INTEGRATED WATER CYCLE MANAGEMENT AT ARMSTRONG CREEK – TOWARDS TARGETS FOR SUSTAINABLE DEVELOPMENT

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Introduction

The Melbourne and Geelong regions of Victoria in Australia are subject to strong population growth that has resulted in an apparent shortage of land available for new urban settlements and decline in the security of centralised urban water sources. New urban growth areas were selected by the Victorian government to increase the supply of land to accommodate expected ongoing population growth. The Armstrong Creek Urban Growth area is located between the City of Geelong and the coastal town of Torquay (COGG, 2006). It is expected that the Armstrong Creek Urban Growth Area will ultimately accommodate 22,000 dwellings, employment precincts and community facilities within the 2,350 ha site. The area will concentrate the majority of the future urban growth for Geelong and surrounding regions in a single location.

Australian capital cities have been historically dependent on rainfall runoff collected at inland dams for the majority of water supply. In recent times, the combined effects of drought, climate change and considerable population growth have raised concerns about the reliability of traditional urban water supplies (PMSIEC, 2007). Relatively small decreases in annual rainfall have resulted in large reductions in annual runoff entering inland water supply reservoirs (Coombes & Barry, 2008). The Melbourne and Geelong regions have been subject to severe water restrictions since 2006 and persistent lower levels of water restrictions since 2000. Combined water storage levels of dams supplying Melbourne have been below 60% of capacity since 2000, reaching a low level of about 26% in 2006 and are currently at 30% of capacity. Water storage levels in dams supplying the Geelong region have declined to a low of 15% in 2007 and are currently at 21% of capacity. The Geelong region is also dependent on groundwater to supplement water supplies from dams.

Population growth will continue to increase pressures on regional water resources. In addition, new urban settlements are increasingly remote from centralised services which compound declining natural resources with increasing infrastructure and conveyance costs. The ongoing sustainability of urban settlements is also further impacted by local and regional environmental impacts. For example, the Armstrong Creek Urban Growth Area is mostly located in the environmentally sensitive Armstrong Creek catchment which discharges to Barwon River and the RAMSAR wetlands Reedy Lake and Lake Connewarre.

The reliability of traditional urban water supplies is uncertain. A diverse portfolio of water management options that includes wastewater reuse, rainwater and stormwater harvesting, demand management and larger regional strategies is required to provide certainty about future urban water supplies (PMSEIC, 2007). It is proposed that the integration of local water cycle management strategies in regional planning for new urban growth areas will improve the sustainability and affordability of new settlements. This study has employed integrated systems analysis to examine integrated water cycle management options for the Armstrong Creek Urban Growth. Objectives for integrated water cycle management strategies should combine best practice stormwater management with reductions in mains water use and wastewater discharges. The analysis also considered greenhouse gas emissions, costs and benefits, and timing of the development. This study references the original conceptual analysis by Bonacci Water (2008) and includes the results of ongoing analysis to test the argument for innovation in land release areas by incorporation of sustainability targets in precinct based infrastructure plans.

Setting Objectives

A wide range of stakeholders were interviewed to determine objectives for water cycle management at the Armstrong Creek growth area. The agreed objectives relating to the control of flooding, management of receiving water quality and targets for reductions in mains water use and waste water discharges by 70% and 50% respectively. The infrastructure system that delivers these services should feature, where possible, reduced greenhouse gas emissions, and low operating and maintenance costs. It was also a key objective to encourage the development of a smart and green community with a high level of amenity.

Options

This study has focused on the opportunities to reduce mains water demands and sewerage discharges from the Armstrong Creek Urban Growth Area whilst minimising impacts on local environments. Six alternative options for water cycle management have been examined. The performance of each Option was compared to the performance of the Business as Usual (BAU) Option.

Option 1: Business As Usual

Water supply to the Armstrong Creek Urban Growth Area will be sourced from the Geelong's centralised water supply managed by Barwon Water. It was assumed that desalinated seawater from Wonthaggi and water from the Goulburn River from the Food bowl Modernisation Project will allow additional capacity in Melbourne's water supply. Transfer of some of Melbourne's water supply capacity to Geelong via the Melbourne to Geelong pipeline will allow additional capacity in Geelong's water supply which can be used to supply the Armstrong Creek Urban Growth Area. Previous studies have estimated that the average cost of desalinated water to be $1,900/ML and the energy demand from desalination to be 4,900 kWh/ML (DSE, 2006). These values were used in this study as the cost and energy impacts of mains water supply. This study has not assumed that the energy demands from desalination are neutralised by green power because the provision of green energy is not usually included in the costs for provision of water projects. In addition, lower carbon energy sources should be utilised to reduce our existing carbon footprint rather than to neutralise new water sources that have a high energy demand.

All sewerage from the Armstrong Creek Urban Growth Area will be directed to the existing Black Rock Treatment Plant and ocean outfall. Stormwater runoff from the Armstrong Creek development will be controlled by use of a series of regional detention basins and stormwater quality will be addressed by provision of constructed wetlands and Gross Pollutant Traps (GPTs). The detention basins were designed to ensure a no worsening of stormwater peak discharges from the fully developed Armstrong Creek area in comparison to existing conditions for all design storm events from a 1 year to 100 years Average Recurrence Intervals (ARI).

Constructed wetlands and Gross Pollutant Traps (GPTs) were designed to ensure that stormwater runoff from the Armstrong Creek area was compliant with “best practice” stormwater quality guidelines that require an 80% reduction in suspended solids, 45% reduction in phosphorus and nitrogen, and a 70% reduction in litter. The installation costs of detention basins, constructed wetlands and Gross Pollutant Traps (GPTs) used in this study were $35/m^3$, $95/m^3$ and $2,000/m^3/s respectively. Annual operation and maintenance costs employed in this study sourced from a range of industry publications for detention basins, wetlands and GPTs were 4% of installation cost, $11,000/ha and 5% of installation cost respectively. This study has defined a net land value of $100,000 per conventional allotment as the sale price of a fully serviced conventional allotment less the land and infrastructure costs.

Option 2: Rainwater Tanks

In Option 2, rainwater collected from 100 m^2 roof areas in conventional and medium density housing and used for toilet flushing, laundry and for garden watering. It was also assumed that 10,000 L rainwater tanks would also collect rainwater from 300 m^2 roof areas of high density buildings to supply clusters of 6 dwellings. Each rainwater supply system will include a small first flush device (20 L) and a mains water bypass system for backup during period when water levels in tanks are low. Option 2a employs 3,000 L rainwater tanks and Option 2b employs 5,000 L rainwater tanks to supply conventional and medium density housing.

The average costs to install 3,000 L and 5,000 L rainwater tanks to supply laundry, toilet and outdoors uses of $2,765 and $3,055, respectively, was sourced from recent research into the rainwater industry (Coombes, 2007). This research has established that the energy use of the most common rainwater pumps (0.45 kWh) is 1,068 kWh/ML of rainwater supply. On average, rainwater pumps will have a design life of 10 years and a replacement cost of $400. A long term annual rainfall sequence (Figure 1) and a monthly distribution of rainfall (Figure 2) from Geelong suggests that rainwater tanks will provide a reliable source of water in the Armstrong Creek Urban Growth Area.

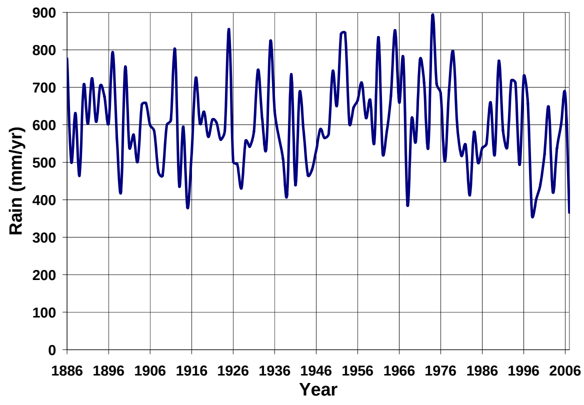

Figure 1: Annual rainfall in the Geelong area

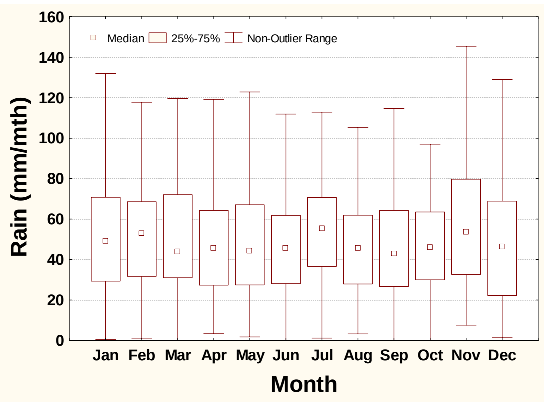

Figure 2: Monthly distribution of rainfall in the Geelong area

Figure 1 shows that Geelong has been subject to a number of droughts since 1886 and the current drought may not be the worst on record. Importantly, sufficient annual rainfall is available, even during droughts, to support the reliable annual yields from rainwater tanks. Similarly, Figure 2 reveals that Geelong is subject to an even distribution of rainfall throughout the year which will facilitate a generally reliable seasonal supply of rainwater.

Option 3: Rainwater Tanks Plus Water Sensitive Urban Design

Option 3 envisions a treatment train philosophy that combines rainwater tanks and accepted water sensitive urban design (WSUD) approaches. Elements of this approach would include linear bio-retention systems along appropriate areas of arterial roads (medians within dual carriageways), suburban streets and public open space. It is assumed that the WSUD systems with sub-surface storage volumes of 42 m^3/ha will be strategically located to reduce the effective impervious areas of development. Two WSUD options were evaluated that incorporate 3,000 L rainwater tanks (Option 3a) and 5,000 L rainwater tanks (Option 3b). The installation costs of the bio-retention strategies were assumed to be \$150/m^3 of storage. Operation and maintenance costs of 4% of installation costs were adopted. Incremental renewal and adaptation expenses of 2% of installation costs were used in this study.

Option 4: Wastewater Reuse

Analysis of Option 4 considers two variants, 4a and 4b, for the delivery of wastewater reuse at the Armstrong Creek Urban Growth Area from a treatment plant at Black Rock or from treatment plants within the Growth Area, respectively. Treated wastewater will be supplied via a third pipe distribution system for toilet, outdoor, commercial, industrial and open space uses. This study has assumed that 50% of non-residential water demand can be supplied with treated wastewater.

The costs of installing the third pipe within the development to deliver treated wastewater were assumed to be $2,000 per dwelling. It was expected that planning controls will be used to ensure dwellings are built to accept recycled wastewater thereby reducing the costs of plumbing connections. The costs of trunk infrastructure and wastewater treatment plants will be dependent on the sewerage and wastewater reuse flow rates in each Option. The operating costs of wastewater treatment using membrane bioreactors and ultra-filtration was estimated to be $328/ML. Additional treatment and distribution costs were assumed to be 1% of installation costs. The energy use to supply treated wastewater from Black Rock was calculated to be 5,220 kWh/ML and wastewater reuse from the Armstrong Creek treatment plants was 3,780 kWh/ML.

Option 5: Water Efficient Appliances and Gardens

Option 5 includes water efficient clothes washers, shower heads and gardens. Water efficient clothes washers are currently adopted in about 8% of Melbourne's households and are expected to reduce laundry water use by 50%. The small proportion of water efficient clothes washers impacting on current water demand trends indicates that adoption in a demand management strategy should produce maximum water savings. Installation of water efficient clothes washers is expected to reduce energy use by 3.5 kWh/ML of water saved. Water efficient shower roses have a 52% adoption in Melbourne and are expected to reduce bathroom water use by 20% from current water use patterns. Energy savings of 6.4 kWh/ML of water saved area expected. It is expected that the incorporation of water efficient gardens in the Armstrong Creek area with support from Council planning policies and a local plant nursery will reduce garden water use by 50%.

Water efficient appliances have design lives of about 10 years. This study estimated the residual cost of installing a water efficient clothes washer to be $300 and $60 for a water efficient shower head. The residual cost is the difference between purchasing traditional and water efficient appliances. Current water use patterns include water savings from water efficient 6/3 L flush toilets that are installed in over 85% of Melbourne's households. Additional water savings from 6/3 flush toilets have not been counted in this study.

Option 6: Rainwater Tanks Plus Water Efficient Appliances and Gardens

This option combines rainwater tanks used to supply household laundry, toilet and outdoors uses (Options 2a and 2b) with water efficient appliances and gardens. Option 6a includes 3,000 L rainwater tanks and Option 6b includes 5,000 L rainwater tanks.

Option 7: Integrated Water Cycle Management

Option 7 is an integrated water cycle management strategy incorporating all of the above elements. Option 7a includes treated effluent from a wastewater treatment plant at Black Rock, 12.5km away, used for toilet flushing, garden watering and open space irrigation. Option 7b includes wastewater treatment plants within the Armstrong Creek Urban Growth Area. Class A+ treated effluent will be distributed to households and commercial users via a third pipe distribution network. Rainwater tanks in Option 7 are used to supply domestic laundry and hot water demand.

Methodology

This study employed a systems analysis of combined infrastructure Options using linked models. The PURRS model was used to continuously simulate residential water demands, sewerage discharges and the performance of lot scale measures at 6 minute time steps over a 122 year period. Non-residential water demands were assigned to each location that included employment or activity centre land as a proportion of residential water demand and land area assigned to employment or activity centres. This study adopted a non-residential water demand of 34% of total water demand for Armstrong Creek that accounted for employment centres, shopping precincts within activity centres, schools and open space.

Results from the PURRS simulations were combined with climate sequences in the network linear program WATHNET to evaluate the performance of the water supply, sewerage disposal and wastewater reuse systems at catchments within the Armstrong Creek Urban Growth Area. The distribution of water, sewerage and recycled water throughout the Growth Area was simulated for a 122 year period at daily time steps. This allowed analysis of peak flows in trunk infrastructure and assessment for regional sewerage discharges and water demands. The long term climate inputs (temperature and rainfall) to the PURRS model were adjusted to account for an assumed "worst case" potential for climate change derived from Coombes & Barry (2008) as shown in Table 1.

Table 1: Expected impacts of climate change on temperature and rainfall

Parameter	Expected change by 2030 for a given season			
	Spring	Summer	Autumn	Winter
Temperature (°C)	+ 1.6	+ 1.3	+ 1.3	+ 1.3
Rainfall (%)	-20	-15	-15	-15

The assessment of the stormwater runoff characteristics of the site in the existing and developed states was undertaken using WUFS (Water Urban Flow Simulator) developed at the University of Newcastle and the MUSIC model provided by the CRC for Catchment Hydrology.

Results and Discussion

Water and Wastewater

The demands for mains water and sewerage discharges at the Armstrong Creek Urban Growth Area from each Option are shown in Figures 3 and 4, respectively.

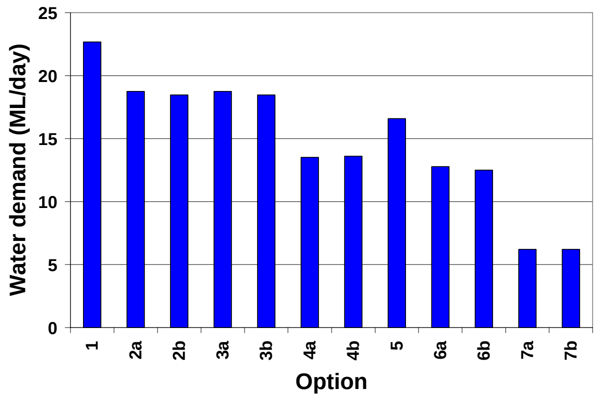

Figure 3: Average daily mains water demand for the Armstrong Creek development.

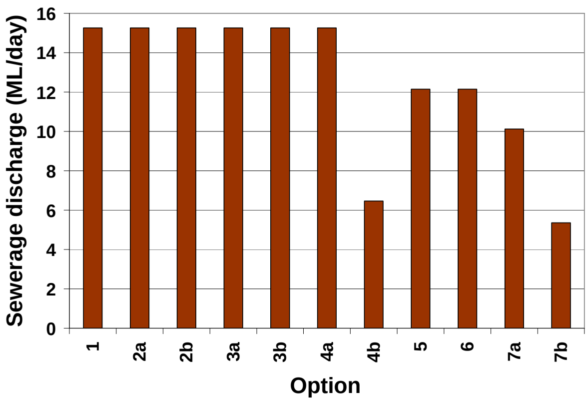

Figure 4: Average daily sewerage discharges from the Armstrong Creek Development.

Figure 3 reveals that significant mains water savings can be achieved by use of an integrated water cycle management strategy. The Options using 3,000 L (2a and 3a) and 5,000 L (2b and 3b) rainwater tanks to supply laundry, toilet and outdoor uses reduced average daily mains water demands by 17% and 19% respectively. Options 4a and 4b involving use of recycled wastewater for household toilet and outdoor uses, and open space irrigation reduced mains water demands by 40%. Whilst the use of water efficient washing machines, shower heads and gardens reduced average annual water demands by 27%.

A combination of rainwater tanks, water efficient appliances and gardens, in Options 6a and 6b, provides 44% and 45% reductions in mains water demands, respectively. Integrated water cycle management Options 7a and 7b that includes 3,000 L rainwater tanks used to supply household laundry and hot water uses, wastewater reuse for toilet, outdoor and open space uses, and water efficient appliances and gardens generates a 73% reduction in mains water demands. Importantly, this Option has reduced average annual water demands to a level that would avoid or defer the need for augmentation of regional water systems.

Figure 4 shows that use of water efficient appliances in Options 5 and 6 (6a and 6b) will reduce sewerage discharges from the Growth Area to Black Rock by 20%. Option 4b that employs wastewater treatment plants within the Growth Area to supply treated wastewater reduced sewerage discharges to Black Rock by 57%. The supply of treated wastewater for toilet, outdoor and open space uses from a treatment plant at Black Rock with water efficient appliances in Option 7a decreases sewerage discharged from the Growth Area by 33%. In contrast, wastewater treatment plants within the Growth Area with water efficient appliances in Option 7b decreases sewerage discharges from the Growth Area by 65%. Options that do not include water efficient appliances or wastewater reuse do not reduce sewerage discharges from the Growth Area and the use of wastewater treatment plants located within the Growth

Area produces considerable additional reductions in sewerage discharges to the Black Rock ocean outfall.

Stormwater

Urban development in the Growth Area will produce substantial increases in stormwater runoff in comparison to existing conditions. The Options using rainwater tanks, 2a and 2b, reduce stormwater runoff volumes from the developed case by 16% and 17% respectively. Options that employ bio-retention systems with rainwater tanks, 3a and 3b, reduce stormwater runoff volumes from the developed Option by 23% and 25% respectively.

Options using rainwater tanks and bio-retention were designed in accordance with best practice guidelines. However substantial increases in stormwater runoff volumes were simulated in comparison to runoff volumes discharging from existing catchments. This result shows that the rainwater tanks and bio-retention systems will not reduce environmental flows to less than existing flows. The requirement for stormwater detention basins and constructed wetlands in each catchment for each Option is shown in Figures 5 and 6 respectively.

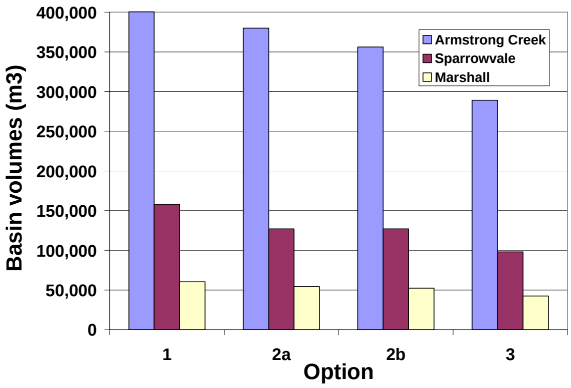

Figure 5: Requirement for detention basins

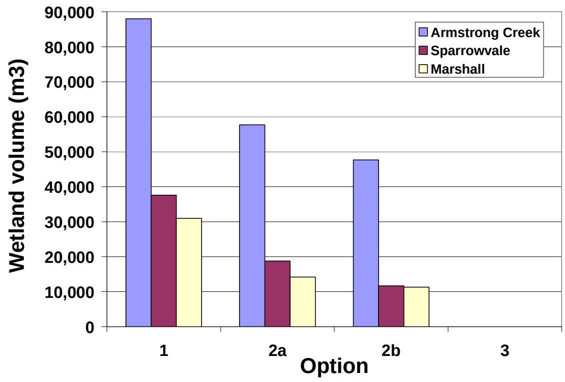

Figure 6: Requirement for constructed wetlands

Figure 5 shows that rainwater tanks reduce the volumes and land areas of detention basins required to manage stormwater peak discharges from the developed catchments. A combination of rainwater tanks and linear bio-retention provides substantial reductions in the requirement for centralised infrastructure. Figure 6 reveals that the use of rainwater tanks will almost halve the requirement for constructed wetlands and land area required to met stormwater best practice guidelines. The combined use of rainwater tanks and linear bio-retention eliminates the requirement for constructed wetlands to meet best practice stormwater quality guidelines.

Economics

The economic performance of each option was evaluated from a whole of society perspective. A net present value of each option was determined using a 30 year horizon that commenced from the 11^{th} year of the development to accommodate City of Greater Geelong's accelerated growth strategy of 10 years and a 5% discount rate. As the net difference to the BAU Option was investigated, the asset values and deterioration of infrastructure has not been included. It is acknowledged that this analysis may under-estimate the value of the alternative Options.

Installation, operation, maintenance and replacement costs for the majority of assets in the alternative Options have been counted in this analysis and are summarised in previous Sections. The replacement costs of assets expected to have an operational life of less than 30 years that were different to the BAU Option were included in this analysis. The maintenance and operational costs including energy costs of alternative water sources used in this analysis are assessed as the net difference to the costs of supplying water from desalination and other centralised schemes reliant on long pipelines. However, this analysis has not counted the transfer costs associated with using desalinated water throughout the Greater Melbourne region. These costs are currently unknown and are the subject of the author's current research. The net installation and lifecycle costs used in this study are summarised in Table 2. Note that a net negative cost (eg; -2.9) indicates a net benefit.

Table 2: Net installation and lifecycle costs for each Option

Option	Net installation costs ($M)				Net lifecycle costs ($M)			
	Water	Sewer	Reuse	SW	Water	Sewer	Reuse	SW
2a	40.7	0	0	-18.9	-2.1	0	0	-0.2
2b	47.3	0	0	-30.1	-2.3	0	0	-0.2
3a	40.7	0	0	-101.8	-2.6	0	0	-0.1
3b	47.3	0	0	-133.6	-3	0	0	-0.1
4a	-18	0	118.2	0	-5.2	0	6.6	0
4b	-17.9	-15	104.9	0	-5.7	-0.2	6.4	0
5	3.9	-5.5	0	0	-6.4	-0.1	0	0
6a	53.7	-5.5	0	-18.9	-6.3	-0.1	0	0
6b	60.3	-5.5	0	-30.1	-6.4	-0.1	0	0
7a	47.2	-10.2	91.5	-101.8	-10.1	-0.1	6.3	-0.1
7b	47.2	-17.4	80.3	-101.8	-10.6	-0.2	6.2	-0.1

Note that the installation costs of rainwater tanks and water efficient appliances are included in the water category in Table 2.

The relative economic performance of each of the Options is summarised as Net Present Values in Figure 7. Use of net present values, in isolation, can be misleading for the assessment of water related alternatives. The magnitude of water savings also needs to be considered in an economic analysis. The "levelised benefit" of each Option was evaluated as the net present value divided by accumulated water savings over the 30 year period used in the economic analysis and shown in Figure 8.

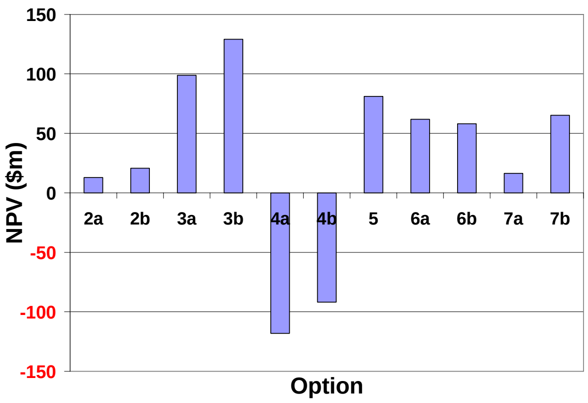

Figure 7: Relative Net Present Value of the alternative Options

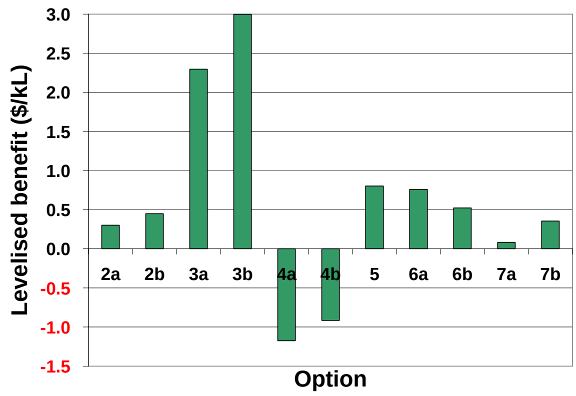

Figure 8: Relative levelised benefits for the alternative Options

Figure 7 shows that the Options 2a and 2b using rainwater tanks are subject to small net present benefits whereas Options that include rainwater tanks in a combined strategy (3a, 3b, 6a, 6b and 7b) produce greater net present benefits. This result highlights the importance of the economic evaluation of Options that include integrated portfolios of measures in preference to the discrete evaluation of each measure.

Incorporation of rainwater tanks in water sensitive urban design “treatment train” Option that is reliant on linear bio-retention strategies as in Options 3a and 3b produces combined stormwater benefits that overwhelm costs. Use of water efficient appliances and gardens (Option 5) was also found to have a net present benefit. Figure 7 also reveals that wastewater reuse for toilets, outdoor and open space purposes in Options 4a and 4b were subject to net present losses whereas the Options that include wastewater reuse in combined strategies (7a and 7b) produce net present benefits. The costs of providing and operating the wastewater reuse infrastructure in Options 4a and 4b overwhelm the benefits derived from water savings and reductions in the requirement for water and sewerage infrastructure. The considerable difference between the net present losses in Options 4a and 4b is also significant. The net present losses in Option 4a are higher due to the additional costs for wastewater treatment, storage and transfer across 12.5 km distance to the Growth Area from a treatment plant at Black Rock.

In contrast, the integrated water cycle management strategies (7a and 7b) provide combined water savings, stormwater benefits, and considerable reductions in the requirement for water and sewerage infrastructure that overwhelm the costs of providing and operating the infrastructure. Some additional insight provided by this study is also important; there is an optimum size, location and target water demands for a wastewater reuse strategy. The location of two smaller wastewater treatment plants within the Armstrong Creek development reduces installation costs by 35% in comparison to a single wastewater treatment plant located at Black Rock. In addition the placement of wastewater treatment plants at strategic locations within the development reduces the costs of water transport and for the provision of water, wastewater reuse and sewerage infrastructure by considerable amounts.

Greenhouse Gas Emissions

The greenhouse gas emissions from the alternative Options are compared to emissions from the BAU Option in Figure 9.

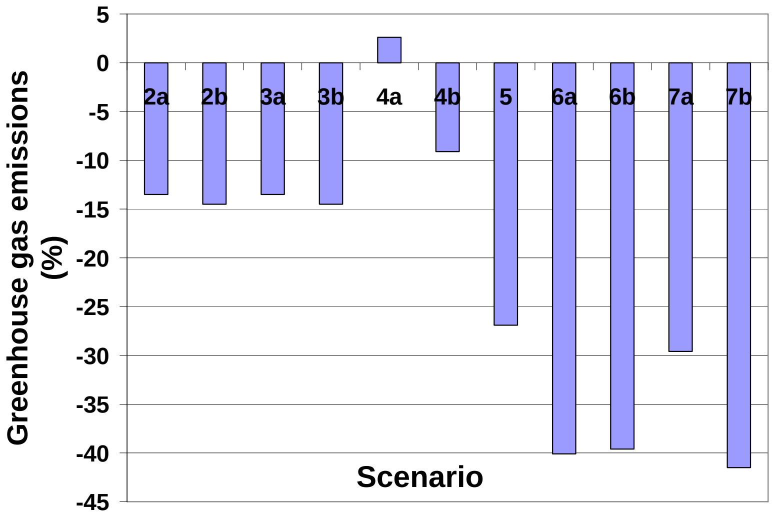

Figure 9: Difference in greenhouse gas emissions for each Option from a BAU Option.

Figure 9 reveals that the supply of treated wastewater from a treatment plant at Black Rock (Option 4a) will increase greenhouse gas emissions due to the additional energy required to pump treated wastewater from Black Rock to the Growth Area. The importance of this issue is highlighted by the relative reduction in greenhouse gas emissions generated by the use of wastewater treatment plants within the Armstrong Creek Urban Growth Area (Option 4b).

The remainder of the Options that include local water management strategies provide significant reductions in greenhouse gas emissions in comparison to the BAU Option. Options using water efficient appliances and gardens (5), combinations of rainwater tanks, water efficient appliances and gardens (6a and 6b), and integrated water cycle management (7a and 7b) produce large reductions in greenhouse gas emissions.

Conclusion

This study provides a compelling argument for innovation in new land release areas that incorporates a precinct based infrastructure planning philosophy. The use of integrated systems analysis to examine water cycle management options allows an understanding of reduced requirement for infrastructure generated by different strategies. A wide range of options for providing water cycle management services for the Armstrong Creek Urban Growth Area were assessed against multi-criteria objectives for the project that included development of a green suburb and a range of community sustainability goals.

An integrated water cycle management that includes the use of rainwater tanks, water efficient appliances and gardens, and wastewater reuse from treatment plants located within the development area provided the greatest benefits. These benefits included a net present benefit, 75% reduction in mains water demand, 63% reduction in wastewater discharges to the ocean and the greatest reductions in greenhouse gas emissions. This strategy will also improve the security of water supplies in the Greater Geelong region allowing the avoidance or deferral of some local and regional augmentation strategies.

Targets for reduction of mains water demands and sewerage discharges of 60% and 50% can be included the planning policies for new land release areas.

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