6 min timestep with a 5 year model period
Bank mobilisation (time > Q2 / 2)	RORB (Q2 – convert to 6 min) MUSIC – 6 min timestep with a 5 year model period

5.4. Modelling Results

5.4.1. Daily Output Metrics

The parameters where daily output was required are low flow duration, Tqmean, R-B index and timing, with results as shown on Figures 16 to 19.

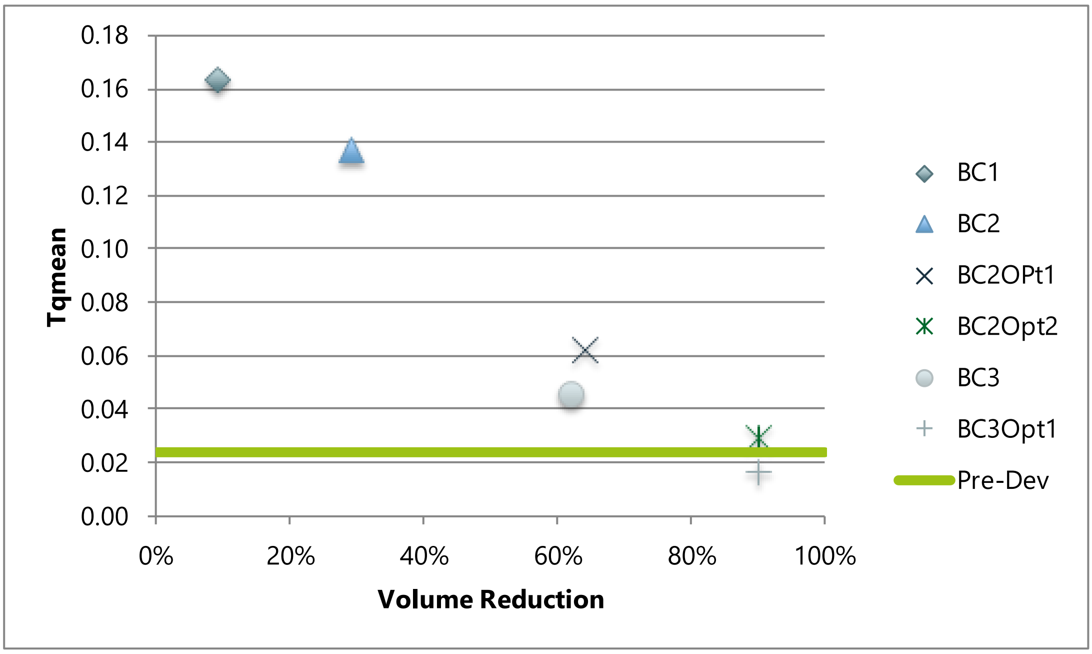

Figure 16 – Tqmean – Fraction of days with daily mean flow is greater than annual mean flow

As expected, the Tqmean reduces with increasing stormwater treatment measures, relating to the increasing Levels of Service. The treatment measures are dampening the excessive peaks incurred by urban development (reflected by the BC1 case with minimal treatment). BC2 Opt2 approaches pre-development levels, with BC3 Opt 1 the only scenario falling below pre-development.

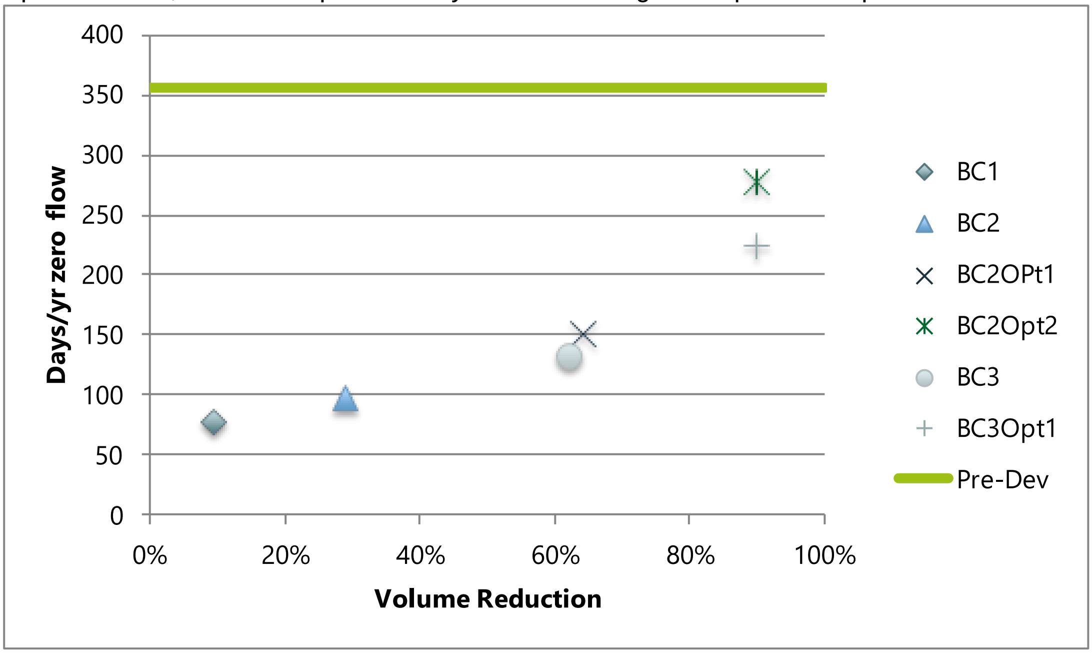

Figure 17 – Low flow duration – mean days per year of zero flow

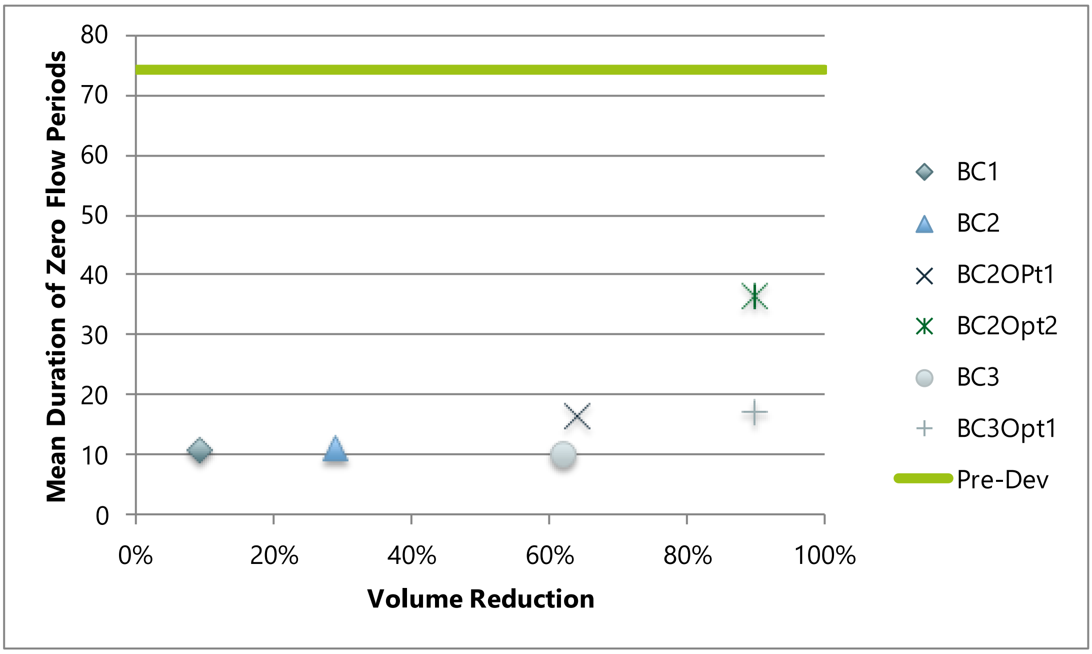

Figure 18 – Low flow duration – mean duration of zero flow periods

The two low flow duration metrics, shown on Figures 17 and 18, indicate none of the options can achieve the low flow characteristics of the pre-developed Olive Grove waterway. This is likely due to the farm dams. At present, the farm dams capture a significant amount of water and limit the flows that occur within the waterway. Removing these allows runoff to flow unhindered to Kororoit Creek. BC2 Option 2 is the configuration that gets closest to pre-developed levels.

The R-B Index, shown in Figure 19, does not show significant variation between the options. A general increase towards pre-development levels occurs, with the exception of BC2 Opt 1 and Opt2. These are approximately equal to or less than the BC1 level.

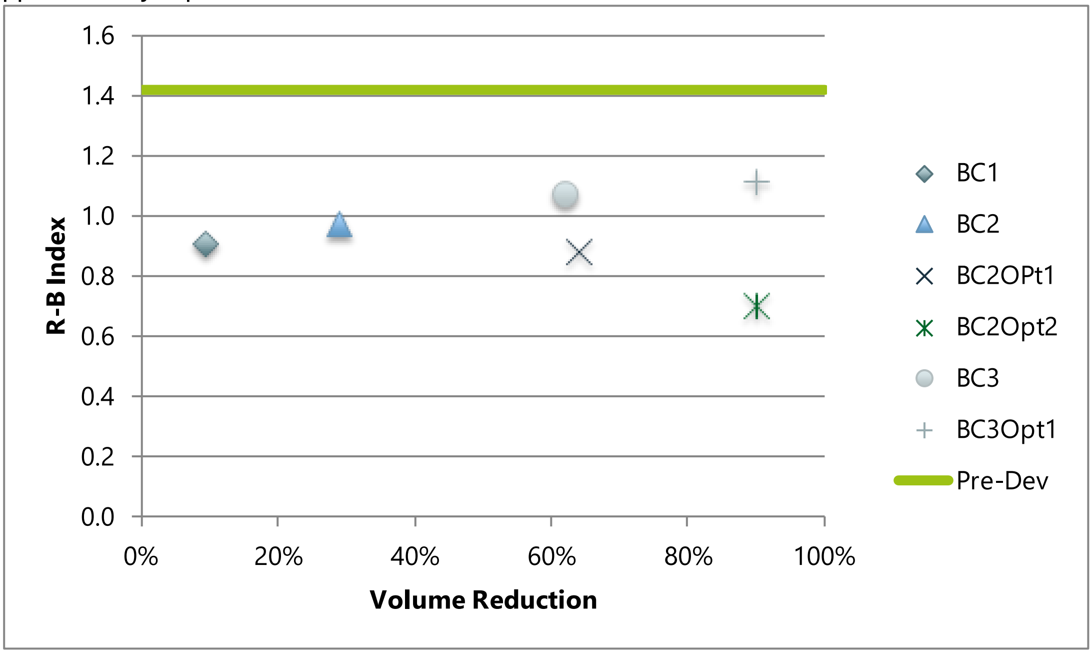

Figure 19 – R-B Index – sum of absolute values of change in mean flow / sum of mean flow

5.4.2. Bed and Bank Mobilisation

The results for the Bed Mobilisation metric are shown in Figures 20 and 21. Figure 20 shows that the 90% reduction Level of Service achieves pre-developed levels for the Q1.5 Yr / 2, however, the options targeting the 60% Levels of Service fall short. By comparison, Figure 21 indicates the 60% reduction options effectively achieve the Q = 0.13 m^3/s level. This indicates pre-developed flows spend a similar amount of time at the lower Q threshold compared to the investigated options (ie pre-development and Levels of Service mobilise fine gravel equivalent amount of time). However, once higher flows are investigated, the only options that can limit the flow to pre-development conditions are those at 90% reduction. This suggests the lower Level of Service does not mitigate the large flows sufficiently to achieve pre-development and allows flow rates to spend a larger amount of time above Q1.5 / 2 (course gravel is mobilised more times for the 60% reduction target than pre-development conditions).

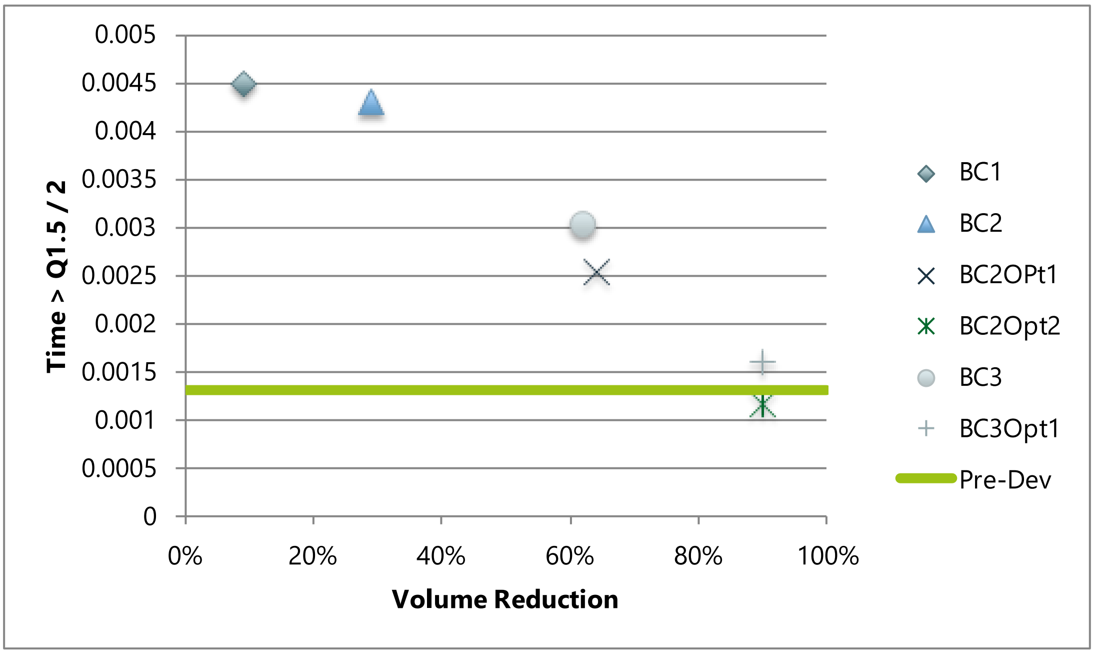

Figure 20 – Bed Mobilisation – fraction of time > Q1.5 / 2

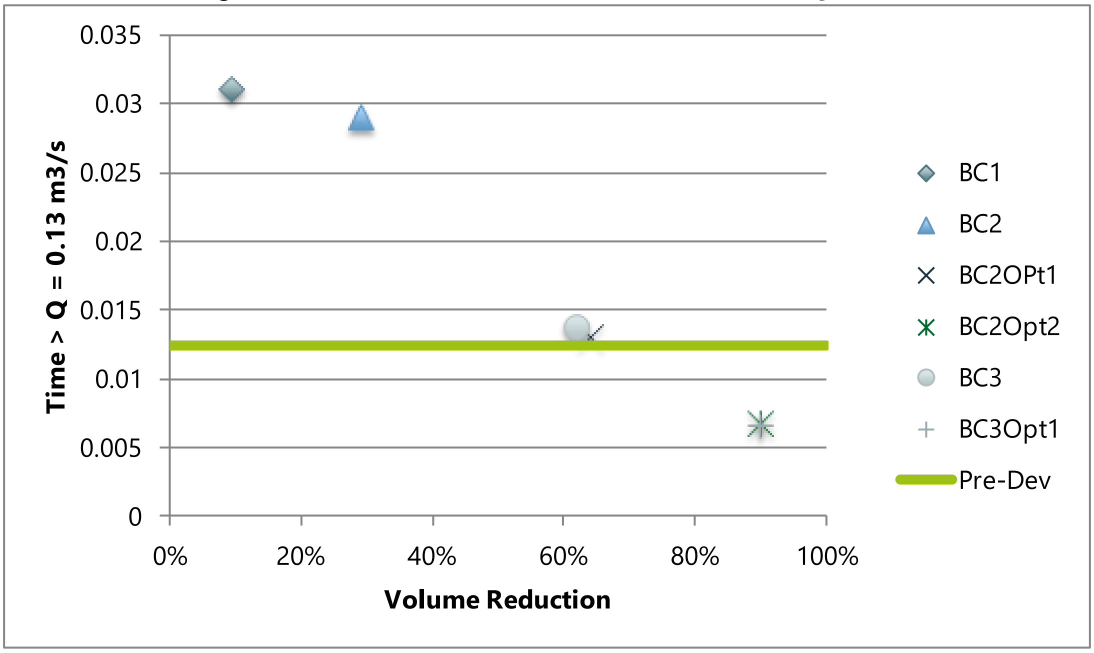

Figure 21 – Bed Mobilisation – fraction of time > 0.13 m3/s

The results for the Bank Mobilisation metric is shown in Figure 22 for all the options. Again the options approach pre-developed levels with increasing stormwater treatment measures. However, the only option for which the target is achieved is BC2 Opt 2.

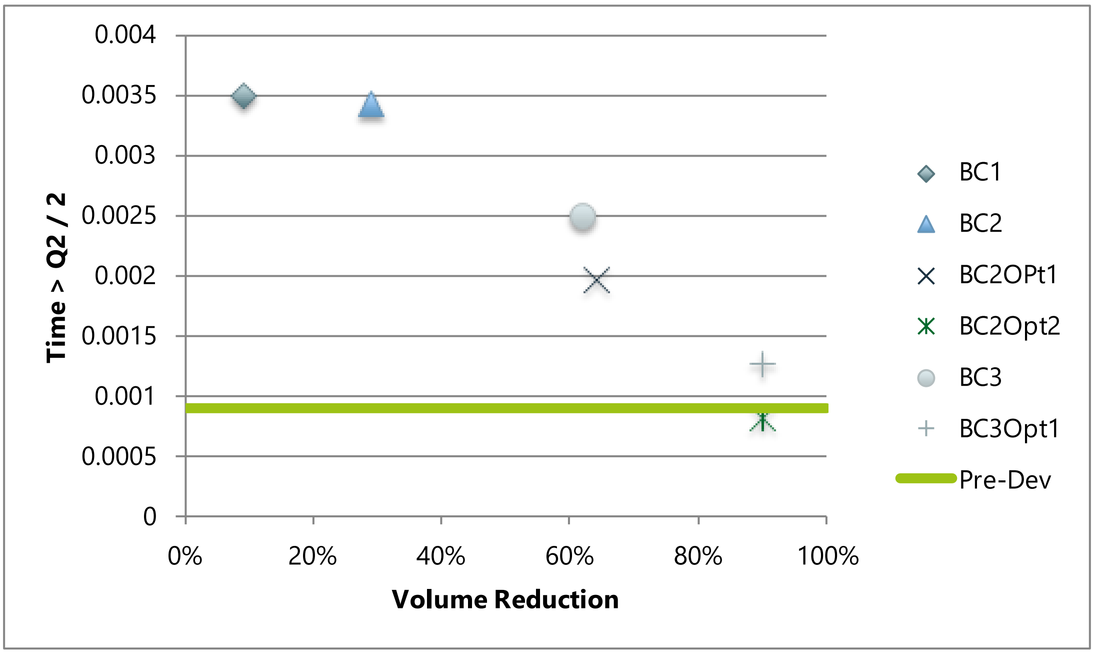

Figure 22 – Low flow duration – mean duration of zero flow periods

These metrics relate to the total treatment train effectiveness of the catchment, however, do not discriminate between which options protect the entire creek (ie between end of line and distributed treatment in the catchment). Base Case 2 Option 2 would be the best scenario in protecting the creek as stormwater is treated before entry to the waterway, with all other options involving measures that protect downstream sections rather than the whole waterway.

6. DISCUSSION AND RECOMMENDATIONS

This study indicates stormwater treatment measures required to achieve specified Levels of Service targeting waterway protection, are a combination of major catchment assets as well as street scale and residential measures. The large catchment assets, including offline wetlands, WSUD on major roads and commercial areas were not sufficient to achieve 60% and 90% reduction alone, and porous road surfaces were found to be the most effective additional measure. However, this was shown to come at the largest cost. This study has presented an upper bound cost for the porous road, assuming current permeable pavement is placed in residential roads, compared to a lower bound cost. The lower bound estimate represents the potential for appropriate technology to become available in Australia. It is pragmatic to assume that costs will reduce over time as new technology is introduced, making Base Case Option 2 and Base Case 3 Option 1 a more realistic and comparable alternative.

The above assessment considers distributed catchment measures as the primary means of reaching the Levels of Service for waterway protection. These measures have been valued higher than end of line treatments for protection of waterways (irrespective of expense) as stormwater is intercepted before entry to the creek. End of line treatments may show the LoS has been achieved, however, stormwater is treated after the water has entered the creek, and only the immediate downstream sections benefit. Nonetheless, there is room for compromise with the provision of proper design, for example, implementation of interception infrastructure along the length of the creek (both sides) to direct stormwater into the local harvesting systems without using the creek as the conduit.

Nonetheless, not all options performed well against selected waterway health metrics. In particular, the 60% Level of Service was insufficient for most metrics (with the exception of Bed Mobilisation for the lower Q threshold). The two options that achieve 90% volume reduction, BC2 Opt2 and BC3 Opt2, achieve close to pre-developed levels for most of the metrics.

The key outcomes of this study and recommendations for future work are as follows:

- Large assets alone cannot achieve high Levels of Service;

- The 90% volume reduction Level of Service generally achieves waterway health metrics (specific to the Olive Grove catchment only);
- Technological advancement in the industry should be encouraged to drive prices down;
- An alternative scenario for effective volume reduction, compared to porous roads and driveways, could be to extend local stormwater harvesting to provide for injection of excess stormwater to supplement Class A demands. This is likely to be a more cost effective option (as illustrated on Figure 16 – refer Section 4.5) and should be explored further.
- The Levels of Service and waterway health metrics do not discriminate effectively between options that protect the 'whole' creek. End of line treatments, such as stormwater harvesting, may involve deterioration of some sections of the creek as volumes have already entered the waterway. The % volume reduction and waterway metrics only assess the discharge downstream of these systems. In this study distributed catchment measures have been valued higher for protection of waterways, despite the much higher expense. However, there is room for compromise with the provision of proper design, for example, intercepting and delivering stormwater to harvesting systems prior to entering and deteriorating the waterway.

7. ACKNOWLEDGMENTS

Contributions were made form the following agencies: Department of Environment Land and Water Planning, City of Melton, City West Water, Melbourne Water, Metropolitan Planning Authority and Western Water. Jessica Ward also deserves specific acknowledgment in that she was a primary contributor to this assessment.

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