Australian Academy of Technological Sciences and Engineering (ATSE)

DRINKING WATER THROUGH RECYCLING

THE BENEFITS AND COSTS OF SUPPLYING DIRECT TO THE DISTRIBUTION SYSTEM

APPENDIX B

HYPOTHETICAL COMPARISON OF FOUR WATER SUPPLY OPTIONS

Date of publication: October 2013

ATSE

Australian Water Recycling Centre of Excellence Study

Financial and Life Cycle Inventory Analysis of Alternative Water Supply and Recycling Options in Australia

June 2013

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1. Introduction

1.1 Background, Scope and Limitations

This report summarizes the outcomes from a study undertaken by GHD in response to a commission by the Australian Academy of Technological Sciences and Engineering (ATSE)[1]. This study forms part of a larger research project funded by the Australian Water Recycling Centre of Excellence and carried out at the University of New South Wales.

The key requirements of the Brief[2] for this study were as follows:

1. To construct four scenarios based on alternative water supplies options for a hypothetical coastal city in Australia. The four scenarios are:

- Seawater desalination (delivery system to be defined in the hypothetical)
- Indirect potable reuse: pumping to a surface reservoir 100 km from the coast at an elevation of 150 m
- Direct potable reuse: with the same delivery system in terms of pipeline length and elevation as for the Seawater desalination option, namely, a delivery system to a drinking water treatment plant 25 km away at an elevation of 50 m
- Dual-pipe systems, with a quality complying with the requirements of the Australian Guidelines for Water Recycling 2008

2. To model the financial (i.e. capital and operating) costs associated with the defined scenarios or variants thereof for comparative purposes. Cost relativities are seen as important within the bounds of the hypothetical scenarios defined for this project. It is recognized that absolute costs (e.g. for the purposes of extrapolating to direct or indirect actual project costs for either budget-setting or project delivery purposes) may differ. Extrapolation from the relative cost model produced in this project to actual projects will therefore not be recommended and fall outside of the intended scope and purpose here.
3. To model the potential environmental impacts of each of the four hypothetical water supply scenarios defined (see above). It is envisaged that these impacts will be assessed from the life cycle inventories associated with the construction and operational phases of the respective options for water supply. The life cycle inventories will allow the relative materials, energy and carbon (greenhouse) intensities of the respective options to be compared.
4. Exclusions:

- Assessment of wider life cycle impact potentials (e.g. due to eutrophication, ecotoxicity, ozone depletion, photochemical pollution, acidification, land use human toxicity), as would be possible using a full life cycle assessment (LCA) methodology, falls outside the scope of this project.
- Economic and social factors (e.g. wider benefits or costs to society; ‘levelised’ costs taking into account embedded capital for existing infrastructure) are also excluded from the study.

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[1] http://www.atse.org.au/

[2] Brief as set out in Expression of Interest (EOI) communications between ATSE and GHD in February 2013. GHD’s letter proposal (Doc. 445660) constituted GHD’s response to the EOI brief issued to us by ATSE via email dated 15 February 2013.

1.2 Purpose of this report

The purpose of this report is to describe the methodology and outcomes of a theoretical cost and life-cycle inventory analysis of alternative water supply and/or water recycling options for a hypothetical city at a coastal location within Australia. The life cycle inventory analysis is intended to be indicative of potential environmental impacts but a full life cycle assessment has not been undertaken here. This and other exclusions are defined in Section 1.1 above. The cost analysis undertaken is theoretical and based on typical values benchmarked against projects from GHD experience. The costs presented are for comparative purposes only within this study and cannot be extrapolated from this study to actual projects, which will be subject to site and project-specific factors that will influence capital and operating costs.

1.3 Assumptions

System boundaries for the options considered in this Study are described in Section 2.1 below and other assumptions relating to each option are further detailed in the relevant Methodology sub-sections (refer to Section 2.3 below).

Costs are indexed to year 2013.

Estimates of greenhouse gas emissions for the options considered in this Study were for activities associated with, pumping, treatment, transport and distribution of water, related by-products (sludge or biosolids) or chemicals supplied to the water treatment plants. All emissions related to corporate or other activities (e.g. corporate offices other than those associated with control of the aforesaid water treatment plants; corporate travel etc.) were excluded.

1.4 Disclaimer

This report: has been prepared by GHD for ATSE and *may only be used and relied on by ATSE for the purpose agreed between GHD and the ATSE as set out in Sections 1.1 and 1.2 of this report.*

GHD otherwise disclaims responsibility to any person other than ATSE arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer to Section 1.3). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has not been involved in the preparation of the report by University of New South Wales to ATSE for the overall project funded by the Australian Water Recycling Centre of Excellence (to which this study by GHD is related) and has had no contribution to, or review of the report by University of New South Wales to ATSE other than in the form of this document (Doc. No. 448202) prepared by GHD*. GHD shall not be liable to any person for any error in, omission from, or false or misleading statement in, any other part of the report by University of New South Wales to ATSE.*

GHD has prepared the preliminary cost estimates set out in Section 3.2 of this report ("Cost Estimate") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD based on cost models and GHD experience with similar projects.

The Cost Estimate has been prepared for the purpose of relative comparison of options presented in this Study and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that actual water supply or recycling projects can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

2. Methodology

2.1 Definition of options

In line with the requirements of the Brief for this study, four hypothetical options were defined for alternative water supply to a urban city at a coastal location in Australia. The options were as follows:

- **OPTION 1: Seawater (SWRO) desalination –** Producing product water that is fed into an assumed *pre-existing* potable water distribution system of the hypothetical city
- **OPTION 2: Indirect Potable Reuse (IPR)** - Advanced water treatment, followed by recycling via a regional impoundment (e.g. dam) that serves as raw water source for conventional potable supply to the hypothetical city. The impoundment with its catchment and conventional potable water supply, treatment and distribution system were all assumed to be *pre-existing.* Water recycling supplements raw water supply in this scenario.
- **OPTION 3: Direct Potable Reuse (DPR)** - Advanced water treatment, followed by recycling via a local reservoir that forms part of the conventional potable supply distribution system to the hypothetical city. The conventional potable water source, supply, treatment and distribution system were all assumed to be *pre-existing.* Water recycling supplements potable water supply in this scenario.
- **OPTION 4: Dual Pipe Reuse** - Advanced treatment of secondary effluent from a modern wastewater treatment plant, producing recycled water of suitable quality for non-potable uses (e.g. toilet flushing and outdoor uses such as of exterior surfaces, irrigation of gardens, parks, golf courses and fire-fighting). A key difference for this option, compared with the other options considered here, is that the recycle water reticulation network (the 'dual pipe system' for urban water supply[3]) was assumed to be new (i.e. *not pre-existing).* That is, it was assumed that the 'dual pipe' system would have to be built (most likely as part of a new urban development) as requirement for this option.

2.2 Capacity, sizing and treatment

The nominal **total** capacity of treatment and delivery systems for all options was **an average of 120 ML/d of product water or at least[4] 40 GL/annum.** However, it was recognised that the number and scale of sizing for treatment and delivery systems would likely differ in reality for the four different options, as defined above. The adopted number and scale of systems for the four options were respectively as follows:

OPTION 1: One SWRO plant delivering an average of 120 ML/d product water capacity via one pipeline (25 km long), and discharging to a suitable local reservoir (at an elevation of 50 m higher than the treatment plant[5]) that forms part of the city's pre-existing potable water supply network. The potable water supply network itself was considered outside the system boundary for this study.

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[3] Pipelines, valves, pumps and local distribution reservoirs etc.
[4] For costing purposes, it was assumed that the treatment plant(s) will have up to 31 days of 'down time' per annum for maintenance purposes (i.e. operating at least 334 days per annum). For life cycle inventory purposes, it was conservatively assumed that treatment operates 365 days per annum.
[5] SWRO plant would be located at or near sea level

OPTION 2: Two Advanced Water Treatment Plants (AWTPs), geographically separate but within the boundaries of the city, each delivering an average 60 ML/d product water capacity. These two AWTPs would be fed separately with secondary effluent from two or more wastewater treatment plants (WWTPs), notionally of the same type and treating to the same effluent quality standard but serving different catchments within the city boundary. (It was reasoned that comparatively few WWTPs in Australia are typically large enough to supply 120 ML/d secondary effluent, whereas 60 ML/d is more representative of average flows treated in medium to large-sized WWTPs serving Australian cities). The product water pipeline from the AWTPs was assumed to be common and spanning a total length of 100 km, discharging to an impoundment at an elevation of 150 m higher than the AWTP, with the AWTPs located close to the coast i.e. notionally at or near sea level. The existing potable water supply system (e.g. conventional dam source, treatment and distribution) itself was considered to be outside the system boundary for this study.

OPTION 3: Two AWTPs (60 ML/d product water capacity each), following the same logic as for Option 2. However, for this option the product water pipeline (common between the AWTPs) was assumed to be span a total length of 25 km and discharging (at an elevation of 50 m higher than the AWTP) to either a local reservoir or drinking water treatment plant that forms part of the city's pre-existing potable water supply network. The potable water supply network itself was considered outside the system boundary for this study. This option therefore has a product water delivery system that is essentially the same as that for Option 1 (SWRO).

OPTION 4: Six AWTPs (20 ML/d product water capacity each), each supplying six separate but notionally identical recycled water (dual pipe) reticulations systems. (It was reasoned that realistically there are unlikely to be any Dual Pipe water recycling systems in Australia, currently or in the near future, that have a single treatment plant and single distribution system with a capacity of 120 ML/d product water. Rather, such systems are more likely to be installed in multiple new sub-regional urban developments that are geographically separate and served by individual AWTPs associated with newly-licensed modern WWTPs serving such new community developments). The recycled water (RW) product delivery pipeline from the AWTP was assumed to have a length of 8 km to notionally the centre of the RW reticulation network, discharging at an elevation 30 m above that of the AWTP. Each RW network (each served by one of the six AWTPs) was assumed to have four local reservoirs, with a combined working capacity sufficient to store up to 8 hours of water at a peak demand of 3 times the average demand. The average demand was set equal to the average product water capacity of the AWTP. The entire RW network (i.e. six such dual pipe reticulation systems) was included in the system boundary for life cycle inventory and costing purposes.

For Options 1, 2 & 3 it was assumed that reverse osmosis (RO) Concentrate (ROC) and other waste streams will be discharged via a pipeline (nominally the "ROC" pipeline) to the ocean. For the materials inventory in Option 1, it was conservatively assumed that the ROC pipeline would be of the same diameter and length (2.5 km) from the SWRO plant as the seawater intake pipeline; this would allow full-bypass of flows in case internal process issues that prevent the RO process from functioning (e.g. maintenance reasons). For Options 2 & 3, the analogous assumption was made, except that two ROC pipelines (1 km length each) were allowed for (i.e. one each from the two AWTPs – see above). Implicit in this approach is the assumption that ROC treatment and discharge to local waterways are excluded. In some situations additional ROC treatment for discharge to local waterways might be mandated (e.g. AWTPs not located at the ocean; or due to environmental license constraints), in which case the additional inventories (which fell outside the system boundary in this study) would need to be added.

A summary of the four options is tabulated in Table 1 below.

A simplified diagrammatic representation of the hydraulic grade line for the four options is given in Appendix A.

Process flow diagrams for the four options are given in Appendix B, Appendix C, Appendix D, and Appendix E respectively.

Table 1 Summary of Options and associated Treatment Processes considered

Option	No. of treatment plants in system boundary	Product water capacity per treatment plant (ML/d)	Indicative recovery (%) of product water relative to feed (range in brackets)	Product water discharge pipeline (km length; discharge elevation m above AWTP)[6]	Product water distribution reticulation included in system boundary?	Main treatment unit processes	Chemicals used
1 – SWRO	1	120	42% (40-46%)	25 km; +50 m	No	Screening; Pre-treatment (flocculation-clarification); UF-RO; Post-treatment/ Stabilisation; Sludge thickening/ Dewatering RO Concentrate/ CIP waste discharge to ocean Sludge disposal (landfill)	Anti-scalants Carbon dioxide Ferric sulphate (coagulant) Hydrated lime Polymers (for coagulation and dewatering) Sodium bisulphite Sodium hypochlorite Sulphuric acid
2 – IPR	2	60	82% (80-84%)	100 km; +150 m	No	Screening; Pre-treatment (flocculation-clarification); UF-RO; Peroxide-UV; Post-treatment/ Stabilisation; Sludge thickening/ Dewatering RO Concentrate/ CIP waste discharge to ocean Sludge disposal (landfill)	Ammonium sulphate Anti-scalants Carbon dioxide Citric Acid Ferric chloride (coagulant) Hydrogen peroxide Hydrated lime Polymers (for coagulation and dewatering) Sodium bisulphite Sodium hydroxide Sodium hypochlorite Sulphuric acid
3 – DPR	2	60	82% (80-84%)	25 km; +50 m	No	As for Option 2 above	As for Option 2

[6] Treatment plant and product water pipeline origin notionally at sea level

Option	No. of treatment plants in system boundary	Product water capacity per treatment plant (ML/d)	Indicative recovery (%) of product water relative to feed (range in brackets)	Product water discharge pipeline (km length; m above AWTP at discharge)[7]	Product water distribution reticulation included in life cycle inventory?	Main treatment unit processes	Chemicals used
4 – Dual Pipe	6	20	94% (90-97%)	8 km; +30 m	Yes	Pre-treatment (Fe/ Mn oxidation & flocculation) Dual Media Filtration UF UV Post-disinfection Backwash/ CIP wash / sludge recycle to WWTP	Aluminium sulphate Sodium hypochlorite Sodium hydroxide Sulphuric acid Citric acid

Abbreviations

UF: Ultrafiltration

RO: Reverse Osmosis

CIP: Clean-in-place (for membrane processes)

WWTP: Wastewater treatment plant

SW: Seawater

[7] Treatment plant and product water pipeline origin notionally at sea level

2.3 Approach for life cycle inventories

2.3.1 Construction inventories

Refer to Appendix F for a detailed breakdown of the construction inventories as applied in this study.

The SWRO plant construction inventory was based largely on data from Munoz et al. (2008), as applied by Lane et al. (2011). This was supplemented with data for pipelines, valves and pumps based on GHD experience, as far as possible, and/or reference information in the public domain from reputable suppliers in Australia.

Embodied greenhouse gas emissions associated with materials was based on the Australian LCA Data Library associated with the SimaPro v.7.1.0 software (Pré Consulting, The Netherlands), supplemented with information from Foley et al. (2010).

Transport of materials was assumed to be via road truck (assumed payloads in the range 24 to 30 tonnes, depending on the material) from a capital city over a distance of 500 km. Greenhouse gas emissions associated with this transport were calculated based on 0.546L / km average diesel fuel consumption and emissions of 2.903 kgCO2-e / L diesel fuel used for the total fuel cycle (DCC, 2008; 2010).

No construction inventories for advanced water treatment or water recycling plants could be found in the published literature within the public domain. This is further discussed in the *Results* section of this report (see below).

Pipelines, valves and pump data for Options 1 to 3 was based as far as possible on assumptions of materials type and pipeline from GHD experience, or provisional estimates. Materials masses and make-up were obtained from reference information in the public domain from reputable suppliers in Australia, supplemented with information from Foley et al. (2010) for typical equipment materials breakdowns.

For Option 4, the recycled water reticulation network was based on actual pipeline inventory data collected by Lane et al. (2010) for the Pimpama-Coomera system on the Gold Coast (2008 data). This system had a total (aggregate) pipeline length of 195 km, covering a range of pipelines, serving an AWTP with a nominal design capacity of 17.1 ML/d. The materials inventory for this system was scaled up on a direct proportional basis to 20 ML/d. Materials make-up of the system was based, as far as possible, on reference information in the public domain from reputable suppliers in Australia. This was supplemented with information from GHD experience associated with the concept design of the Pimpama-Coomera Waterfuture system (GHD, 2005).

For all options, construction materials associated with pipelines, valves and pumps only were considered. For Option 4 only, where recycled water network reservoirs were included, only reinforced concrete (assumed 300 mm thick) was considered for covered circular tanks. Additional materials and energy associated with construction (e.g. excavation, sand or other fill, additional materials such as for welding, additional transport, materials and energy for site offices, landscaping, access roads etc.) were excluded. A more comprehensive LCA analysis would be required to capture all these associated inventories.

2.3.2 Operations inventories

Refer to Appendix G for a detailed breakdown of the operations inventories as applied in this study.

Operations inventory data was based largely on data collected by Lane et al. (2011; 2012) for systems in South-East Queensland.

Power consumption data was supplemented with and benchmarked against other reference material, notably Vince et al. (2008; 2009); Poussade et al. (2011); and Cooley and Heberger (2013)

For Options 2 and 3, where the source inventory data included ROC treatment, this was removed (i.e. removal of methanol requirement for biological denitrification; reduction of power consumption for treatment by 5%, based on the breakdown given by Poussade et al., 2011). Pumping for ROC discharge to ocean was included.

Uncertainty in the chemicals and other materials use (e.g. membrane replacement) was based on GHD experience, as far as possible, or provisional estimates. No attempt was made to determine correlated uncertainties in chemicals use (e.g. flocculant dose and disinfectant dose). Sludge production was modelled on estimates of sludge production from feed water solids removal and chemicals dosed, based on GHD experience, as far as possible, or provisional estimates. Dewatered sludge cake was assumed to be: 28% dry solids (d.s.) for Option 1 from seawater; 20 % d.s. for Options 2 & 3 from secondary effluent solids with a relatively high pre-treatment coagulant dose; and 18% for Option 4 when admixed with WWTP extended aeration activated sludge.

Membrane life was assumed to be between 3 and 7 years (typically 5) for SWRO systems; and 5 to 7 years (typically 6) for the AWTPs fed with secondary effluent from treated wastewater.

Embodied greenhouse gas emissions associated with materials (chemicals and membrane replacement) was based on the Australian LCA Data Library associated with the SimaPro v.7.1.0 software (Pré Consulting, The Netherlands), supplemented with information from Foley et al. (2010). Where an exact match of the chemical or material used could not be found in the available LCA database library, the nearest 'fit' was adopted (e.g. nylon substituted for polyamide in membrane material; acetic acid substituted for citric acid in chemicals). Emissions associated with sludge disposal were based on typical emission rates for landfill sites receiving mixed municipal solid waste (DCCEE, 2010). All embodied emissions associated with materials use (chemicals and membrane replacement, as well as sludge disposal, including transport) were assigned to Scope 3 on the basis that these are indirect emissions or contractor services (i.e. not emitted at the water treatment facility).

Greenhouse emissions factors due to electricity purchased from the grid (i.e. Scope 2) were taken from the NGERS Technical Guidelines (DECC, 2012). For uncertainty estimation purposes in calculating Scope 2 emissions, the most likely value was set at the average of the tabulated values (0.85 kg CO_2-e/kWh) for all mainland states in Australia, except Tasmania[8]. However, the range for uncertainty estimation was set between 0.26 and 1.19 kg CO_2-e/kWh, being the lowest and highest tabulated values in the NGERS Guidelines for all states (DECC, 2012). The analogous approach was taken for Scope 3 emissions factors associated with electricity transmission (DCCEE, 2010b): average 0.13 (range 0.03 to 0.17 kg kg CO_2-e/kWh).

Transport of materials was assumed to be via road truck (assumed payloads in the range 10 to 24 tonnes, depending on the material) from a capital city over a distance of typically 100 km for chemicals (range 12 to 1000 km for uncertainty analysis) and 25 km for sludge wet cake (range 10 to 100 km for uncertainty analysis). Greenhouse gas emissions associated with this transport were calculated based on 0.546L / km average diesel fuel consumption and emissions of 2.903 kgCO2-e / L diesel fuel used for the total fuel cycle (DCC, 2008; 2010a). All transport was assumed to be undertaken by contractors and therefore assigned to 'Scope 3' (i.e. indirect emissions not emitted at the water treatment facility).

[8] Due its high proportion of hydro-electric power, Tasmania's electricity grid was assumed to be non-representative of typical Australian cities on the mainland.

Combined uncertainty in the operations inventories was calculated using a Monte Carlo-type approach[9]. Uncertainty in both the activity data (e.g. power or chemicals consumption) as well as certain of the key emissions factors were taken into account. For each uncertain parameter, the Monte-Carlo value was calculated using an 'expert opinion' approach (bounded PERT distribution). The PERT distribution was defined by most likely, lower and upper bound values derived as far as possible from plant operating inventory data, or literature. In the absence of better information, the lower and upper bounds were nominally set to the 5%ile and 95%ile values calculated on the assumption that the data is log-normally distributed and that the geometric standard deviation equals 1.1. The assigned Most Likely, "Low" and "High" bounds adopted are listed for each uncertain parameter in the tables of Appendix G. In summary, the following uncertainties were taken into account, with a focus on estimating combined probability of greenhouse gas emissions:

- Water recovery (%)
- Flow-specific power consumption (feed or intake water; production; and product water delivery, respectively in kWh/ML)
- Chemical dose (listed by chemical name, expressed as kg/ML (i.e. mg/L) product water or kg/tonne d.s. in the case of sludge dewatering)
- Membrane module replacement (listed by main materials makeup of the membranes themselves and pressure vessels, based on an assumed life of the materials, as described above, and typical average flux rates per membrane module as listed by the supplier[10] or stated in the literature (kg/ML product water)
- Sludge production (kg/d dry solids based on feed water solids, chemicals dosed and model assumptions for flocculation from aquatic chemistry and mass balance theory
- Transport distances (km) for materials (chemicals, membrane replacement and wet sludge cake) based on assumptions stated above
- Scopes 2 & 3 greenhouse gas emission factors for electricity purchased from the grid, as discussed above (according to DCEE, 2010; 2012).

A more detailed combined uncertainty analysis may be recommended as part of future work, particularly where there is interest in indentifying the largest sources of uncertainty and taking into account any correlated uncertainties (e.g. in chemical doses of different compounds, water recovery or energy use). These aspects were not investigated as part of the present study.

2.4 Approach for Costing

The approach used for the development of indicative costs for the options considered in this investigation was as follows:

- Costs were developed based on actual cost estimates for process train for plants of similar size to each of the options described above. Costs were then scaled to the capacity assumed for this study (120 ML/d product water).
- In order for the reference costing to be compared, the reference plants used as the basis of the benchmarking were required to be of a similar size. The overall costs are comparable to those for recent projects; however in this study the application is for an entirely hypothetical city.

[9] RiskAMP® proprietary software Excel Add-On
[10] Membranes adopted: SWRO TORAY SU-820FA (as per Munoz et al., 2008); AWTP (for IPR and DPR) membrane data from Poussade *et al.* (2011); and Dual Pipe system AWTP UF membranes TORAY HFU-2020 (assumption).

- Capital (CAPEX) and operating (OPEX) costs were obtained from GHD database of CAPEX and OPEX costing for similar projects and GHD experience.
- Costs were indexed to current 2013 costs (assuming a CPI of 3% over the past 4 years, as benchmarked via Reserve Bank of Australia (RBA) website)
- Costs refer to Total CAPEX cost for the project including pipelines etc. The Total CAPEX cost is influenced by the Project Delivery methodology. These costings have been developed using the same database and therefore reflect to some extent an 'average' of the influence of those factors.
- Plant costs for the key components for the Desalination Plant were benchmarked against Desalination Plants in Australia to verify the % of total cost that each key component typically comprised. The approach provides some confidence that the basis of estimating is comparable to real plant costs.
- Costings for the IPR (opr DRP) AWTP and Dual Pipe options were based on costs for key components of a similar size (20 ML/d capacity plant).
- For the Pipeline, Pump Stations and Storage Reservoirs, costs were based on the GHD cost database for similar sized projects.
- The cost assumed was based on a rate of $2,500 per connection for an assumed 55,000 tenements served per 20 ML/d Dual Pipe Recycled Plant. This was based on cost data obtained for the Pimpama-Coomera system. In order to correlate to Options 1, 2 & -3, there was assumed to be 6 No. 20 ML/d Dual Pipe Recycled Water Plants, as discussed in Section 2.2. Each of these plants was assumed to require a wet weather storage facility (80 ML capacity each) to minimise surplus secondary effluent discharge to the environment during the wet season.

3. Results and Discussion

3.1 Life cycle inventory results

In this study, the life cycle inventory (for electrical energy use, materials use and estimate emissions of greenhouse gases) is taken as a surrogate of potential for environmental impact.

Refer to Appendix H for a summary of the life cycle inventory results from this investigation. The results are listed two separate inventories: Operations and Construction, respectively. The Operations inventory results are based on the Monte Carlo simulation output for combined uncertainty (50th, 5th and 95th percentiles are listed).

Some key outputs are further discussed below.

3.1.1 Electricity consumption

Figure 1 shows the flow-specific power consumption for the four options. The results are broadly in agreement with other published data, which served as benchmarks for this study (*inter alia* Vince et al., 2008; Poussade et al., 2011; Cooley and Heberger, 2013). Option 1 (SWRO) has the highest electricity (power) consumption, compared with the other options. Power consumption is dominated by that required for production, which in turn is largely due to the higher osmotic pressure (and hence for reverse osmosis) of seawater compared to the other options. The water recycling options (Options 2, 3 & 4) take feed in the form of treated wastewater at lower osmotic pressures (closer to tap water).

A breakdown of the power consumption is given in Figure 2.

It is worth noting that the increased power required for product water delivery in Option 2 (IPR) is due to the longer pipeline and higher discharge elevation for this option (discharge to regional impoundment e.g. dam). However, despite this increase, the power consumption, Option 1 still has the higher power consumption on a flow-specific basis than Option 2 even when taking into account uncertainty, comparing 5^{th} and 95^{th} percentiles (see error bars in Figure 2). It can be concluded that Option 2 would approach Option 1 in terms of power consumption on this basis if the product delivery pipeline was significantly longer than 100 km in Option 2. However, for most city applications in Australia, it is unlikely to be feasible or cost-effective to pump recycled water for IPR purposes over a distance much further than 100 km.

Option 3 (DPR) has a lower flow-specific power requirement, as expected, given the shorter pumping distance for product delivery. However, implementation of this option is likely to be governed more by socio-political factors relating to the perceptions and risks associated with direct recycling of water into the potable water distribution network.

Option 4 (Dual Pipe) has the lowest flow-specific power requirement of the options considered here, mainly due to the absence of reverse osmosis and shorter pumping distances with lower elevations assumed for product delivery in the local areas connected to the Dual Pipe recycled water network. Scale, geographical details and resultant network designs will strongly influence the life cycle operational inventory and for such systems, however.

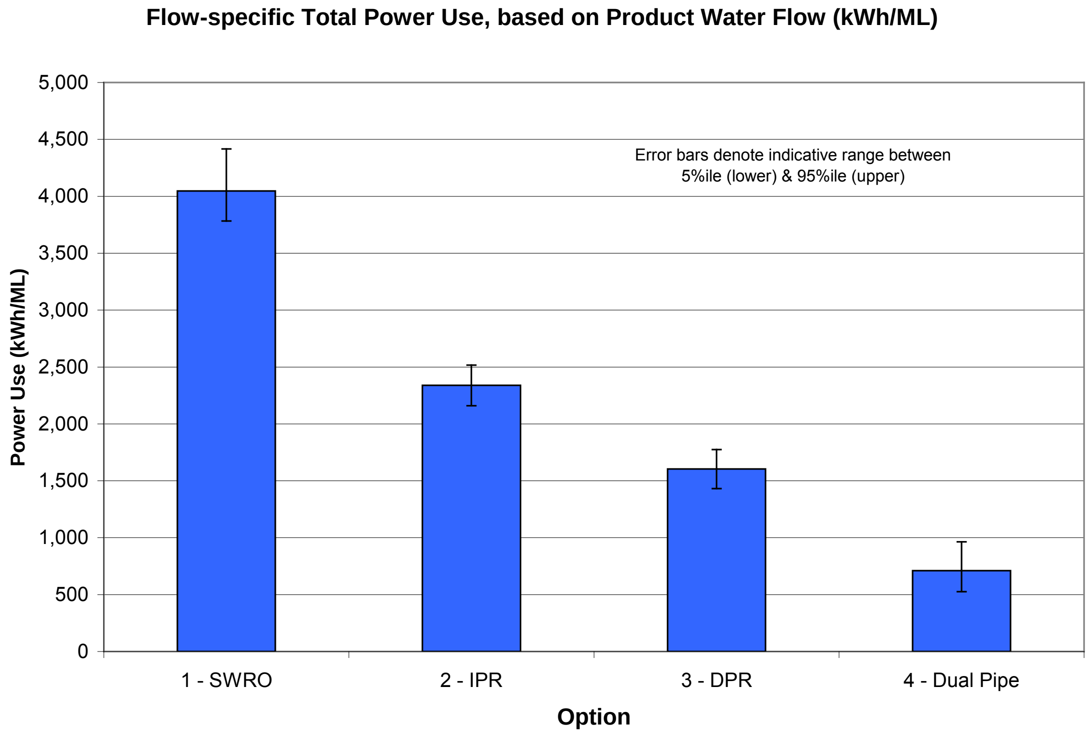

Figure 1 Flow-specific power use for the options considered in this study

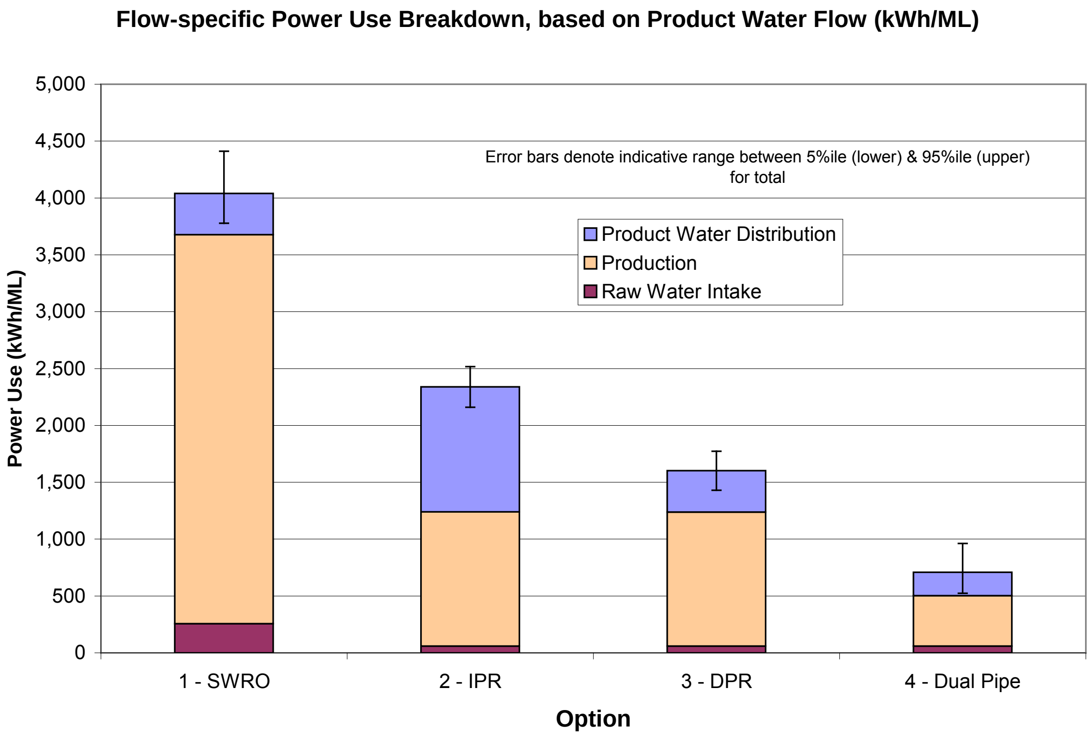

Figure 2 Flow-specific power use, with breakdown, for the options considered in this study

3.1.2 Materials use

Figure 3 shows the operational materials use, on a flow-specific basis for the four options, including a breakdown into categories of chemicals, membrane module replacement and sludge disposal. It is worth noting that the y-axis in this figure is logarithmic. The results show that sludge disposal dominates the materials 'use' (as a broad definition), while chemicals use is much greater in relative terms of materials than membrane replacement.

From a life cycle perspective, it is useful to consider the relative importance of the construction vs. operational inventories. Figure 4 shows that when considering only one year of operation, the materials use for construction is relatively large and dominant. However, Figure 5 shows that for operational periods in the range 20 to 50 years, the construction inventory becomes relatively insignificant compared with the cumulative operational inventory, in terms of materials use. In this study, the lack of construction inventory data for the water recycling plants represented a significant obstacle in this assessment. However, it is clear that even if the AWTP construction materials inventory in Options 2, 3 or 4 is double that of the SWRO plant in Option 1 (for the same product water capacity, as in this assessment), it will not substantially change the conclusion; the operational inventory is likely to dominate over that for construction in life cycle terms. That conclusion is borne out by the comparison in Figure 6 where (for illustrative purposes), the treatment plant construction materials inventory was set equal for all options. It is clear that for life cycles of 30+ years, the construction inventory is likely to contribute indicatively <20% of the total life cycle inventory and typically ≤10% for all the options over a life cycle of 50 years. Although not assessed as part of this study, the work of Lane et al. (2011) and others (e.g. Munoz et al., 2008) found this to be true for other urban water supply or treatment systems. It will be true to an even greater extent for energy (mainly electricity), which is dominates in life cycle terms for operational requirements (de Haas et al., 2012), as would be expected.

The options considered in this study are quite similar in terms of operational materials use intensity (Figure 3). The greater sludge disposal 'use' for Options 2 and 3, in relative terms, is partly driven by the assumptions of slightly poorer effluent quality (in terms of suspended solids and soluble organics) that are removed by pre-treatment of the conventional WWTP secondary effluent in these options. This is reflected in higher chemical doses for flocculation/ coagulation during pre-treatment in the actual inventory data provided by water utilities operating such facilities. Furthermore, the high chemical doses were assumed to produce a high proportion of amorphous iron-hydroxide type precipitates in the primary sludge and a somewhat lower wet cake for the dewatered sludge cake was assumed for Options 2 & 3 AWTPs compared with the SWRO plant (Option 1). This contributed further to the higher materials use in terms of wet cake material disposed to landfill for Options 2 & 3.

Compared to Options 2 and 3, Option 4 was assumed to have a relatively good secondary effluent quality (refer to Appendix G[11]). This assumption was based on the premise that the AWTP supplying the 'dual pipe' scheme(s) would be supplied with secondary effluent from a relatively newly-licensed modern biological nutrient removal WWTP serving a new development[12]. This tends to make it more practically to achieve the lesser degree of tertiary treatment for suitable 'Dual Pipe' non-potable recycled water quality. However, in this study,

---

[11] Compare Assumptions for Sludge Production in Operations Life Cycle Inventory

[12] One of the assumptions underlying the dataset for the materials inventory in this study was that water recycling for non-potable purposes is such schemes is typically only feasible for new developments where the "dual pipe" systems (for potable + recycled water) can be laid *de novo*. In our experience, only a portion of the total wastewater secondary effluent generated can be recycled via dual pipe schemes. The treatment plants serving such communities with dual pipe schemes, typically being new, are often subject to higher effluent quality targets by regulators for environmental reasons related to new development applications (i.e. surplus flows discharged to the environment).

secondary feed effluent quality assumptions for Option 4 (versus the other options) would make little difference to the materials inventory and is unlikely to change the study outcomes. For example, an increase in secondary effluent total suspended solids would increase that portion of sludge disposal attributable to the AWTP (rather than the WWTP) in this study. However, since the solids stream from the AWTP is wasted back to the WWTP for Option 4, in practice the difference would be insignificant.

Options 2 & 3 require more advanced treatment since the latter were aimed at potable reuse. For example, the typical flocculant doses applied for pre-treatment in Option 4 were lower (in mass terms per unit flow) from actual inventory data supplied by water utilities operating such facilities, compared with Options 2 & 3. This was partly for reasons of more advanced pre-treatment in the latter (e.g. including near complete P removal to protect RO membranes from scaling) and partly due to the fact that alum was used in the Option 4 AWTP, whereas ferric chloride was used in the Option 2 and 3 AWTPs considered here[13].

Despite a relatively pessimistic sludge wet cake dryness assumed (see above), the previous two considerations (better feed quality and lower chemical dose) led to a lower sludge materials 'use', in relative terms, for Option 4. The lesser membrane content (UF only; no RO) also led to a lower membrane materials use for Option 4. However a high oxidant/disinfectant dose (sodium hypochlorite) for Option 4 tended to make chemicals materials use higher overall, in relative terms, for this option compared with the other options. The net effect was quite similar total materials use for Option 4 relative to the other two water recycling options (Options 2 & 3) – refer to Figure 3.

Option 1 (SWRO) had the overall lowest operational materials use, in relative terms (Figure 3).

[13] Based on the source data from which the options considered in this study were modelled. Refer to Appendix G for Operations Life Cycle Inventory details.

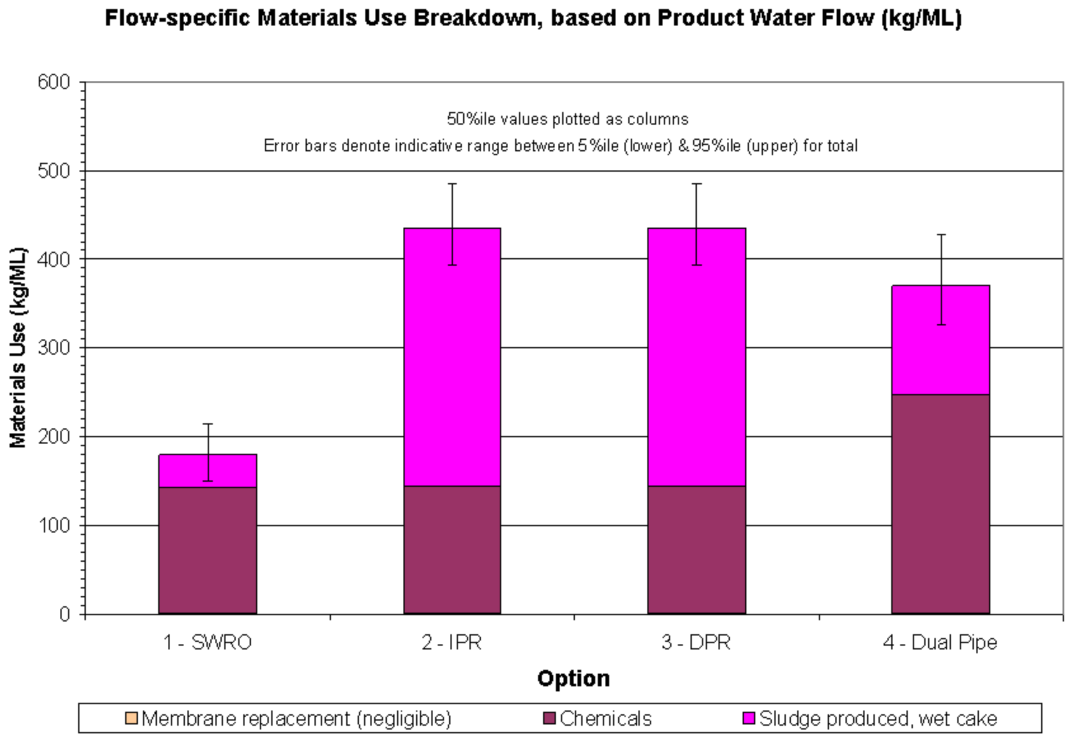

Figure 3 Flow-specific total materials use, with breakdown, for the options considered in this study

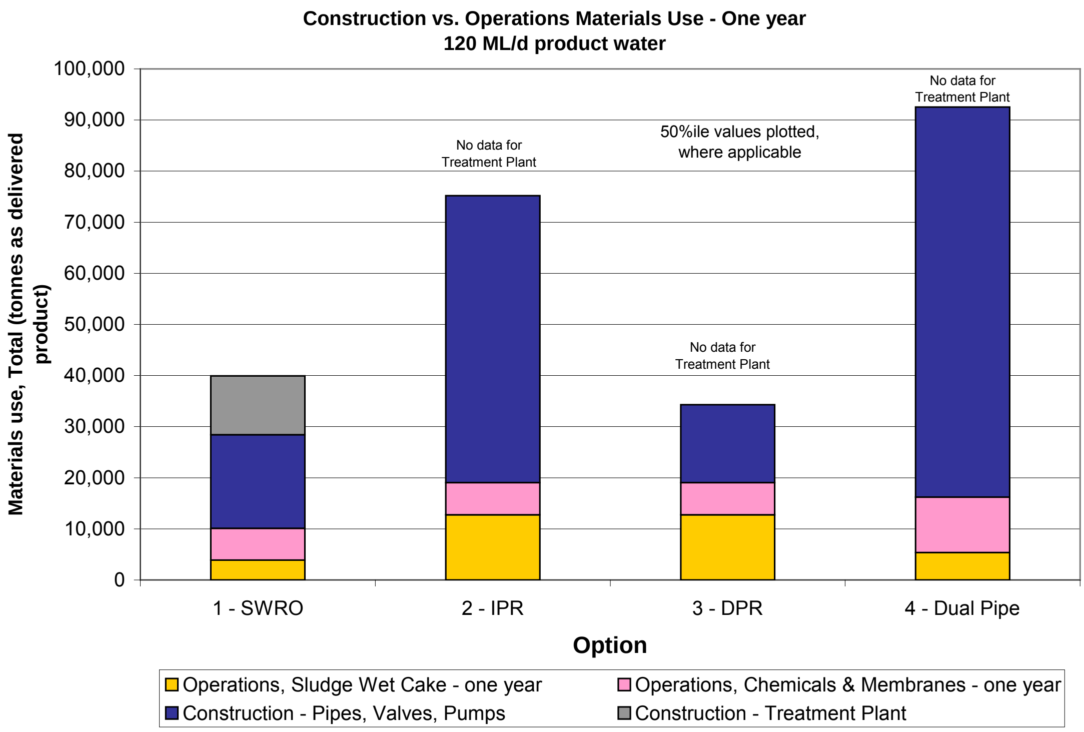

Figure 4 Total materials use in absolute terms, with breakdown, comparing construction vs. operations over a one year period for the options considered in this study

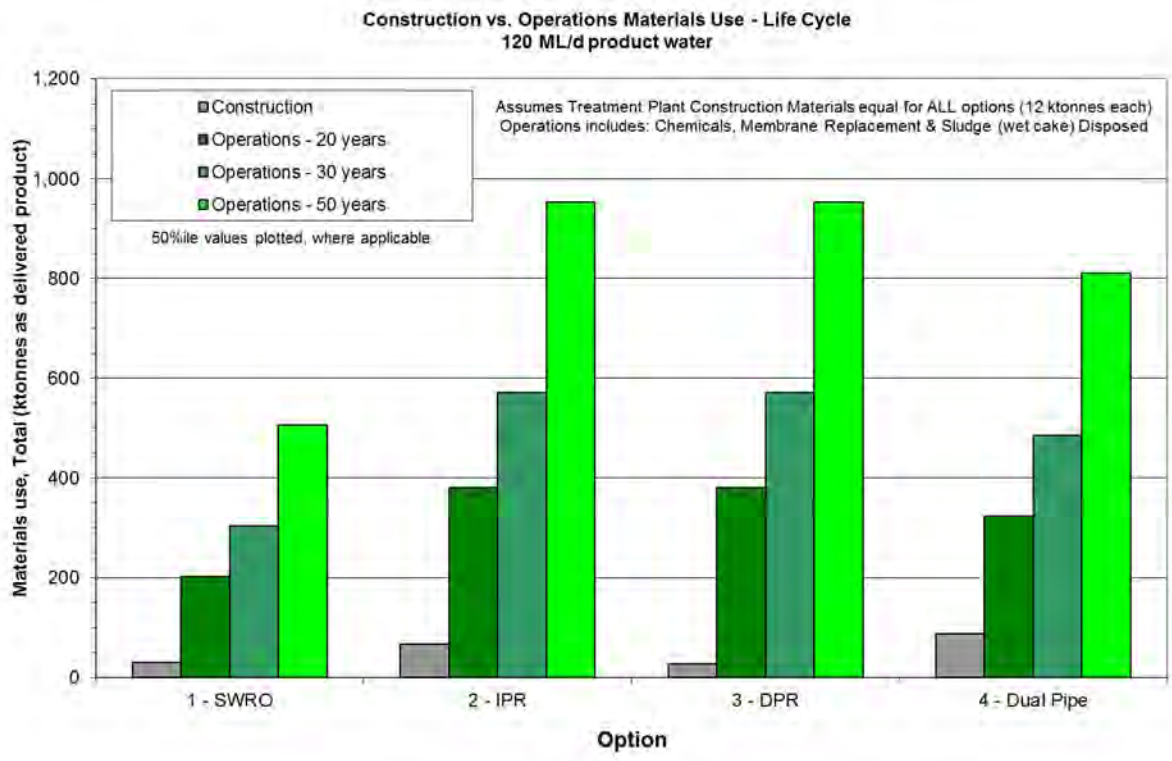

Figure 5 Life cycle total materials use in absolute terms, with breakdown, comparing construction vs. for the options considered in this study

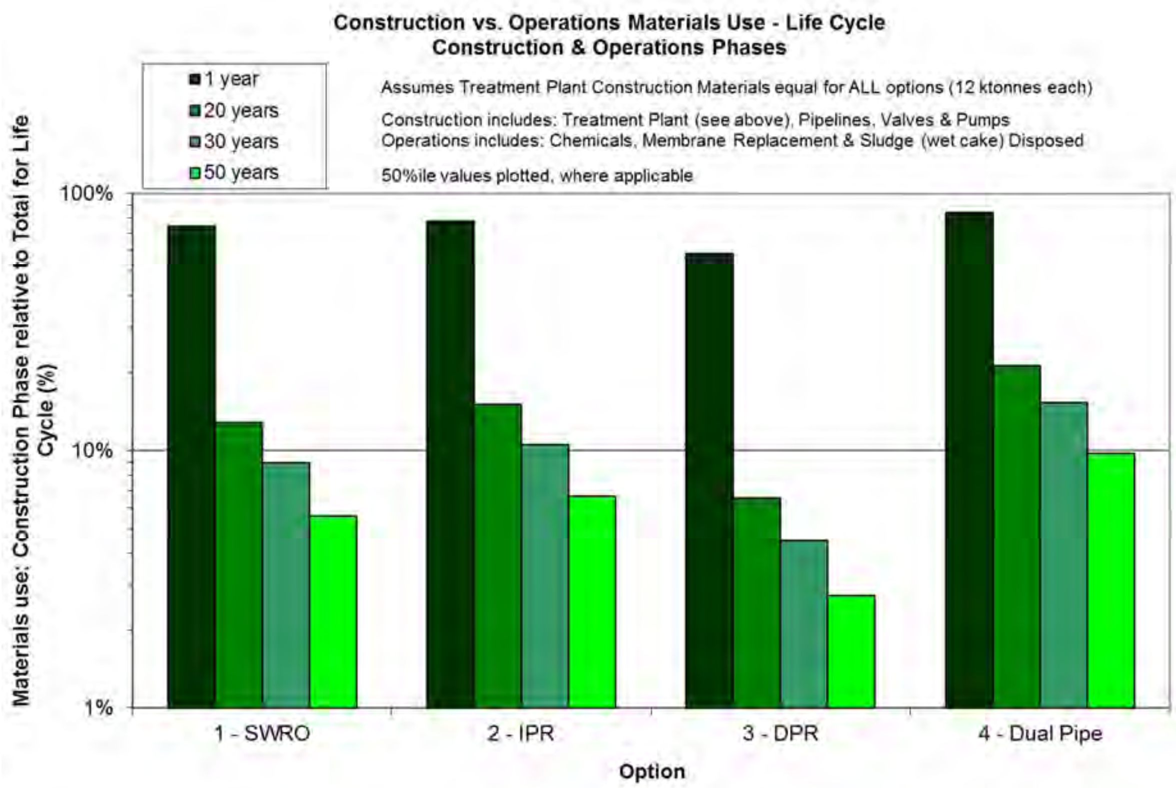

Figure 6 Life cycle materials use for options considered in this study: Construction inventory as a percentage of total for life cycle

3.1.3 Greenhouse gas emissions

Figure 7 shows a comparison of the options on a flow-specific basis for greenhouse gas (GHG) emissions, with a breakdown between Scopes 2 and 3 (refer to DCCEE, 2010a; 2012) given in Figure 8.

This assessment shows that the GHG emission profiles are dominated by electricity (power) purchased from the grid, which is the sole contributor to Scope 2 (refer to Figure 8). Scope 3 emissions make a bigger relative contribution for the options with the lower overall power requirement. For example, for Option 4, at the 50^{th} percentile, Scope 3 contribution was 43% of the total emissions. At the other extreme, for Option 1, Scope 3 contributed 17% of the total emissions on the same basis.

Figure 8 gives a breakdown of the GHG emissions. Since these are derived from the energy and materials inventories, it is not surprising to find that electricity-related emissions dominate the emissions profile, followed by smaller Scope 3 emissions stemming from embodied emissions and transport, related to chemicals and sludge disposal. Only for Option 4 were the chemicals-related Scope 3 emissions more prominent, on a relative basis. Sludge transport and disposal was a more significant Scope 3 emissions contributor, particularly for Options 2 and 3, for reasons related to assumptions around sludge quantities generated for these options, as discussed for the Materials inventory (see above).

Uncertainty in the emissions estimates are dominated by uncertainty in the Scope 2 emission factors, as discussed above and as reflected by the range in state-based emission factors across Australia (DCCEE, 2012). This not unexpected, since all the options are heavily dependent on electrical energy for pumping and treatment. Supplying the energy requirements for these alternative forms of water supply in a sustainable manner will hinge heavily on the extent to which this can be done from renewable sources of power (e.g. hydro, wind or solar).

Overall, the results in Figure 7 show that Option 1 has the highest greenhouse emission potential and Option 4 the lowest, following a similar pattern to that for electrical power requirements (Figure 1). However, it is worth noting that at the extremes of probability there is potential for overlap between some of the options in terms of GHG emissions potential. For example an energy-efficient SWRO system (Option 1) with a large component of it energy requirements met from renewable sources (i.e. lower end of the ranges evaluated for SWRO production energy requirements and electricity-related emissions factors from the NGERS guidelines – see above) has the potential to have equivalent or lower GHG emissions profile compared with an IPR scheme (Option 2) with high product delivery power requirements and supplied largely from non-renewable energy sources (i.e. higher end of the range evaluated for electricity-related emissions factors).

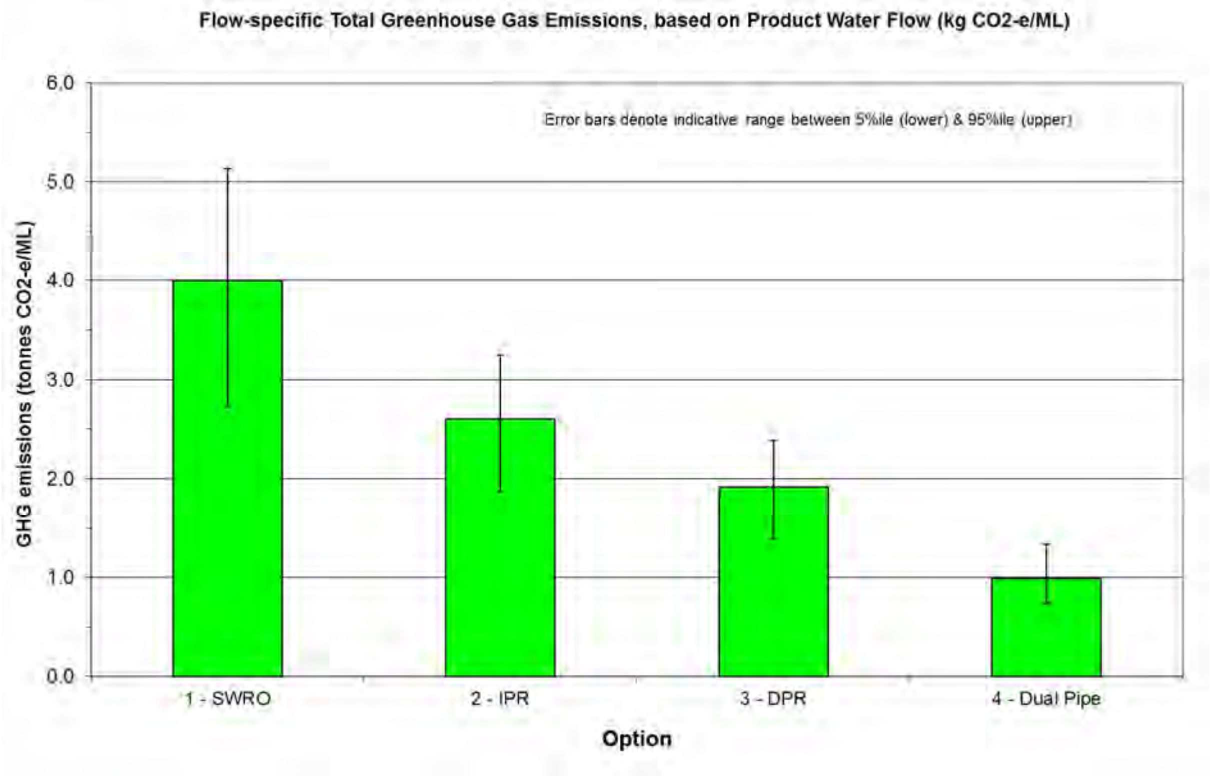

Figure 7 Flow-specific greenhouse gas estimates for the options considered in this study

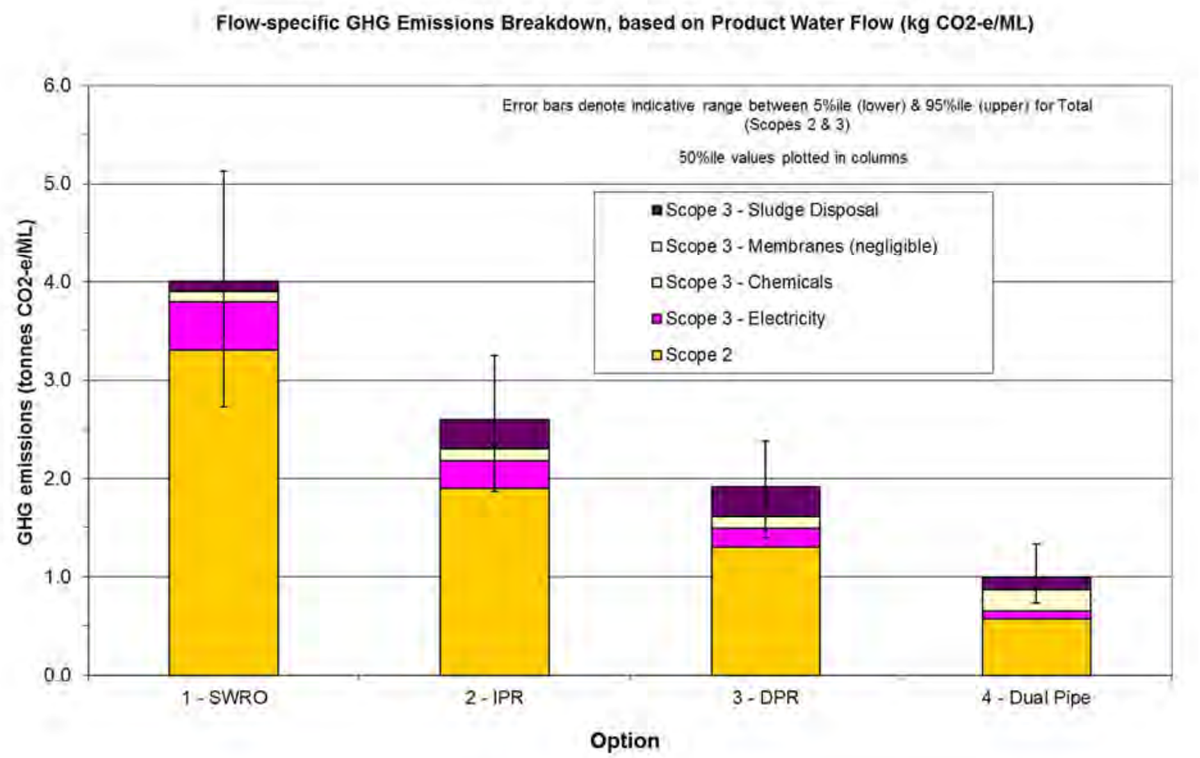

Figure 8 Flow-specific greenhouse gas estimates, with breakdown, for the options considered in this study

3.2 Cost results

A summary of the indicative Capital (CAPEX) Operating (OPEX) Costs and Net Present Value (NPV) for comparing options is presented in Table 2 below.

Table 2- Summary of Indicative Capital and Operating Costs and Net Present Value for options considered

Cost $ Million (M)	Option 1	Option 2	Option 3	Option 4
CAPEX	Desalination Plant	Indirect Potable Reuse	Direct Potable Reuse	Dual Pipe Reuse
Plant CAPEX	$729 M	$387 M	$387 M	$289 M
Transfer & Reticulation CAPEX	$230 M	$900 M	$230 M	$920 M
TOTAL $M	**$959 M**	**$1,287 M**	**$616 M**	**$1,209 M**
OPEX $M per year	$89 M/yr	$72 M/yr	$53 M/yr	$18 M/yr
NPV ($M), Note 1	$2,128 M	$2,199 M	$1,316 M	$1,386 M

Note 1: NPV assumes 6% discount rate over 30 years, with all CAPEX occurring in Year 1

Figure 9 and Figure 10 below show the contribution of the key components of each option to the overall project CAPEX.

3.2.1 Commentary on costs

Based on the results presented in Table 2 and Figure 9 below, the following points are noted from the costing assessment undertaken:

- The Desalination Plant CAPEX is high compared to the alternative options, but given desalination plants are located in close proximity to the sea at sea level, there is a shorter transfer pipeline and lower head required resulting in a considerably lower transfer system cost as compared to some of the other options. This emphasises a key point in comparing different options. Pipelines are expensive and increase operating costs for energy also. So the location of treatment facilities and the network locations that they might connect to are significant, possibly even overriding factors in cost comparison. Hence, to some extent, option comparison will always be a location-specific consideration.
- Due to the longer distance specified to transfer recycled water from the point of wastewater collection and treatment to raw water dams as source of Potable Water, and the requirement to construct such a pipeline through city and rural areas, the Indirect Potable Reuse option has a high transfer system cost which is the dominating cost factor for this option. Given WWTPs are located at low elevation and dams at higher elevations for gravity supply, this factor is likely to affect the cost competitiveness of the IPR option compared to alternative options.
- Based on the options as defined in the Brief for this investigation (refer to Section 1.1), the capital cost for Dual Pipe Reuse is essentially the same as the IPR option. Given the shorter connection to supply recycled water directly to the reticulation the transfer pipeline

for the DPR option, and essentially the same process treatment train as for the IPR option, the DPR is more attractive from a lower capital cost point of view. In fact some comparison between the graphs can be done to see that considerable additional treatment could be applied before the cost penalty for the longer pipeline length for the IPR option is matched.

- To be able to realistically compare Dual Pipe Recycled Water Plants to the larger alternative Options presented, it was necessary to assume multiple smaller plants are located in close proximity to WWTPs. Total Plant Costs will therefore be higher due to the penalty of loss of economies of scale, but transfer costs will be lower due to the shorter distance to the point of supply. However, the Dual Pipe reticulation systems (assumed not to be pre-existing in this study) add significant capital cost for this option, compared with, for example the DPR option (where the potable water reticulation network was assumed to be pre-existing).
- Recognising that a dominant cost factor for the Dual Pipe Recycled Water option is the reticulation connection costs, it should be noted the costs for connection are highly sensitive to the number of dual pipe connections assumed as part of the scheme. Thism in turn, is highly dependent on the number of residential connections, versus commercial, industrial or irrigation connections and respective demands for recycled water in each of these connections. This leads to a costing basis for this option having quite different assumptions to the other options, and it could be considered to be less valid on that basis.
- In any case, the analysis illustrates the point that additional reticulation is expensive, and based on the assumptions used in this assessment, that additional cost for recycled water (including Dual Pipe schemes) significantly outweighs the cost reduction due to less treatment.
- Finally, on a whole-of-life cost (NPV) basis (Table 2), given the assumptions underlying the options defined for this investigation, Options 1 and 2 (Seawater Desalination and Indirect Potable Reuse) are comparable and have the highest NPV. Options 3 and 4 (Direct Potable Reuse and Dual Pipe Recycled Water) have lower and comparable NPV. There is a trade-off for all options between feed transfer and treatment plant costs on the one hand, and product water transfer (or reticulation system) costs on the other hand.

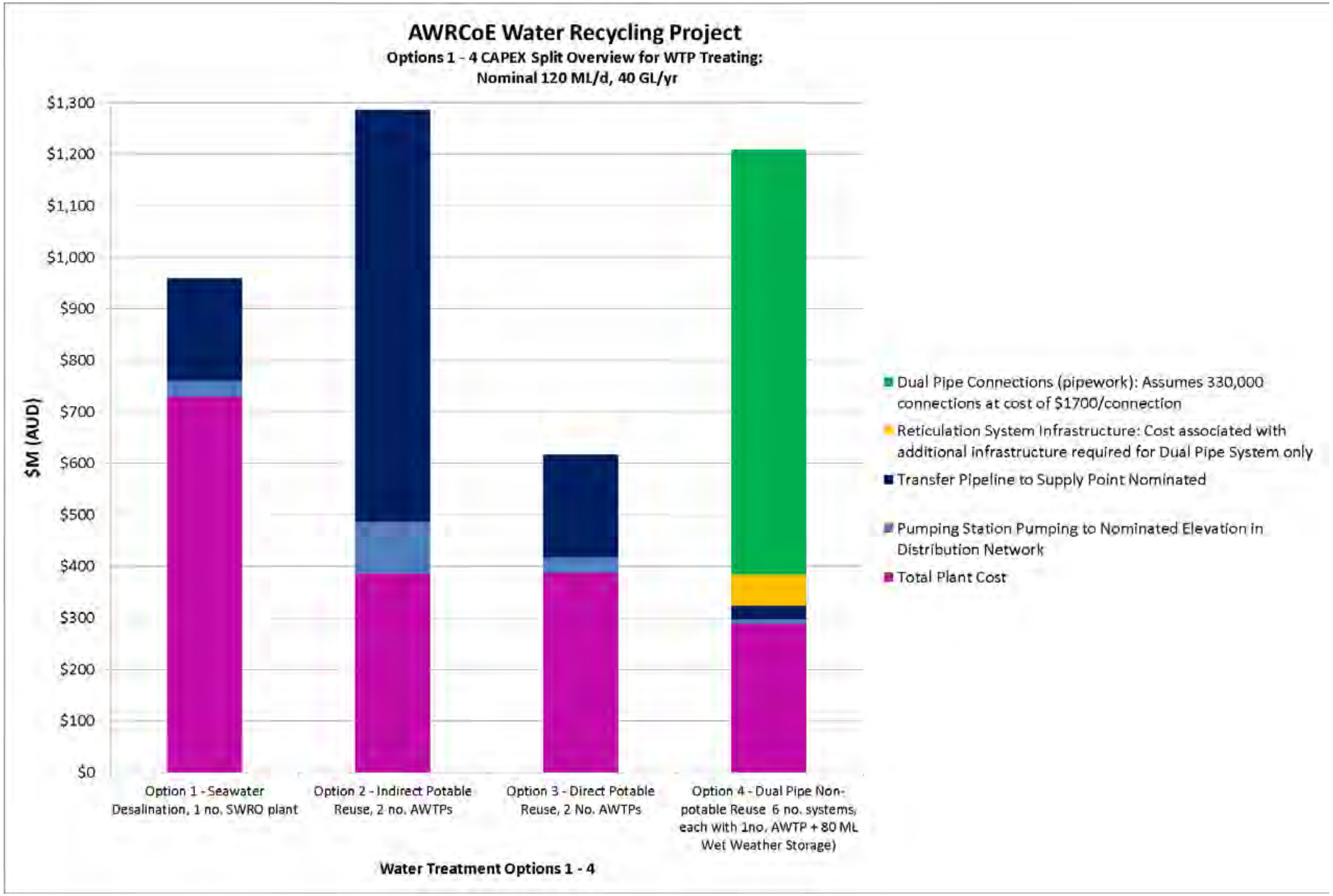

Figure 9 Indicative project capital cost breakdown for four options considered in this investigation

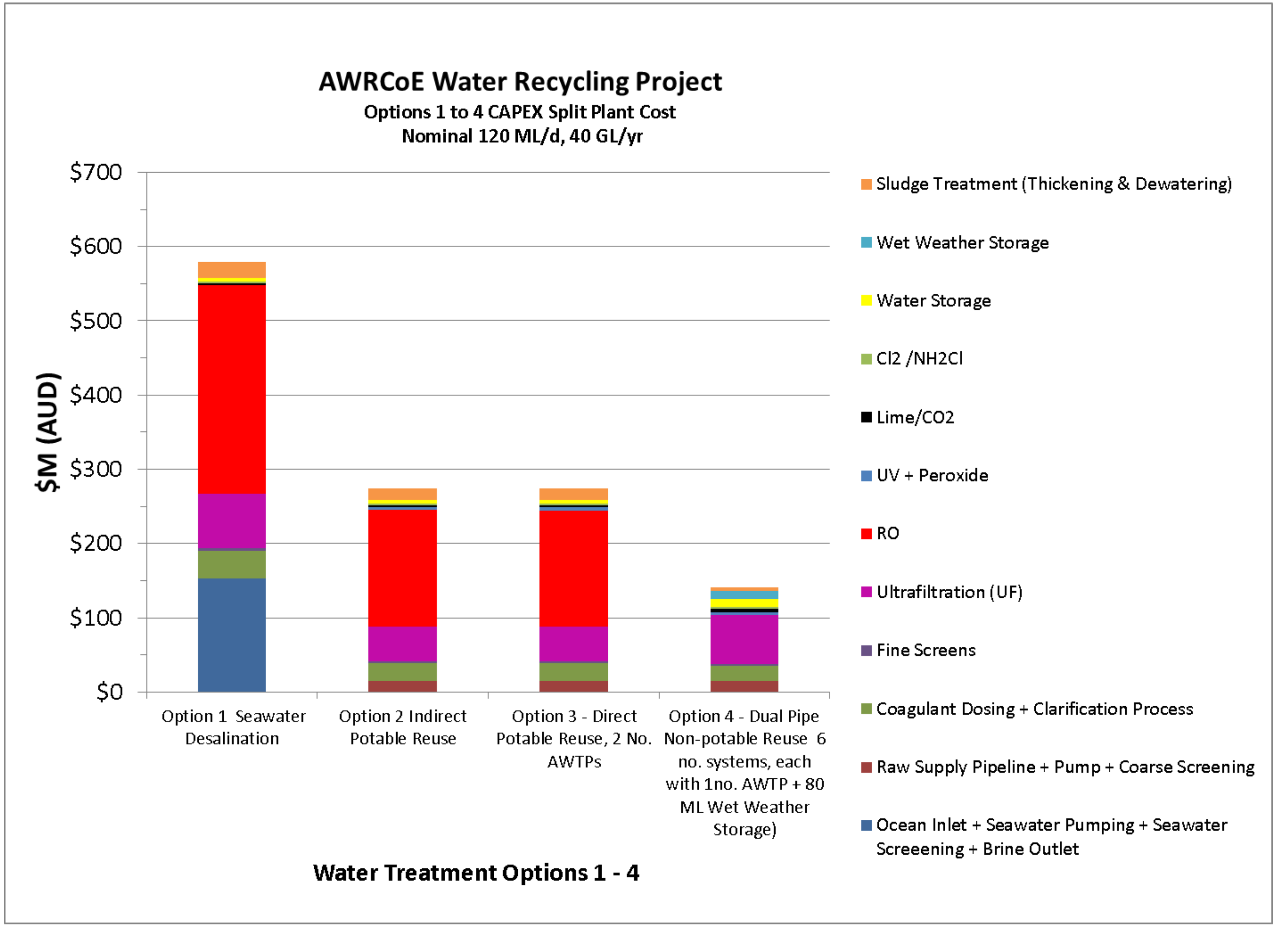

Figure 10 Treatment plant only indicative capital cost breakdown for four options considered in this investigation

4. Conclusions

This study has shown that useful insights into the relative energy, materials and greenhouse gas intensity of alternative water supply or recycling systems can be obtained using a life cycle inventory (LCI) approach. Such inventories can be taken as surrogates for environmental impact potentials. Further insights, including a greater capture of 'upstream'and 'downstream' effects across a wider suite of environmental impact potentials can be obtained by taking the LCI data to a full Life Cycle Assessment (LCA). However, in our experience, such detailed LCA assessments typically require a broader definition of system boundary (e.g. to include the receiving water, land and air sheds) in order to provide more meaningful insights into wider environmental impact potentials or damage. With the broader system boundary come also greater LCA model complexity associated with such issues as ecotoxicity or human health impacts, population densities and the effects of nutrients, metals or micropollutants on the receiving environments (Lane et al., 2011). The added effort for a detailed LCA would be warranted where actual system boundaries can be precisely defined for specific cases and LCA model applicability can be tested.

In general terms, for the four options considered in this study, the energy, materials and greenhouse life cycle inventories are dominated by energy (i.e. electrical power) requirements. In terms of environmental impact potential, the options may be broadly ranked (in order to decreasing environmenral impact potential) as: Seawater Desalination; followed by Indirect Potable Reuse (IPR); Direct Potable Reuse (DPR); and Dual Pipe systems.

Relative comparison of capital, operating and whole-of-life costs based on the options (and underlying assumptions) defined in this study shows that there is a trade-off between feed transfer and treatment plant costs on the one hand, and product water transfer (or reticulation system) costs on the other hand. As a general observation, of the options defined for this study, In NPV terms, Seawater Desalination and IPR are the highest cost options, while DPR and Dual Pipe Recycled Water systems are lower. However, in capital cost terms, IPR and Dual Pipe systems could potentially carry the highest cost, followed by Desalination, with DPR systems potentially the lowest capital cost option, subject to lengths of transfer pipelines and product delivery system head requirements.

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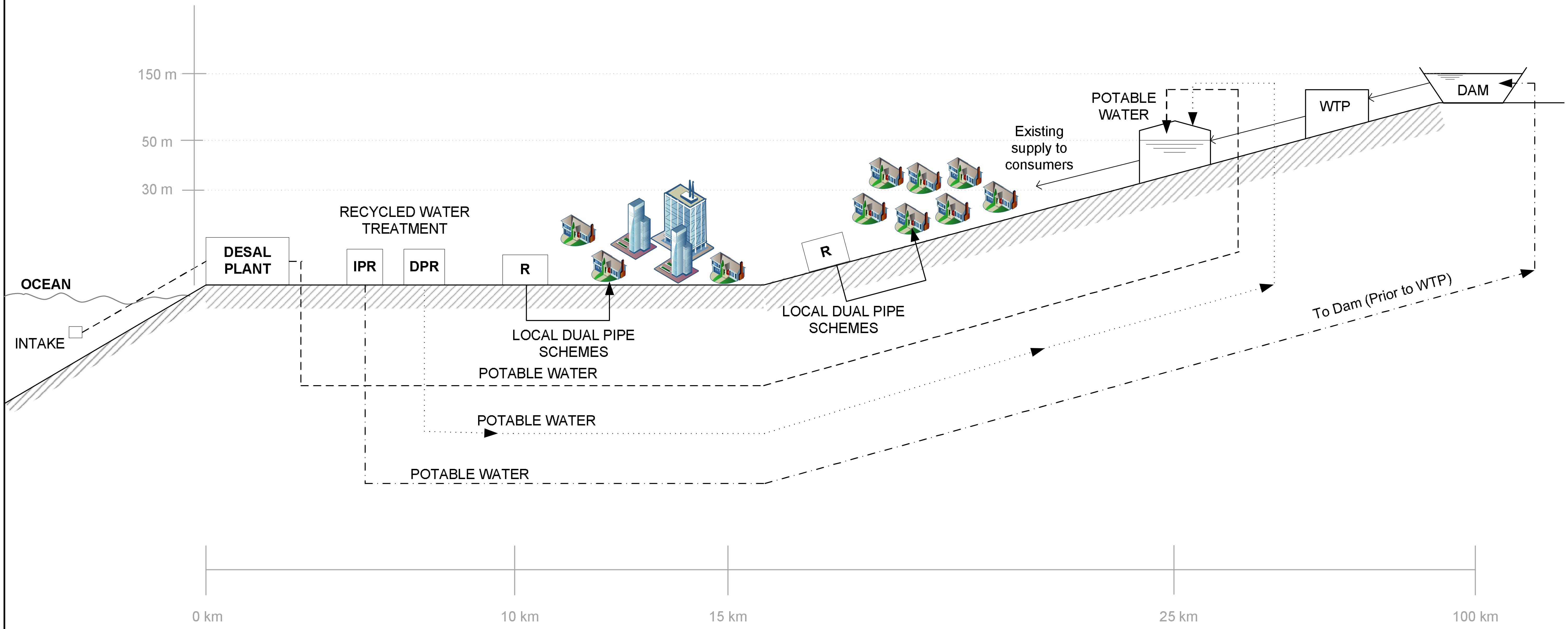
Appendices

Appendix A – Diagrammatic Hydraulic Grade Line for Options

HYDRAULIC PROFILES FOR SUPPLY



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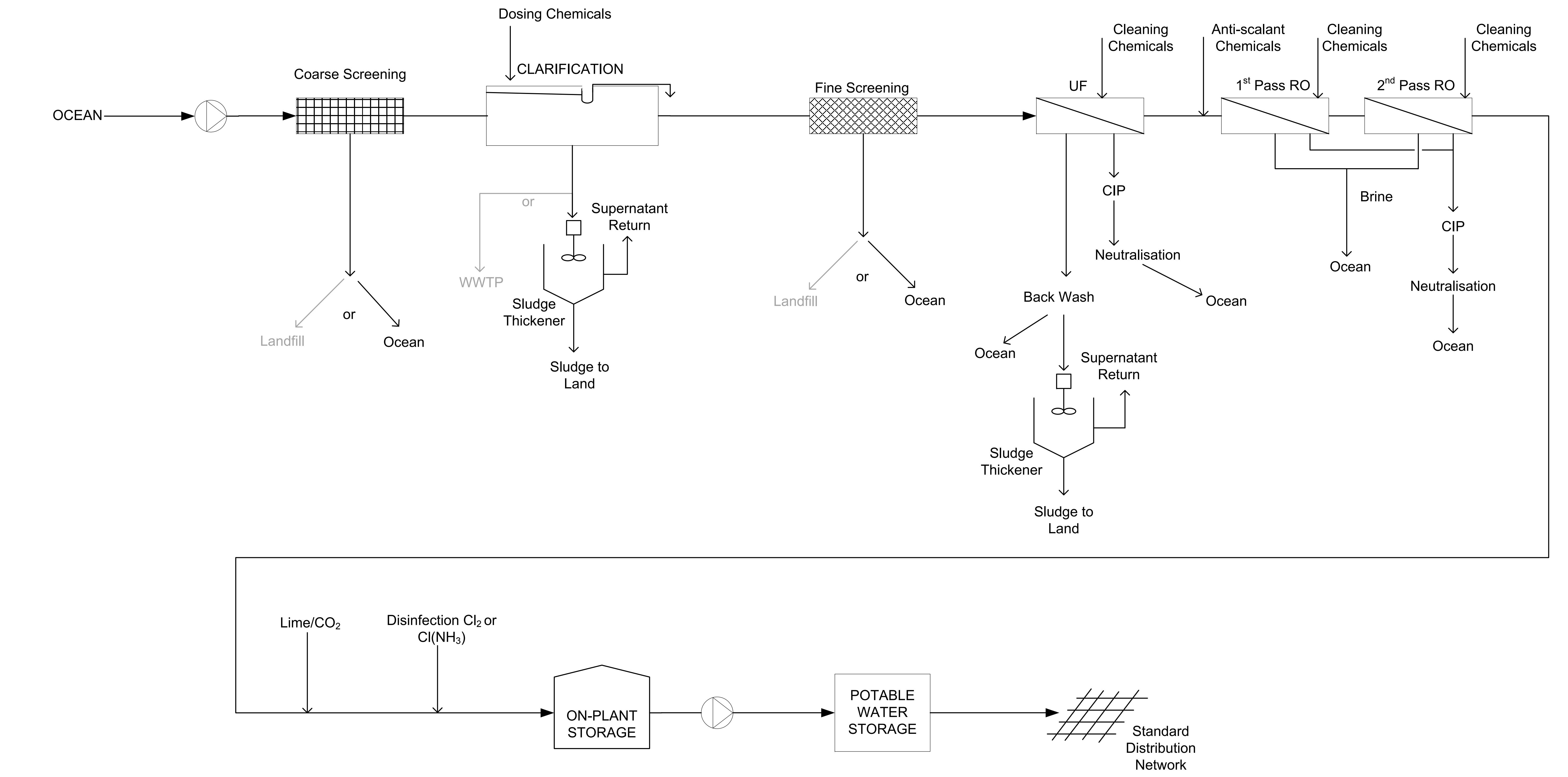
Title: Hydraulic Profile for Supply – All Options
Original Size A3
Rev: 0

Appendix B – Option 1 Process Flow Diagram



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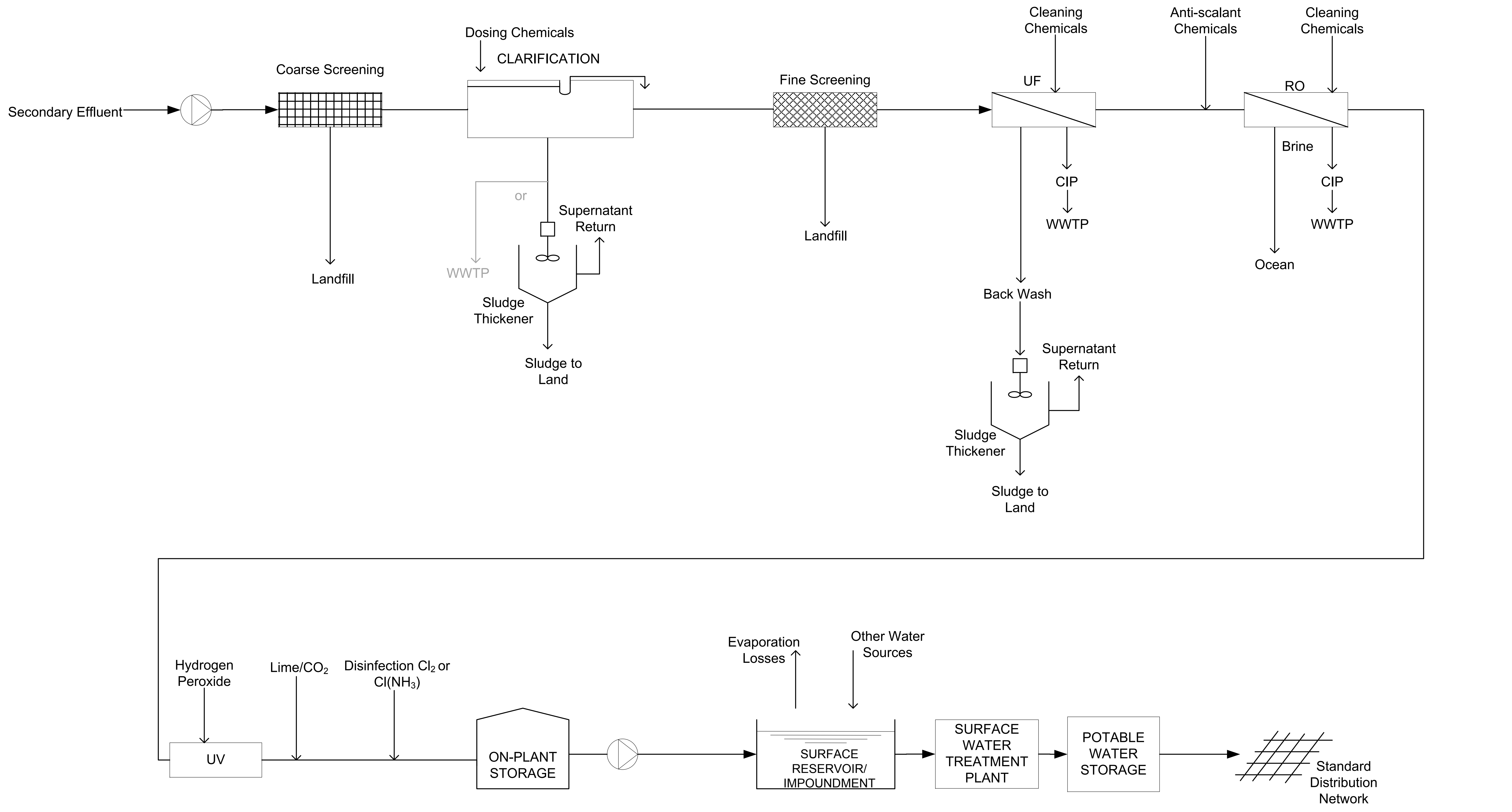
Appendix C – Option 2 Process Flow Diagram



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Title: PFD for Water Supply Option 2 INDIRECT POTABLE REUSE
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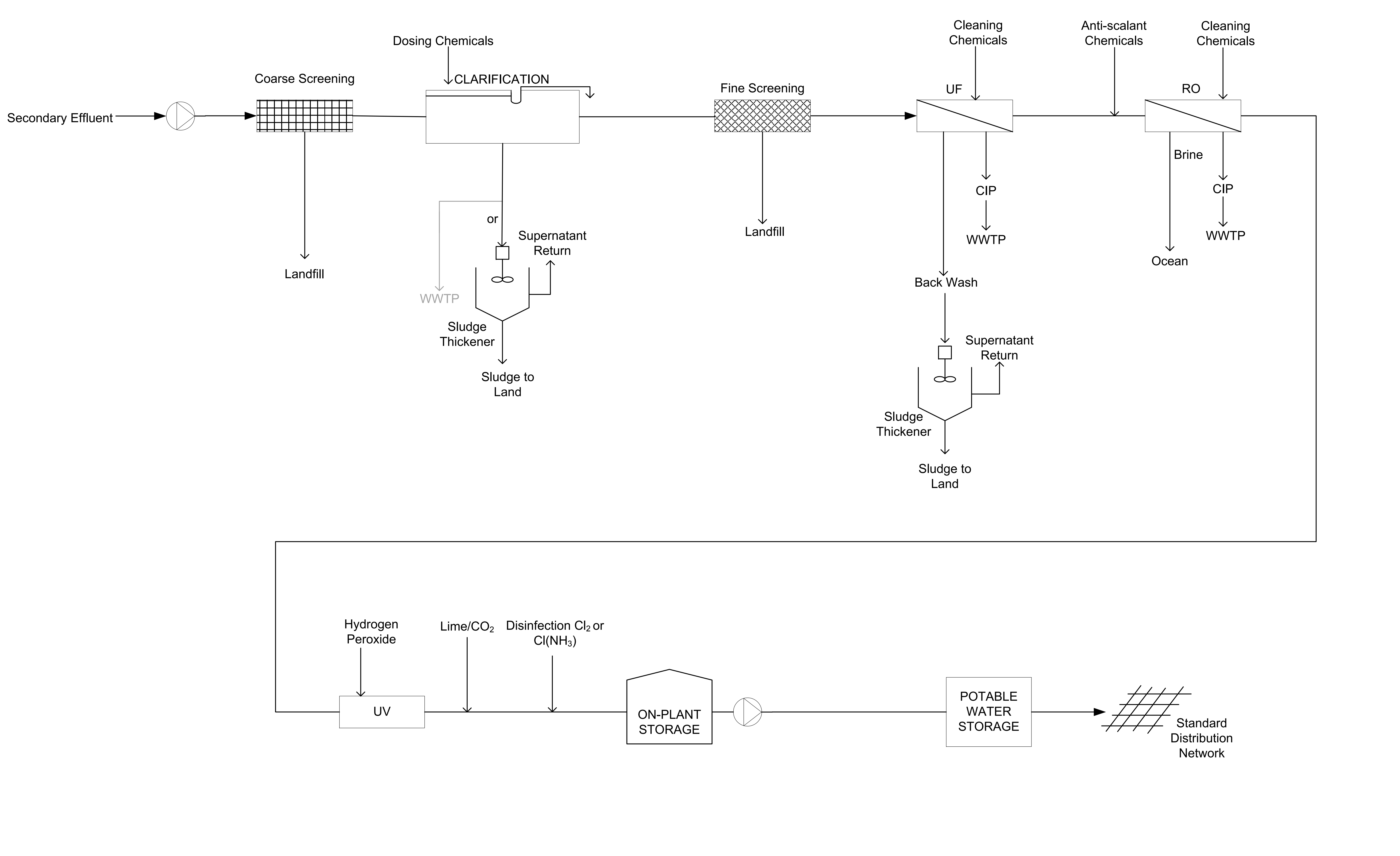
Appendix D – Option 3 Process Flow Diagram



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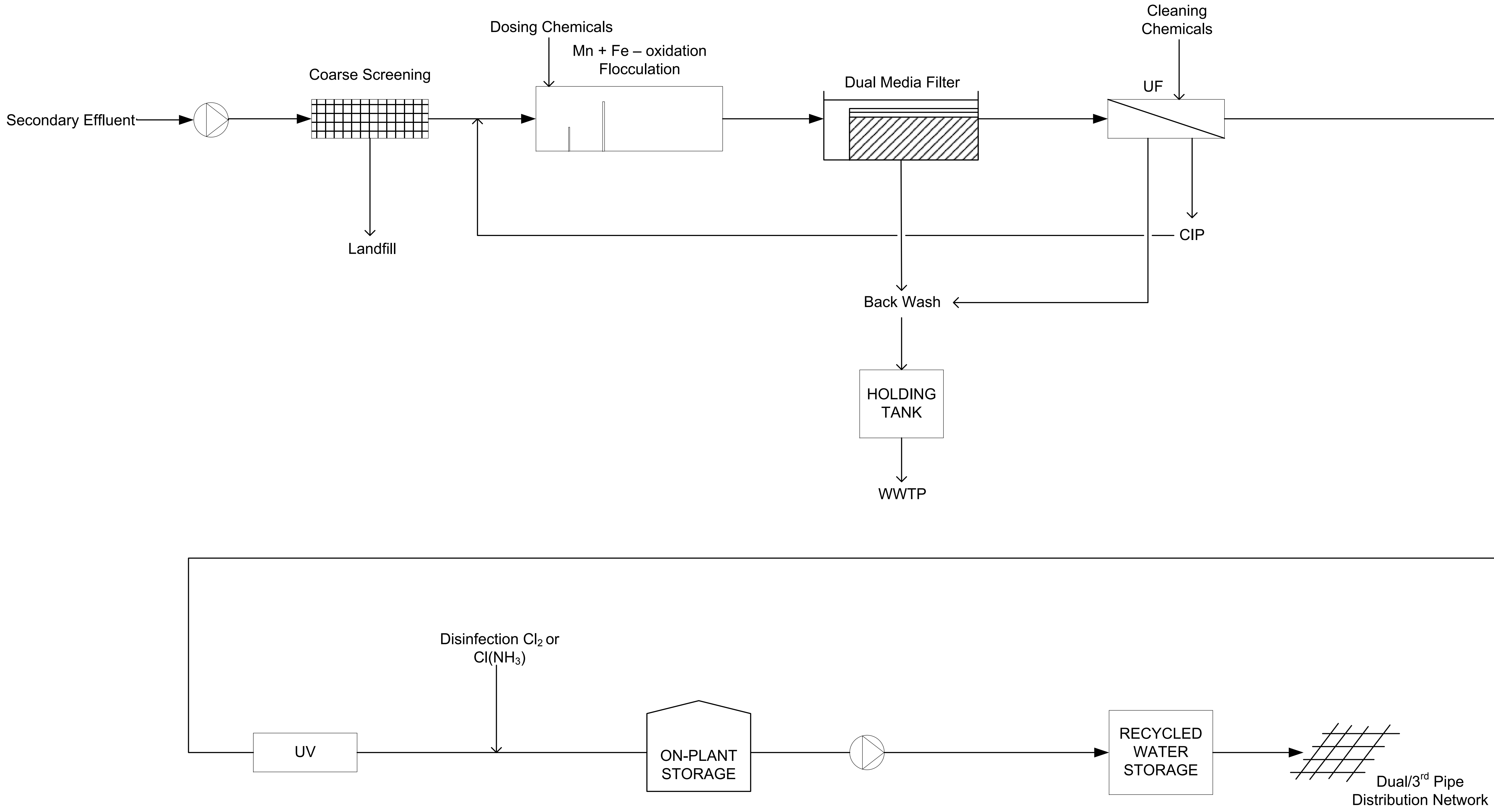
Appendix E – Option 4 Process Flow Diagram



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Project: Drinking Water Through Recycling: The Benefits & Costs of Supplying Direct to Distribution System
Title: PFD for Water Supply Option 4 DUAL PIPE REUSE
Original Size A3
Rev: 0

Appendix F – Construction Life Cycle Inventories

OPTON 1 - SWRO plant, Pipelines, Pumps & Valves
Construction Inventory

Materials & transport only	Based on the data from Munoz et al. (2008)/ Raluy (2003) *with modifications of transport distances in some cases*				
	ROC discharge to sea	As above for Seawater intake			
		Total mass, GRP (tonnes)		**1,296**	2,767
		Concrete mass (tonnnes)		**1,001**	141
		Steel mass (tonnes)		**33**	67
	Product delivery	No. of pipes	1		
		Pipeline length (each)	25000		
		MSCL pipe total length (m)	25000		
		Diameter (mm), nominal	1200		
		Steel Wall thickness (mm)	10.0		
		Cement mortar lining thickness (mm)	25		
		Steel mass (kg per m length)	336		
		Cement mass (kg per m length)	206		
		Total mass, Mild Steel (tonnes)		**8,396**	17,417
		Total mass, Cement mortar (tonnes)		**5,147**	1,187
	pipelines embodied GHG emissions				see above
	pipelines transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	607		
		Greenhouse gas emissions (Scope 3, transport)			962
Valves	Seawater intake & ROC discharge	No. of valves	4		
		Diameter, mm	1200		
		Type	Knife gate		
		Material (mass, kg per valve)	4730		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**18**	37
		Total mass, Stainless steel (tonnes)		**1.1**	2
		Total mass, PTFE &/or EDPM (tonnes)		**0.02**	
	Product delivery	No. of air valves	10		
		No. of isolation valves	20		
		No. of scour valves	20		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1200		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1200 materials (mass, kg per valve)	4730		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**95**	198
		Total mass, Stainless steel (tonnes)		**6.2**	13
		Total mass, PTFE &/or EDPM (tonnes)		**0.18**	0.39
		Total mass, Polyamide(tonnes)		**0.01**	0.03
	valves embodied GHG emissions				see above
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	3		
		Greenhouse gas emissions (Scope 3, transport)			5

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
Membranes	membrane details	model	TORAY SU-820FA		
		materials	aromatic polyamides		
		construction type	spiral wound		
		surface area [m^2] of membrane material per element	32		
		max P [kPa]	8,969		
		dry weight [kg], range per membrane element	18-20		
		dry weight [kg], adopt per membrane element	20		
		lifespan [y]	5		
	no. of membranes	no. of modules	21		
		tubes per module	82		
		membrane elements per tube	7		
		total number of membrane elements	11,979		
	total mass	**Total mass of membrane material (tonnes)**		**240**	
	membrane supply	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	8		
		Greenhouse gas emissions (Scope 3, transport)			**13**
Membrane housing	housing (tube)	materials	plastic reinforced with fibreglass & epoxy resin		
		mass [kg]	35		
		total number	1,711		
	total mass	**Total mass of housing material (tonnes)**		**60**	
	housing supply	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	2		
		Greenhouse gas emissions (Scope 3, transport)			**3.2**
Sand filters	details	configuration	horizontal		
		number	13		
		width [m]	4		
		length [m]	13		
	construction	wall materials	Steel		
		materials density [kg/m^3]	7,800		
		wall thickness [m]	0.05		
		mass of each filter [tonnes]	30.44		
		Total mass, rolled steel (tonnes)		**396**	**821**
	filters supply	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	13		
		Greenhouse gas emissions (Scope 3, transport)			**20.9**
	sand fill	materials	insoluble, silica sand		
		mass (for each filter) [tonnes]	200		
		Total mass, sand (tonnes)		**2,600**	**103**
	filters sand supply	transport type	truck		
		transport distance [km], one way	50		
		no. of truck payloads	87		
		Greenhouse gas emissions (Scope 3, transport)			**13.7**
Pumps	details	total mass [tonnes]	678		
		Steel		**227**	**471**
		Cast iron		**332**	**226**
		Aluminium		**19**	**341**
		Copper		**30**	**163**
		Resin		**4**	**11**
		Cardboard		**57**	**99**
		Miscelleneous		**9**	**23**
	pumps sujppy	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	28		
		Greenhouse gas emissions (Scope 3, transport)			**44.8**
			per 46 ML/d product water	per 120 ML/d product water	
Civil Works	materials	concrete [tonnes]	2000	**5217**	**736**
		reinforced concrete [tonnes]	750	**1957**	**276**
		steel [tonnes]	100	**261**	**541**
		cast iron [tonnes]	10	**26**	**18**
		aluminium	25	**66**	**1,181**
	supply - concrete	transport type	truck		
		transport distance [km], one way	50		
		no. of truck payloads	299		
		Greenhouse gas emissions (Scope 3, transport)			**47.4**
	supply - steel & iron	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	15		
		Greenhouse gas emissions (Scope 3, transport)			**23.3**

OPTION 2 - Indirect Potable Reuse Pipelines, Pumps & Valves
Construction Inventory
Materials & transport only Based on the assumptions for Life Cycle Inventory here

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
Pipelines	Feed	No. of pipes	2		
		Pipeline length (each)	1000		
		MSCL pipe total length (m)	2000		
		Diameter (mm), nominal	1050		
		Steel Wall thickness (mm)	8.0		
		Cement mortar lining thickness (mm)	19		
		Steel mass (kg per m length)	228		
		Cement mass (kg per m length)	130		
		Total mass, Mild Steel (tonnes)		**456**	**945**
		Total mass, Cement mortar (tonnes)		**261**	**4**
	ROC discharge	No. of pipes	2		
		Pipeline length (each)	1000		
		MSCL pipe total length (m)	2000		
		Diameter (mm), nominal	1050		
		Steel Wall thickness (mm)	8.0		
		Cement mortar lining thickness (mm)	19		
		Steel mass (kg per m length)	228		
		Cement mass (kg per m length)	130		
		Total mass, Mild Steel (tonnes)		**456**	**945**
		Total mass, Cement mortar (tonnes)		**261**	**55**
	Product delivery	No. of pipes	1		
		Pipeline length (each)	100000		
		MSCL pipe total length (m)	100000		
		Diameter (mm), nominal	1200		
		Steel Wall thickness (mm)	10.0		
		Cement mortar lining thickness (mm)	25		
		Steel mass (kg per m length)	336		
		Cement mass (kg per m length)	206		
		Total mass, Mild Steel (tonnes)		**33,582**	**69,668**
		Total mass, Cement mortar (tonnes)		**20,589**	**4,747**
	pipelines embodied GHG emissions				**see above**
	pipelines transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1,853		
		Greenhouse gas emissions (Scope 3, transport)			**2,938**
Valves	Feed & ROC discharge	No. of air valves	8		
		No. of isolation valves	48		
		No. of scour valves	8		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1000		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1000 materials (mass, kg per valve)	3059		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**141**	**293**
		Total mass, Stainless steel (tonnes)		**9.1**	**19**
		Total mass, PTFE &/or EDPM (tonnes)		**0.21**	**0.47**
		Total mass, Polyamide (tonnes)		**0.00**	**0.01**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	5		
		Greenhouse gas emissions (Scope 3, transport)			**8**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Product delivery	No. of air valves	40		
		No. of isolation valves	80		
		No. of scour valves	80		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1000		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1000 materials (mass, kg per valve)	3059		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**256**	**530**
		Total mass, Stainless steel (tonnes)		**16.7**	**35**
		Total mass, PTFE &/or EDPM (tonnes)		**0.58**	**1.27**
		Total mass, Polyamide(tonnes)		**0.02**	**0.12**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	9		
		Greenhouse gas emissions (Scope 3, transport)			**14**
Pumps	Feed	Assumed pump station design capacity (L/s max.)	932		
		Max, capacity (m3/h)	3354		
		Assumed system head (m)	10		
		Approx. pump kW rating per pumpstation	200		
		No. of pump stations	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	12		
		Max. capacity per pump (m3/h)	670		
		Approx. pump motor kW rating per duty pump	29		
		Assumed pump + motor mass each (kg)	910		
		Total mass (pumps + motors) installed (tonnes)	10.92		
		Steel		**3.7**	**7.6**
		Cast iron		**5.4**	**3.6**
		Aluminium		**0.3**	**5.5**
		Copper		**0.5**	**2.6**
		Resin		**0.1**	**0.2**
		Cardboard		**0.9**	**1.6**
		Miscelleneous		**0.1**	**0.4**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1		
		Greenhouse gas emissions (Scope 3, transport)			**2**
	ROC discharge	Assumed pump station design capacity (L/s max.)	168		
		Max, capacity (m3/h)	604		
		Assumed system head (m)	4		
		Approx. pump kW rating per pumpstation	11		
		No. of pump stations	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	12		
		Max. capacity per pump (m3/h)	121		
		Approx. pump motor kW rating per duty pump	3		
		Assumed pump + motor mass each (kg)	152		
		Total mass (pumps + motors) installed (tonnes)	1.824		
		Steel		**0.61**	**1.3**
		Cast iron		**0.89**	**0.6**
		Aluminium		**0.05**	**0.9**
		Copper		**0.08**	**0.4**
		Resin		**0.01**	**0.0**
		Cardboard		**0.15**	**0.3**
		Miscelleneous		**0.02**	**0.1**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1		
		Greenhouse gas emissions (Scope 3, transport)			**2**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Product delivery	Assumed pump station design capacity (L/s max.)	764		
		Max, capacity (m3/h)	2750		
		Assumed Total system head (m)	263		
		No. of pumping Stages	3		
		Assumed system head (m) per Stage	88		
		Approx. pump total kW rating per pumpstation	1000		
		No. of pump stations per Stage	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	36		
		Max. capacity per pump (m3/h)	550		
		Approx. pump motor kW rating per duty pump	200		
		Assumed pump + motor mass each (kg)	2301		
		Total mass (pumps + motors) installed (tonnes)	82.836		
		Steel		**27.7**	**57.5**
		Cast iron		**40.6**	**27.6**
		Aluminium		**2.3**	**41.6**
		Copper		**3.6**	**20.0**
		Resin		**0.5**	**1.4**
		Cardboard		**7.0**	**12.0**
		Miscelleneous		**1.1**	**2.9**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	4		
		Greenhouse gas emissions (Scope 3, transport)			**6**

OPTION 3 - Direct Potable Reuse Pipelines, Pumps & Valves
Construction Inventory
Materials & transport only Based on the assumptions for Life Cycle Inventory here

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
Pipelines	Feed	No. of pipes	2		
		Pipeline length (each)	1000		
		MSCL pipe total length (m)	2000		
		Diameter (mm), nominal	1050		
		Steel Wall thickness (mm)	8.0		
		Cement mortar lining thickness (mm)	19		
		Steel mass (kg per m length)	228		
		Cement mass (kg per m length)	130		
		Total mass, Mild Steel (tonnes)		**456**	**945**
		Total mass, Cement mortar (tonnes)		**261**	**4**
	ROC discharge	No. of pipes	2		
		Pipeline length (each)	1000		
		MSCL pipe total length (m)	2000		
		Diameter (mm), nominal	1050		
		Steel Wall thickness (mm)	8.0		
		Cement mortar lining thickness (mm)	19		
		Steel mass (kg per m length)	228		
		Cement mass (kg per m length)	130		
		Total mass, Mild Steel (tonnes)		**456**	**945**
		Total mass, Cement mortar (tonnes)		**261**	**55**
	Product delivery	No. of pipes	1		
		Pipeline length (each)	25000		
		MSCL pipe total length (m)	25000		
		Diameter (mm), nominal	1200		
		Steel Wall thickness (mm)	10.0		
		Cement mortar lining thickness (mm)	25		
		Steel mass (kg per m length)	336		
		Cement mass (kg per m length)	206		
		Total mass, Mild Steel (tonnes)		**8,396**	**17,417**
		Total mass, Cement mortar (tonnes)		**5,147**	**1,187**
	pipelines embodied GHG emissions				**see above**
	pipelines transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	499		
		Greenhouse gas emissions (Scope 3, transport)			**791**
Valves	Feed & ROC discharge	No. of air valves	8		
		No. of isolation valves	48		
		No. of scour valves	8		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1000		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1000 materials (mass, kg per valve)	3059		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**141**	**293**
		Total mass, Stainless steel (tonnes)		**9.1**	**19**
		Total mass, PTFE &/or EDPM (tonnes)		**0.21**	**0.47**
		Total mass, Polyamide (tonnes)		**0.00**	**0.01**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	5		
		Greenhouse gas emissions (Scope 3, transport)			**8**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Product delivery	No. of air valves	10		
		No. of isolation valves	20		
		No. of scour valves	20		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1000		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1000 materials (mass, kg per valve)	3059		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**64**	**133**
		Total mass, Stainless steel (tonnes)		**4.2**	**9**
		Total mass, PTFE &/or EDPM (tonnes)		**0.14**	**0.32**
		Total mass, Polyamide(tonnes)		**0.01**	**0.03**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	2		
		Greenhouse gas emissions (Scope 3, transport)			**4**
Pumps	Feed	Assumed pump station design capacity (L/s max.)	932		
		Max, capacity (m3/h)	3354		
		Assumed system head (m)	10		
		Approx. pump kW rating per pumpstation	200		
		No. of pump stations	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	12		
		Max. capacity per pump (m3/h)	670		
		Approx. pump motor kW rating per duty pump	29		
		Assumed pump + motor mass each (kg)	910		
		Total mass (pumps + motors) installed (tonnes)	10.92		
		Steel		**3.7**	**7.6**
		Cast iron		**5.4**	**3.6**
		Aluminium		**0.3**	**5.5**
		Copper		**0.5**	**2.6**
		Resin		**0.1**	**0.2**
		Cardboard		**0.9**	**1.6**
		Miscelleneous		**0.1**	**0.4**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1		
		Greenhouse gas emissions (Scope 3, transport)			**2**
	ROC discharge	Assumed pump station design capacity (L/s max.)	168		
		Max, capacity (m3/h)	604		
		Assumed system head (m)	4		
		Approx. pump kW rating per pumpstation	11		
		No. of pump stations	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	12		
		Max. capacity per pump (m3/h)	121		
		Approx. pump motor kW rating per duty pump	3		
		Assumed pump + motor mass each (kg)	152		
		Total mass (pumps + motors) installed (tonnes)	1.824		
		Steel		**0.61**	**1.3**
		Cast iron		**0.89**	**0.6**
		Aluminium		**0.05**	**0.9**
		Copper		**0.08**	**0.4**
		Resin		**0.01**	**0.0**
		Cardboard		**0.15**	**0.3**
		Miscelleneous		**0.02**	**0.1**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1		
		Greenhouse gas emissions (Scope 3, transport)			**2**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Product delivery	Assumed pump station design capacity (L/s max.)	764		
		Max, capacity (m3/h)	2750		
		Assumed system head (m)	86		
		Approx. pump kW rating per pumpstation	1000		
		No. of pump stations	2		
		No. of duty pumps (n) per pump station	5		
		Total no. of pumps installed	12		
		Max. capacity per pump (m3/h)	550		
		Approx. pump total kW rating per pumpstation	200		
		Assumed pump + motor mass each (kg)	2021		
		Total mass (pumps + motors) installed (tonnes)	24.252		
		Steel		**8.1**	**16.8**
		Cast iron		**11.9**	**8.1**
		Aluminium		**0.7**	**12.2**
		Copper		**1.1**	**5.8**
		Resin		**0.2**	**0.4**
		Cardboard		**2.0**	**3.5**
		Miscelleneous		**0.3**	**0.8**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	2		
		Greenhouse gas emissions (Scope 3, transport)			**3**

OPTION 4 - Dual Pipe System Reuse Pipelines, Pumps & Valves
Construction Inventory
Materials & transport only Based on the assumptions for Life Cycle Inventory here

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
Pipelines	Feed	No. of pipes	6		
		Pipeline length (each)	250		
		uPVC pipe total length (m)	1500		
		Diameter (mm), nominal	600		
		(u)PVC mass (kg per m length)	60		
		Total mass, PVC (tonnes)		**90**	**215**
	Backwash discharge	No. of pipes	6		
		Pipeline length (each)	250		
		uPVC pipe total length (m)	1500		
		Diameter (mm), nominal	225		
		(u)PVC mass (kg per m length)	12		
		Total mass, PVC (tonnes)		**18**	**39**
	Product delivery	No. of pipes	6		
		Pipeline length (each)	8000		
		MSCL pipe total length (m)	48000		
		Diameter (mm), nominal	600		
		Steel Wall thickness (mm)	6.5		
		Cement mortar lining thickness (mm)	13		
		Steel mass (kg per m length)	228		
		Cement mass (kg per m length)	130		
		Total mass, Mild Steel (tonnes)		**10,936**	**22,688**
		Total mass, Cement mortar (tonnes)		**6,253**	**1,442**
	pipelines embodied GHG emissions				**see above**
	pipelines transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	577		
		Greenhouse gas emissions (Scope 3, transport)			**914**
	RW Distribution	**Total mass, Asbestos cement (tonnes)**		**847**	**681**
		Total mass, Cement mortar (lining) (tonnes)		**3,838**	**885**
		Total mass, Ductile Iron (tonnes)		**3,751**	**2,554**
		Total mass, Mild steel (tonnes)		**5,206**	**10,799**
		Total mass, Stainless steel (tonnes)		**0.3**	**1**
		Total mass, MPVC (tonnes)		**93**	**224**
		Total mass, UPVC (tonnes)		**1,677**	**4,016**
		Total mass, Polyethylene (tonnes)		**150**	**328**
		Total mass, Polypropylene (tonnes)		**0.4**	**1**
Valves	Feed & Recycle discharg	No. of air valves	0		
		No. of isolation valves	72		
		No. of scour valves	12		
		Diameter or isolation valves (mm)	600		
		Diameter or scour valves (mm)	150		
		Gate valves DN 600 materials (mass, kg per valve)	828		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 150 materials (mass, kg per valve)	42.3		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**56**	**117**
		Total mass, Stainless steel (tonnes)		**3.6**	**7**
		Total mass, PTFE &/or EDPM (tonnes)		**0.06**	**0.13**
		Total mass, Polyamide (tonnes)		**0.00**	**0.00**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	2		
		Greenhouse gas emissions (Scope 3, transport)			**3**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Product delivery	No. of air valves	19		
		No. of isolation valves	38		
		No. of scour valves	38		
		Diameter or air valves (mm)	150		
		Diameter or isolation valves (mm)	1000		
		Diameter or scour valves (mm)	375		
		Air valves materials (mass per valve)	194		
		Ductile Iron	85%		
		Steel (Galvanised/ Powder coated)	10%		
		Stainless Steel	4%		
		Polyethylene	1%		
		Gate valves DN 1000 materials (mass, kg per valve)	3059		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		PTFE/ EPDM (seals)	0.1%		
		Scour valves DN 375 materials (mass, kg per valve)	255.6		
		Ductile iron (body)	94%		
		Stainless steel (stem, bolts, nuts)	6%		
		Polyamide (bushes)	0.1%		
		EPDM (seals)	0.1%		
		Total mass, Ductile iron (tonnes)		**123**	**254**
		Total mass, Stainless steel (tonnes)		**8.0**	**17**
		Total mass, PTFE &/or EDPM (tonnes)		**0.28**	**0.61**
		Total mass, Polyamide(tonnes)		**0.01**	**0.06**
	RW Distribution	**Total mass, Ductile Iron (tonnes)**		**521**	**355**
		Total mass, Mild Steel (tonnes)		**16.3**	**34**
		Total mass, Stainless Steel (tonnes)		**18.2**	**38**
		Total mass, Polyethylene (tonnes)		**1.1**	**2.4**
		Total mass, EPDM (tonnes)		**2.3**	**5.05**
		Total mass, Rubber (tonnes)		**0.06**	**0.13**
		Total mass, Polyamide (tonnes)		**2.2**	**13.4**
		Total mass, Brass (tonnes)		**4.5**	**24.6**
	valves embodied GHG emissions				**see above**
	valves transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	4		
		Greenhouse gas emissions (Scope 3, transport)			**7**
Pumps	Feed	Assumed pump station design capacity (L/s max.)	271		
		Max, capacity (m3/h)	975		
		Assumed system head (m)	13		
		Approx. pump kW rating per pumpstation	100		
		No. of pump stations	6		
		No. of duty pumps (n) per pump station	2		
		Total no. of pumps installed	18		
		Max. capacity per pump (m3/h)	490		
		Approx. pump motor kW rating per duty pump	28		
		Assumed pump + motor mass each (kg)	764		
		Total mass (pumps + motors) installed (tonnes)	13.752		
		Steel		**32.3**	**67.0**
		Cast iron		**47.3**	**32.2**
		Aluminium		**2.7**	**48.5**
		Copper		**4.2**	**23.3**
		Resin		**0.6**	**1.6**
		Cardboard		**8.1**	**14.0**
		Miscelleneous		**1.3**	**3.3**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	5		
		Greenhouse gas emissions (Scope 3, transport)			**8**

Item	Purpose	Item (units)	Amount	Inventory input	GHG emissons (tonnes CO2-e)
	Backwash discharge	Assumed pump station design capacity (L/s max.)	30		
		Max, capacity (m3/h)	106		
		Assumed system head (m)	5		
		Approx. pump kW rating per pumpstation	3		
		No. of pump stations	6		
		No. of duty pumps (n) per pump station	2		
		Total no. of pumps installed	18		
		Max. capacity per pump (m3/h)	53		
		Approx. pump motor kW rating per duty pump	2.0		
		Assumed pump + motor mass each (kg)	193		
		Total mass (pumps + motors) installed (tonnes)	3.474		
		Steel		**1.16**	**2.4**
		Cast iron		**1.70**	**1.2**
		Aluminium		**0.10**	**1.7**
		Copper		**0.15**	**0.8**
		Resin		**0.02**	**0.1**
		Cardboard		**0.29**	**0.5**
		Miscelleneous		**0.05**	**0.1**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	1		
		Greenhouse gas emissions (Scope 3, transport)			**2**
	Product delivery	Assumed pump station design capacity (L/s max.)	255		
		Max, capacity (m3/h)	917		
		Assumed system head (m)	44		
		Approx. pump kW rating per pumpstation	200		
		No. of pump stations	6		
		No. of duty pumps (n) per pump station	2		
		Total no. of pumps installed	18		
		Max. capacity per pump (m3/h)	460		
		Approx. pump total kW rating per pumpstation	90		
		Assumed pump + motor mass each (kg)	1465		
		Total mass (pumps + motors) installed (tonnes)	26.37		
		Steel		**8.8**	**18.3**
		Cast iron		**12.9**	**8.8**
		Aluminium		**0.7**	**13.3**
		Copper		**1.2**	**6.4**
		Resin		**0.2**	**0.4**
		Cardboard		**2.2**	**3.8**
		Miscelleneous		**0.3**	**0.9**
	pumps embodied GHG emissions				**see above**
	pumps transport	transport type	truck		
		transport distance [km], one way	500		
		no. of truck payloads	2		
		Greenhouse gas emissions (Scope 3, transport)			**3**
Reservoirs	Product delivery	Peak demand vs. average production	3		
		Hours of storage at peak demand (h)	8		
		Total storage volume required (ML) per AWTP	20		
		No. of reservoirs in distribution system per AWTP	4		
		Total no. of reservoirs	24		
		Volume per reservoir (ML)	5		
		Depth of each reservoir when at max. capacity (m)	6		
		Surface Area per reservoir (m2)	833		
		Diameter per reservoir (m)	32.6		
		Concrete Wall thickness (mm)	300		
		Concrete Volume per reservoir (m3)	716		
		Floor	250		
		Walls	216		
		Roof	250		
		Reinforcing steel (kg per m3 of concrete)	78		
		Total mass, Concrete (tonnes)		**41,235**	**5,816**
		Total mass, Reinforcing steel (tonnes)		**1,333**	**2,765**

Appendix G – Operations Life Cycle Inventories

OPTION 1 - SWRO plant
Operations Inventory

Flows	Units	Estimate Most likely	Estimate Low	Estimate High
Water Recovery	%	42%	40%	46%
Seawater intake (Feed)	ML/d	286		
Product Water	ML/d	120		
Brine (ROC) & Reject/ Backwash	ML/d	166		

Power	Per ML product water	Estimate Most likely	Estimate Low	Estimate High		Power consumption	Estimate Most likely	Estimate Low	Estimate High	Average power	Estimate Most likely	Estimate Low	Estimate High
Seawater Intake & ROC discharge pumping	kWh/ML	250	200	350	7%	kWh/d	30,000	24,000	42,000	kW	1,250	1,000	1,750
SWRO plant, most likely with ERD	kWh/ML	3350	3100	4150	93%	kWh/d	402,000	372,000	498,000	kW	16,750	15,500	20,750
Product water distribution	kWh/ML	360	250	500		kWh/d	43,200	30,000	60,000	kW	1,800	1,250	2,500
Total	kWh/ML	3960	3550	5000		kWh/d	475,200	426,000	600,000	kW	19,800	17,750	25,000
Seawater intake & ROC pumping as % toTotal (excl product water distribution		7%	6%	8%									
SWRO plant % toTotal (excl product water distribution		93%	94%	92%									

	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High
SUM (Scope 2 + 3) GHG emissions							
				tonnes CO2-e/ annum	**178,264**	**50,671**	**312,404**
				tonnes CO2-e/ ML product water	4.07	1.16	7.13
Scope 2 GHG emissions factor	0.85	0.26	1.19	**Scope 2 GHG emissions**			
Seawater Intake & ROC discharge pumping				tonnes CO2-e/ annum	9,326	2,278	18,243
SWRO plant, most likely with ERD				tonnes CO2-e/ annum	124,965	35,303	216,306
Product water distribution				tonnes CO2-e/ annum	13,429	2,847	26,061
				Sub-Total	**147,720**	**40,427**	**260,610**
Scope 3 GHG emissions factor	0.13	0.03	0.17	**Scope 3 GHG emissions**			
Seawater Intake & ROC discharge pumping				tonnes CO2-e/ annum	1,387	263	2,606
SWRO plant, most likely with ERD				tonnes CO2-e/ annum	18,586	4,073	30,901
Product water distribution				tonnes CO2-e/ annum	1,997	329	3,723
				Sub-Total	**21,970**	**4,665**	**37,230**

	63%	Allocation to Seawater Intake Pumping																		
		Implied system pumping head, at 65% wire-water efficiency	Most likely	Low	High	Assumed static pumping head	Most likely	Low	High	Implied assumed dynamic pumping head	Most likely	Low	High	Assume average pipe dian		No. of pipes	Implied average pipe internal velocity		Assume length	
Seawater Intake		Head, m	38	30	53	Head, m	20	15	30	Dyn Head, m	18	15	23	diameter (mm)	1800	1	velocity (m/s)	1.3	pipe length (m)	2500
ROC discharge		Head, m	22	18	31	Head, m	10	5	13	Dyn Head, m	12	13	18	diameter (mm)	1800	1	velocity (m/s)	0.75	pipe length (m)	2500
Product water		Head, m	86	60	119	Head, m	50	30	75	Dyn Head, m	36	30	44	diameter (mm)	1200	1	velocity (m/s)	1.2	pipe length (m)	25000

Chemicals

Name or Type	Per ML product water	Estimate Most likely	Estimate Low	Estimate High	Chemical consumption (averaged per day)	Estimate Most likely	Estimate Low	Estimate High	Embodied GHG emissions		Payload		Transport distance (chemicals) km: Most likely 100	Low 12	High 1000	Scope 3 (materials + transport) GHG emissions	Most likely	Low	High
Ferric sulphate	mg/L as Fe2(SO4)3	10.0	7.3	17.9	kg/d as 42% w/w Fe2(SO4)3 solution	2857	2096	5112	kgCO2-e/ kg product	*0.802*	24	tonnes				tonnes CO2-e/ annum	843	614	1,619
Polymer for coagulation	mg/L as flocculant product (dry)	0.26	0.1	0.4	kg/d as 48% w/w active polymer solution	65	25	100	kgCO2-e/ kg product	1.182	10	tonnes				tonnes CO2-e/ annum	28	11	49
Sodium Hypochlorite	mg/L as avail. Cl2	3.0	2.4	4.0	kg/d as 12.5% w/w available Cl2 solution	2880	2304	3840	kgCO2-e/ kg product	0.885	24	tonnes				tonnes CO2-e/ annum	938	745	1,333
Pre RO (incl. shock dose)	mg/L as avail. Cl2	2.5	2	3.3															
Post RO (disinfection)	mg/L as avail. Cl2	0.5	0.4	0.7															
Sodium bisulphite	mg/L as NaHSO3	3.0	2.0	4.6	kg/d as 34% w/w NaHSO3 solution, SG = 1.34	1048	699	1607	kgCO2-e/ kg product	*0.272*	10	tonnes				tonnes CO2-e/ annum	110	70	253
Sulphuric acid	mg/L as H2SO4	5	3.5	7.2	kg/d as 60% w/w H2SO4 solution, SG = 1.50	1000	694	1440	kgCO2-e/ kg product	0.078	10	tonnes				tonnes CO2-e/ annum	34	20	124
Hydrated lime	mg/L as Ca(OH)2	30	21	43	kg/d as dry white hydrated lime (min. 68% CaO)	4006	2604	5400	kgCO2-e/ kg product	1.640	24	tonnes				tonnes CO2-e/ annum	2,408	1,560	3,363
Carbon dioxide	mg/L as CO2	35	24	50	kg/d as CO2 (pure gas)	4200	3038	6300	kgCO2-e/ kg product	0.000	10	tonnes				tonnes CO2-e/ annum	24	2	364
Antiscalant																tonnes CO2-e/ annum			
Polycarboxylates / (Poly)Phosphonates	mg/L as ?	2.5	1.8	3	kg/d (dry) 100% active powder	300	225	375	kgCO2-e/ kg product	*1.182*	10	tonnes				tonnes CO2-e/ annum	131	97	183
Polymer for dewatering	kg/ tonne d.s.	7	5	9	kg/d (dry) 100% active powder	20	9	45	kgCO2-e/ kg product	1.182	10	tonnes				tonnes CO2-e/ annum	9	4	22
					Sub-total	**16,377**	**11,694**	**24,219**								**Sub-total**	**4,525**	**3,123**	**7,311**

RO Membrane replacement	Specific membrane material use per unit volume product water	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High			Payload		Transport distance (membranes) km: Most likely 100	Low 12	High 1000	Scope 3 (materials + transport) GHG emissions	Most likely	Low	High
Membranes	kg/ML Polyamide	1.15	0.41	1.92	kg/d Polyamide	138	49	231	kgCO2-e/ kg product	6.001	13	tonnes				tonnes CO2-e/ annum	304	108	526
Membrane pressure vessel	kg/ML FRP / Epoxy resin	0.29	0.10	0.48	kg/d FRP / Epoxy resin	35	12	58	kgCO2-e/ kg product	*2.206*	1.4	tonnes				tonnes CO2-e/ annum	31	10	96
Pressure vessel seals	kg/ML EPDM	0.005	0.003	0.008	kg/d EPDM	0.5	0.4	1.0	kgCO2-e/ kg product	*2.206*	0.05	tonnes				tonnes CO2-e/ annum	1.7	0.4	23
Approx. no. of membrane modules replaced per year		2526	1805	4211	**Sub-total**	**174**	**62**	**289**								**Sub-total**	**337**	**119**	**645**
Approx. no. of pressure vessels replaced per year		361	258	602															

Sludge production	From Pre-treatment per ML Feed Water	Estimate Most likely	Estimate Low	Estimate High
Assumptions				
Seawater TSS	mg/L	2.5	1.2	5
Seawater DOC	mg/L	1.5	1	2
Seawater dissolved ortho P removed in pretreatment	mg/L as P	0.05	0.003	0.10
Fe:P ratio of ppt	molar ratio	33	n/a	29
Fe~P precipitate, theory	MW g/mol	3601	107	3127
Fe dosed	mmol/L	0.050	0.037	0.090
Fe~P formed	mg/L	5.4	3.9	9.7
DOC coagulated	mg/L	1.125	0.75	1.5
Total Precipitate formed in pre-treatment	mg/L	10.7	7.0	18.4
Pre-treatment solids capture	%	93%	90%	95%
Pre-treament effluent TSS	mg/L	0.7	0.7	0.9

	Units	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High	Payload		Transport distance (sludge) km: Most likely	Low	High		Scope 3 GHG emissions (transport + disposal)	Most likely	Low	High
Sludge production TSS	mg/L	10	6	17	kg/d TSS dry	2836	1790	4990										
					kg/d wet cake, 28% d.s.	10129	6394	17821	20	tor km	25	10	100	Tr	tonnes CO2-e/ annum	15	4	103
					Wet cake kg/ML product water	84	53	149						Di	tonnes CO2-e/ annum	3697	2334	6505
															Sub-total	**3712**	**2338**	**6608**

OPTION 2 - AWTP for treatment and water recycling via Indirect Potable Reuse (to regional impoundment serving as raw water source for potable water network)
Operations Inventory

Flows	Units	Estimate Most likely	Estimate Low	Estimate High
Water Recovery	%	82%	80%	84%
Secondary Effluent Feed (intake)	ML/d	73		
Product Water	ML/d	60		
Brine (ROC) & Reject/ Backwash	ML/d	13		

Power	Per ML product water	Estimate Most likely	Estimate Low	Estimate High	Power consumption	Estimate Most likely	Estimate Low	Estimate High	Average power	Estimate Most likely	Estimate Low	Estimate High	Scope 2 GHG emissions factor Most likely	Low	High	Scope 2 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Sec. Effluent Feed & ROC discharge pumping	kWh/ML	60	50	70	kWh/d	3,600	3,000	4,200	kW	150	125	175	0.85	0.26	1.19	tonnes CO2-e/ annum	1,119	285	1,824
AWTP plant	kWh/ML	1180	930	1420	kWh/d	70,800	55,800	85,200	kW	2950	2325	3550				tonnes CO2-e/ annum	22,009	5,295	37,007
Product water distribution	kWh/ML	1100	950	1250	kWh/d	66,000	57,000	75,000	kW	2750	2375	3125				tonnes CO2-e/ annum	20,517	5,409	32,576
Total	kWh/ML	2340	1930	2740	kWh/d	**140,400**	**115,800**	**164,400**	kW	5850	4825	6850				**Sub-Total**	**43,645**	**10,989**	**71,407**

	Scope 3 GHG emissions factor Most likely	Low	High	Scope 3 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Sec. Effluent Feed & ROC discharge pumping	0.13	0.03	0.17	tonnes CO2-e/ annum	166	33	261
AWTP plant				tonnes CO2-e/ annum	3,273	611	5,287
Product water distribution				tonnes CO2-e/ annum	3,051	624	4,654
				Sub-Total	**6,491**	**1,268**	**10,201**

SUM (Scope 2 + 3) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
tonnes CO2-e/ annum	**58,885**	**19,139**	**94,330**
tonnes CO2-e/ ML product water	2.69	0.87	4.31

Implied system pumping head, at 65% wire-water efficiency	Estimate Most likely	Estimate Low	Estimate High	Assumed static pumping head	Estimate Most likely	Estimate Low	Estimate High	Implied assumed dynamic pumping head	Estimate Most likely	Estimate Low	Estimate High	Assume average pipe diam		No. of pipes	Implied average pipe internal velocity		Assume length	
Head, m	14	12	17	Head, m	8	6	10	Dyn Head, m	6	6	7	diameter (mm)	1050	1	velocity (m/s)	1.0	pipe length (m)	1000
n/a	----------	----------	----------	n/a				n/a				n/a						
Head, m	263	227	298	Head, m	150	120	180	Dyn Head, m	113	107	118	diameter (mm)	1200	1	velocity (m/s)	1.2	pipe length (m)	100000

Chemicals

Name or Type	Per ML product water	Most likely	Low	High	Chemical consumption (averaged per day)	Most likely	Low	High	Embodied GHG emissions		Payload		Transport distance (chemicals) km: 100 (Most likely)	12 (Low)	1000 (High)	Scope 3 (materials + transport) GHG emissions	Most likely	Low	High
Ammonium Sulphate	mg/L as NH3	1.8	1.2	2.5	kg/d as 10% as NH3 or 40% as (NH4)2 SO4 solution, SG = 1.23	105	73	152	kgCO2-e/ kg product	0.402	24	tonnes				tonnes CO2-e/ annum	16	11	26
Anti Scalant	mg/L product	1.7	1.2	2.4	kg/d (dry)100% active powder	102	71	147	kgCO2-e/ kg product	*1.182*	10	tonnes				tonnes CO2-e/ annum	45	31	72
Antiscalant non-phosphonate base:	mg/L product	0.7	0.5	1.0	as above	42	29	60	as above	*1.182*	10	tonnes				tonnes CO2-e/ annum	18	13	29
Antiscalant Phosphonate base:	mg/L product	1.0	0.7	1.4	as above	60	42	86	as above	*1.182*	10	tonnes					26	18	42
Carbon Dioxide	mg/L CO2	16.2	11.3	23.4	kg/d as CO2 (pure gas)	974	676	1403	kgCO2-e/ kg product	0.000	10	tonnes					6	0	81
Citric Acid	mg/L as citric acid	0.5	0.4	0.8	kg/d as 50% w/w solution, SG = 1.24	33	23	47	kgCO2-e/ kg product	*0.721*	10	tonnes				tonnes CO2-e/ annum	9	6	15
Ferric Chloride (Coagulant)	mg/L as FeCl3	40	28	58	kg/d as 42% w/w Fe2(SO4)3 solution	2398	1665	3453	kgCO2-e/ kg product	*0.802*	24	tonnes				tonnes CO2-e/ annum	707	488	1,094
Hydrogen Peroxide	mg/L as H2O2	3.8	2.7	5.5	kg/d as 50% w/w solution, SG = 1.13	230	160	331	kgCO2-e/ kg product	2.330	24	tonnes				tonnes CO2-e/ annum	196	136	289
Lime (hydrated white lime)	mg/L dry product	29	20	41	kg/d as dry white hydrated lime (min. 68% CaO)	1716	1192	2472	kgCO2-e/ kg product	1.640	24	tonnes				tonnes CO2-e/ annum	1,032	714	1,539
Polymer for coagulation	mg/L dry product	0.15	0.10	0.22	kg/d as 48% w/w active polymer solution	9	6	13	kgCO2-e/ kg product	1.182	10	tonnes				tonnes CO2-e/ annum	4	3	6
Sodium Bisulphite	mg/L as NaHSO3	10.3	7.2	14.9	kg/d as 34% w/w NaHSO3 solution, SG = 1.34	619	430	892	kgCO2-e/ kg product	*0.272*	10	tonnes				tonnes CO2-e/ annum	65	43	140
Sodium Hydroxide	mg/L as NaOH	0.9	0.6	1.3	kg/d as 48-50% w/w solution, SG = 1.5	53	37	77	kgCO2-e/ kg product	0.838	10	tonnes				tonnes CO2-e/ annum	17	11	28
Sodium Hypochlorite	mg/L as Cl2	11.8	8.2	17.0	kg/d as 12.5% w/w available Cl2 solution	707	491	1018	kgCO2-e/ kg product	0.885	24	tonnes				tonnes CO2-e/ annum	230	159	353
Sulphuric Acid	mg/L as H2SO4	17.5	12.2	25.3	kg/d as 60% w/w H2SO4 solution, SG = 1.50	1053	731	1516	kgCO2-e/ kg product	0.078	10	tonnes				tonnes CO2-e/ annum	36	21	131
Polymer for dewatering	kg/ tonne d.s.	5	4	7	kg/d (dry) 100% active powder	17	11	32	kgCO2-e/ kg product	1.182	10	tonnes				tonnes CO2-e/ annum	7	5	16
Methanol (excluded)	mg/L product (CH3OH)	10.0	?	?	kg/d as methanol (>99% pure liquid), SG = 0.79	601													
					Sub-total	**8,720**	**5,637**	**11,698**								**Sub-total**	**2,414**	**1,658**	**3,862**

MF Membrane replacement	Specific membrane material use per unit volume product water	Most likely	Low	High		Most likely	Low	High			Payload		Transport distance (membranes) km: 100 (Most likely)	12 (Low)	1000 (High)	Scope 3 (materials + transport) GHG emissions	Most likely	Low	High
Polyvinylidene Fluoride (PVDF)	kg/ML PVDF	0.060	0.052	0.072	kg/d PVDF	3.6	3.1	4.3	kgCO2-e/ kg product	2.395	0.66	ton				tonnes CO2-e/ annum	3.8	2.8	11.4
Polyurethane	kg/ML Polyurethane	0.060	0.052	0.072	kg/d Polyurethane	3.6	3.1	4.3	kgCO2-e/ kg product	2.206	0.09	tonnes				tonnes CO2-e/ annum	7.3	3.0	56.7
Polyethylene	kg/ML Polyethylene	0.040	0.034	0.048	kg/d Polyethylene	2.4	2.1	2.9	kgCO2-e/ kg product	2.180	0.06	tonnes				tonnes CO2-e/ annum	6.4	2.1	55.6
Polyamide	kg/ML Polyamide	0.030	0.026	0.036	kg/d Polyamide	1.8	1.5	2.2	kgCO2-e/ kg product	6.001	0.33	tonnes				tonnes CO2-e/ annum	4.6	3.5	12.4
EPDM	kg/ML EPDM	0.010	0.009	0.012	kg/d EPDM	0.6	0.5	0.7	kgCO2-e/ kg product	2.206	0.11	tonnes				tonnes CO2-e/ annum	1.1	0.5	8.2
Approx. no. of membrane modules replaced	per year	400	343	480															
Approx. no. of pressure vessels replaced per year		57	49	69															

RO Membrane replacement	Specific membrane material use per unit volume product water	Most likely	Low	High		Most likely	Low	High			Payload						Most likely	Low	High
Polyamide	kg/ML Polyamide	0.028	0.024	0.034	kg/d Polyamide	1.7	1.4	2.0	kgCO2-e/ kg product	6.001	0.31	tonnes				tonnes CO2-e/ annum	4.3	3.2	12.0
Polyether sulphone	kg/ML Polyether sulphone	0.112	0.096	0.134	kg/d Polyether sulphone	6.7	5.8	8.1	kgCO2-e/ kg product	2.206	1.22	tonnes				tonnes CO2-e/ annum	6.0	4.7	14.1
Polyester	kg/ML Polyester	0.224	0.192	0.268	kg/d Polyester	13.4	11.5	16.1	kgCO2-e/ kg product	2.206	2.45	tonnes				tonnes CO2-e/ annum	11.4	9.3	20.6
PVC	kg/ML PVC	0.140	0.120	0.168	kg/d PVC	8.4	7.2	10.1	kgCO2-e/ kg product	2.395	0.22	tonnes				tonnes CO2-e/ annum	11.8	6.7	62.1
FRP	kg/ML FRP	0.028	0.024	0.034	kg/d FRP	1.7	1.4	2.0	kgCO2-e/ kg product	2.206	0.04	tonnes				tonnes CO2-e/ annum	5.8	1.6	54.9
EPDM	kg/ML EPDM	0.028	0.024	0.034	kg/d EPDM	1.7	1.4	2.0	kgCO2-e/ kg product	2.206	0.04	tonnes				tonnes CO2-e/ annum	5.8	1.6	54.9
Approx. no. of membrane modules replaced	per year	108	93	130	**Sub-total**	**46**	**39**	**55**								**Sub-total**	**68**	**39**	**363**
Approx. no. of pressure vessels replaced per year		15	13	19															

Sludge production	From Pre-treatment per ML Feed Water	Most likely	Low	High		Most likely	Low	High	Payload		Transport distance (sludge) Most likely	Low	High		Scope 3 GHG emissions (transport + disposal)	Most likely	Low	High
Assumptions																		
Sec. Effluent TSS	mg/L	9	5	15														
Sec. Effluent soluble COD	mg/L	34	28	40														
Sec. Effluent ortho P removed in pretreatment	mg/L as P	1.0	0.7	1.4														
Fe:P ratio of ppt	molar ratio	6	6	6														
Fe~P precipitate, theory	MW g/mol	706	706	706														
Fe dosed	mmol/L	0.052	0.036	0.074														
Fe~P formed	mg/L	22.7	25.3	32.7														
Soluble COD coagulated	mg/L	20	14	20														
Total Precipitate formed in pre-treatment	mg/L	50.3	43.1	65.9														
Pre-treatment solids capture	%	93%	90%	95%														
Pre-treament effluent TSS	mg/L	3.5	4.3	3.3														
Sludge production TSS	mg/L	46.7	38.8	62.6	kg/d TSS dry	3421	2836	4583										
					kg/d wet cake, 20% d.s.	17103	14181	22914	20	ton	km 25	10	100	Tra	tonnes CO2-e/ annum	25	8	133
					Wet cake kg/ML feed water	234	194	313						Dis	tonnes CO2-e/ annum	6242	5176	8364
Estimate of sludge prod. Due to Methanol in ROC treatment	mg/L	3													**Sub-total**	**6267**	**5184**	**8496**
		6%																

OPTION 3 - AWTP for treatment and water recycling via Direct Potable Reuse (to local water reservoir serving as part of potable water network)
Operations Inventory

SUM (Scope 2 + 3) GHG emissions

	Estimate Most likely	Estimate Low	Estimate High
tonnes CO2-e/ annum	**43,030**	**14,693**	**71,992**
tonnes CO2-e/ ML product water	1.96	0.67	3.29

Flows	Units	Estimate Most likely	Estimate Low	Estimate High
Water Recovery	%	82%	80%	84%
Secondary Effluent Feed (intake)	ML/d	73		
Product Water	ML/d	60		
Brine (ROC) & Reject/ Backwash	ML/d	13		

Power	Per ML product water	Estimate Most likely	Estimate Low	Estimate High	Power consumption	Estimate Most likely	Estimate Low	Estimate High	Average power	Estimate Most likely	Estimate Low	Estimate High	Scope 2 GHG emissions factor	Estimate Most likely	Estimate Low	Estimate High	Scope 2 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Sec. Effluent Feed & ROC discharge pumping	kWh/ML	60	50	70	kWh/d	3,600	3,000	4,200	kW	150	125	175	0.00	0.85	0.26	1.19	tonnes CO2-e/ annum	1,119	285	1,824
AWTP plant	kWh/ML	1180	930	1420	kWh/d	70,800	55,800	85,200	kW	2950	2325	3550					tonnes CO2-e/ annum	22,009	5,295	37,007
Product water distribution	kWh/ML	360	250	500	kWh/d	21,600	15,000	30,000	kW	900	625	1250					tonnes CO2-e/ annum	6,715	1,424	13,031
Total	kWh/ML	1600	1230	1990	kWh/d	**96,000**	**73,800**	**119,400**	kW	4000	3075	4975					**Sub-Total**	**29,842**	**7,004**	**51,861**

	Scope 3 GHG emissions factor			Scope 3 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Sec. Effluent Feed & ROC discharge pumping	0.13	0.03	0.17	tonnes CO2-e/ annum	166	33	261
AWTP plant				tonnes CO2-e/ annum	3,273	611	5,287
Product water distribution				tonnes CO2-e/ annum	999	164	1,862
				Sub-Total	**4,438**	**808**	**7,409**

Chemicals

Transport distance (chemicals): km 100 (Most likely), 12 (Low), 1000 (High)

Name or Type	Per ML product water	Estimate Most likely	Estimate Low	Estimate High	Chemical consumption (averaged per day)	Estimate Most likely	Estimate Low	Estimate High	Embodied GHG emissions		Payload	Scope 3 (materials + transport) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Ammonium Sulphate	mg/L as NH3	1.8	1.2	2.5	kg/d as 10% as NH3 or 40% as (NH4)2 SO4 solution, SG = 1.23	105	73	152	kgCO2-e/ kg product	0.402	24 tonnes	tonnes CO2-e/ annum	16	11	26
Anti Scalant	mg/L product	1.7	1.2	2.4	kg/d (dry)100% active powder	102	71	147	kgCO2-e/ kg product	*1.182*	10 tonnes	tonnes CO2-e/ annum	45	31	72
Antiscalant non-phosphonate base	mg/L product	0.7	0.5	1.0	as above	42	29	60	as above	*1.182*	10 tonnes	tonnes CO2-e/ annum	18	13	29
· Antiscalant Phosphonate base:	mg/L product	1.0	0.7	1.4	as above	60	42	86	as above	*1.182*	10 tonnes		26	18	42
Carbon Dioxide	mg/L CO2	16.2	11.3	23.4	kg/d as CO2 (pure gas)	974	676	1403	kgCO2-e/ kg product	0.000	10 tonnes		6	0	81
Citric Acid	mg/L as citric acid	0.5	0.4	0.8	kg/d as 50% w/w solution, SG = 1.24	33	23	47	kgCO2-e/ kg product	*0.721*	10 tonnes	tonnes CO2-e/ annum	9	6	15
Ferric Chloride (Coagulant)	mg/L as FeCl3	40	28	58	kg/d as 42% w/w Fe2(SO4)3 solution	2398	1665	3453	kgCO2-e/ kg product	*0.802*	24 tonnes	tonnes CO2-e/ annum	707	488	1,094
Hydrogen Peroxide	mg/L as H2O2	3.8	2.7	5.5	kg/d as 50% w/w solution, SG = 1.13	230	160	331	kgCO2-e/ kg product	2.330	24 tonnes	tonnes CO2-e/ annum	196	136	289
Lime (hydrated white lime)	mg/L dry product	29	20	41	kg/d as dry white hydrated lime (min. 68% CaO)	1716	1192	2472	kgCO2-e/ kg product	1.640	24 tonnes	tonnes CO2-e/ annum	1,032	714	1,539
Polymer for coagulation	mg/L dry product	0.15	0.10	0.22	kg/d as 48% w/w active polymer solution	9	6	13	kgCO2-e/ kg product	1.182	10 tonnes	tonnes CO2-e/ annum	4	3	6
Sodium Bisulphite	mg/L as NaHSO3	10.3	7.2	14.9	kg/d as 34% w/w NaHSO3 solution, SG = 1.34	619	430	892	kgCO2-e/ kg product	*0.272*	10 tonnes	tonnes CO2-e/ annum	65	43	140
Sodium Hydroxide	mg/L as NaOH	0.9	0.6	1.3	kg/d as 48-50% w/w solution, SG = 1.5	53	37	77	kgCO2-e/ kg product	0.838	10 tonnes	tonnes CO2-e/ annum	17	11	28
Sodium Hypochlorite	mg/L as Cl2	11.8	8.2	17.0	kg/d as 12.5% w/w available Cl2 solution	707	491	1018	kgCO2-e/ kg product	0.885	24 tonnes	tonnes CO2-e/ annum	230	159	353
Sulphuric Acid	mg/L as H2SO4	17.5	12.2	25.3	kg/d as 60% w/w H2SO4 solution, SG = 1.50	1053	731	1516	kgCO2-e/ kg product	0.078	10 tonnes	tonnes CO2-e/ annum	36	21	131
Polymer for dewatering	kg/ tonne d.s.	5	4	7	kg/d (dry) 100% active powder	17	11	32	kgCO2-e/ kg product	1.182	10 tonnes	tonnes CO2-e/ annum	7	5	16
Methanol (excluded)	mg/L product (CH3OH)	10.0	?	?	kg/d as methanol (>99% pure liquid), SG = 0.79	601									
					Sub-total	**8,720**	**5,637**	**11,698**				**Sub-total**	**2,414**	**1,658**	**3,862**

Transport distance (membranes): km 100 (Most likely), 12 (Low), 1000 (High)

MF Membrane replacement	Specific membrane material use per unit volume product water	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High	Embodied GHG emissions		Payload	Scope 3 (materials + transport) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Polyvinylidene Fluoride (PVDF)	kg/ML PVDF	0.060	0.052	0.072	kg/d PVDF	3.6	3.1	4.3	kgCO2-e/ kg product	2.395	0.66 tonnes	tonnes CO2-e/ annum	3.8	2.8	11.4
Polyurethane	kg/ML Polyurethane	0.060	0.052	0.072	kg/d Polyurethane	3.6	3.1	4.3	kgCO2-e/ kg product	2.206	0.09 tonnes	tonnes CO2-e/ annum	7.3	3.0	56.7
Polyethylene	kg/ML Polyethylene	0.040	0.034	0.048	kg/d Polyethylene	2.4	2.1	2.9	kgCO2-e/ kg product	2.180	0.06 tonnes	tonnes CO2-e/ annum	6.4	2.1	55.6
Polyamide	kg/ML Polyamide	0.030	0.026	0.036	kg/d Polyamide	1.8	1.5	2.2	kgCO2-e/ kg product	6.001	0.33 tonnes	tonnes CO2-e/ annum	4.6	3.5	12.4
EPDM	kg/ML EPDM	0.010	0.009	0.012	kg/d EPDM	0.6	0.5	0.7	kgCO2-e/ kg product	2.206	0.11 tonnes	tonnes CO2-e/ annum	1.1	0.5	8.2
Approx. no. of membrane modules replaced per year		400	343	480											
Approx. no. of pressure vessels replaced per year		57	49	69											

RO Membrane replacement	Specific membrane material use per unit volume product water	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High	Embodied GHG emissions		Payload	Scope 3 (materials + transport) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Polyamide	kg/ML Polyamide	0.028	0.024	0.034	kg/d Polyamide	1.7	1.4	2.0	kgCO2-e/ kg product	6.001	0.31 tonnes	tonnes CO2-e/ annum	4.3	3.2	12.0
Polyether sulphone	kg/ML Polyether sulphone	0.112	0.096	0.134	kg/d Polyether sulphone	6.7	5.8	8.1	kgCO2-e/ kg product	2.206	1.22 tonnes	tonnes CO2-e/ annum	6.0	4.7	14.1
Polyester	kg/ML Polyester	0.224	0.192	0.268	kg/d Polyester	13.4	11.5	16.1	kgCO2-e/ kg product	2.206	2.45 tonnes	tonnes CO2-e/ annum	11.4	9.3	20.6
PVC	kg/ML PVC	0.140	0.120	0.168	kg/d PVC	8.4	7.2	10.1	kgCO2-e/ kg product	2.395	0.22 tonnes	tonnes CO2-e/ annum	11.8	6.7	62.1
FRP	kg/ML FRP	0.028	0.024	0.034	kg/d FRP	1.7	1.4	2.0	kgCO2-e/ kg product	2.206	0.04 tonnes	tonnes CO2-e/ annum	5.8	1.6	54.9
EPDM	kg/ML EPDM	0.028	0.024	0.034	kg/d EPDM	1.7	1.4	2.0	kgCO2-e/ kg product	2.206	0.04 tonnes	tonnes CO2-e/ annum	5.8	1.6	54.9
Approx. no. of membrane modules replaced per year		108	93	130	**Sub-total**	**46**	**39**	**55**				**Sub-total**	**68**	**39**	**363**
Approx. no. of pressure vessels replaced per year		15	13	19											

Sludge production	From Pre-treatment per ML Feed Water	Estimate Most likely	Estimate Low	Estimate High
Assumptions				
Sec. Effluent TSS	mg/L	9	5	15
Sec. Effluent soluble COD	mg/L	34	28	40
Sec. Effluent ortho P removed in pretreatment	mg/L as P	1.0	0.7	1.4
Fe:P ratio of ppt	molar ratio	6	6	6
Fe~P precipitate, theory	MW g/mol	706	706	706
Fe dosed	mmol/L	0.052	0.036	0.074
Fe~P formed	mg/L	22.7	25.3	32.7
Soluble COD coagulated	mg/L	20	14	20
Total Precipitate formed in pre-treatment	mg/L	50.3	43.1	65.9
Pre-treatment solids capture	%	93%	90%	95%
Pre-treament effluent TSS	mg/L	3.5	4.3	3.3

Transport distance (sludge): km 25 (Most likely), 10 (Low), 100 (High)

		Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High	Payload		Scope 3 GHG emissions (transport + disposal)	Estimate Most likely	Estimate Low	Estimate High
Sludge production TSS	mg/L	46.7	38.8	62.6	kg/d TSS dry	3421	2836	4583						
					kg/d wet cake, 20% d.s.	17103	14181	22914	20 tonnes	Tra	tonnes CO2-e/ annum	25	8	133
					Wet cake kg/ML feed water	234	194	313		Dis	tonnes CO2-e/ annum	6242	5176	8364
Estimate of sludge prod. Due to Methanol in ROC treatment	mg/L	3 (6%)									**Sub-total**	**6267**	**5184**	**8496**
Total Materials intensity					kg/ML product water	**431**	**331**	**578**						

Implied system pumping head, at 65% wire-water efficiency	Estimate Most likely	Estimate Low	Estimate High	Assumed static pumping head	Estimate Most likely	Estimate Low	Estimate High	Implied assumed dynamic pumping head	Estimate Most likely	Estimate Low	Estimate High	Assume average pipe diam		No. of pipes	Implied average pipe internal velocity		Assume length	
Head, m	14	12	17	Head, m	8	6	10	Dyn Head, m	6	6	7	diameter (mm)	1050	1	velocity (m/s)	1.0	pipe length (m)	1000
n/a	----------	----------	----------	n/a				n/a					n/a					
Head, m	86	60	119	Head, m	50	30	75	Dyn Head, m	36	30	44	diameter (mm)	1200	1	velocity (m/s)	1.2	pipe length (m)	25000

OPTION 4 - Dual pipe reticulation (3rd pipe scheme) Advanced Water Treatment Plant & associated reticulation network (non-potable)
Operations Inventory

Flows	Units	Estimate Most likely	Estimate Low	Estimate High
Water Recovery	%	94%	90%	97%
Secondary Effluent intake (Feed)	ML/d	21.3		
Product Water	ML/d	20		
Washwater/Backwash return	ML/d	1.3		

	SUM (Scope 2 + 3) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
	tonnes CO2-e/ annum	**7,070**	**2,619**	**16,629**
	tonnes CO2-e/ ML product water	0.97	0.36	2.28

Power	Per ML product water	Estimate Most likely	Estimate Low	Estimate High	Power consumption	Estimate Most likely	Estimate Low	Estimate High	Average power	Estimate Most likely	Estimate Low	Estimate High	Scope 2 GHG emissions factor	Estimate Most likely	Estimate Low	Estimate High	Scope 2 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Secondary Effluent Feed pumping from WWTP	kWh/ML	60	50	70	kWh/d	1277	1064	1489	kW	53	44	62		0.85	0.26	1.19	tonnes CO2-e/ annum	397	101	647
AWTP plant	kWh/ML	400	203	933	kWh/d	8000	4056	18660	kW	333	169	778					tonnes CO2-e/ annum	2487	385	8105
Product water distribution	kWh/ML	200	150	300	kWh/d	4000	3000	6000	kW	167	125	250					tonnes CO2-e/ annum	1243	285	2606
Total	kWh/ML	660	403	1303	kWh/d	13277	8119	26149	kW	553	338	1090					**Sub-Total**	**4,127**	**771**	**11,358**

	Implied system pumping head, at 60% wire-water efficiency	Estimate Most likely	Estimate Low	Estimate High	Assumed static pumping head	Estimate Most likely	Estimate Low	Estimate High	Implied assumed dynamic pumping head	Estimate Most likely	Estimate Low	Estimate High	Assume average pipe		No. of pipes	Implied average pipe internal velocity		Assume length	
Secondary Effluent Feed pumping from WWTP	Head, m	13	11	15	Head, m	8	6	10	Dyn Head, m	5	5	5	diameter (mm)	600	1	velocity (m/s)	0.9	length (m)	250
AWTP plant	n/a	----------	----------	----------	n/a				n/a				n/a						
Product water distribution	Head, m	44	33	66	Head, m	30	20	50	Dyn Head, m	14	13	16	diameter (mm)	600	1	velocity (m/s)	0.8	length (m)	8000

	Scope 3 GHG emissions factor	Estimate Most likely	Estimate Low	Estimate High	Scope 3 GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Secondary Effluent Feed pumping from WWTP		0.13	0.03	0.17	tonnes CO2-e/ annum	59	12	92
AWTP plant					tonnes CO2-e/ annum	370	44	1,158
Product water distribution					tonnes CO2-e/ annum	185	33	372
					Sub-Total	**614**	**89**	**1,623**

Chemicals

Name or Type	Per ML feed water	Estimate Most likely	Estimate Low	Estimate High	Chemical consumption (averaged per day)	Estimate Most likely	Estimate Low	Estimate High	Embodied GHG emissions		Payload		Transport distance (chemicals) km	100	12	1000	Scope 3 (materials + transport) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Aluminium sulphate	mg/L as Al2(SO4)3.14H2O	11	9	15	kg/d as 46% w/w Al2(SO4)3.14H2O solution	522	400	699	kgCO2-e/ kg product	0.248	24	tonnes					tonnes CO2-e/ annum	48	36	80
Sodium Hypochlorite	mg/L as avail. Cl2	27	20	41	kg/d as 12.5% w/w available Cl2 solution	4246	3207	6603	kgCO2-e/ kg product	0.885	24	tonnes					tonnes CO2-e/ annum	1,382	1,037	2,293
Hypo for Mn Oxidation	mg/L as avail. Cl2	19	14	30																
Hypo for UF	mg/L as avail. Cl2	0.9	0.5	4.1																
Hypo for CLASS A+	mg/L as avail. Cl2	6.4	5.5	7.1																
Sodium Hydroxide UF pH	L/ML	0.03	0.00	0.07	kg/d as 48-50% w/w solution, SG = 1.5	1.2	0.0	2.7	kgCO2-e/ kg product	0.838	10	tonnes					tonnes CO2-e/ annum	0.4	0.0	1.0
Sulphuric acid for UF pH	L/ML	0.31	0.02	0.95	kg/d as 60% w/w H2SO4 solution, SG = 1.50	10	0.7	32	kgCO2-e/ kg product	0.078	10	tonnes					tonnes CO2-e/ annum	0.4	0.0	2.7
Citric Acid for UF CIP	L/ML	0.33	0.10	0.93	kg/d as 50% w/w solution, SG = 1.24	13.3	4.0	37.3	kgCO2-e/ kg product	*0.721*	10	tonnes					tonnes CO2-e/ annum	3.6	1.1	12.0
					Sub-total	**4,793**	**3,612**	**7,374**									**Sub-total**	**1,435**	**1,075**	**2,389**

UF Membrane replacement	Specific membrane material use per unit volume product water	Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High			Payload		Transport distance (membranes)				Scope 3 (materials + transport) GHG emissions	Estimate Most likely	Estimate Low	Estimate High
Membranes	kg/ML PVDF	0.18	0.15	0.25	kg/d PVDF	3.5	3.1	4.9	kgCO2-e/ kg product	2.395	1.3	ton	km	100	12	1000	tonnes CO2-e/ annum	3	3	4
Membrane pressure vessel	kg/ML PVC	0.16	0.14	0.22	kg/d PVC	3.2	2.8	4.5	kgCO2-e/ kg product	2.395	1.2	tonnes					tonnes CO2-e/ annum	3	2	4
Pressure vessel potting	kg/ML Epoxy resin	0.027	0.02	0.04	kg/d Epoxy resin	0.5	0.5	0.8	kgCO2-e/ kg product	*2.206*	0.2	tonnes					tonnes CO2-e/ annum	0.4	0.4	1
Approx. no. of membrane modules replaced	per year	40	35	56	**Sub-total**	**7**	**6**	**10**									**Sub-total**	**6**	**6**	**9**
Approx. no. of pressure vessels replaced per year		40	35	56																

Sludge production

Assumptions	From Pre-treatment per ML Feed Water	Estimate Most likely	Estimate Low	Estimate High
Sec. Effluent TSS	mg/L	5	3	10
Sec. Effluent soluble COD	mg/L	34	28	40
Sec. Effluent ortho P removed in pretreatment	mg/L as P	0.8	0.6	1.2
Al:P ratio of ppt	molar ratio	1.47	1.62	1.37
Al~P precipitate, theory	MW g/mol	159	171	151
Al dosed	mmol/L	0.038	0.029	0.051
Al~P formed	mg/L	4.0	3.0	5.6
Sol. COD coagulated	mg/L	14	11	16
Total Precipitate formed in pre-treatment	mg/L	21	16	30
Pre-treatment solids capture	%	93%	93%	93%
Pre-treament effluent TSS	mg/L	1.0	0.5	2.0

		Estimate Most likely	Estimate Low	Estimate High		Estimate Most likely	Estimate Low	Estimate High	Payload		Transport distance (sludge)					Scope 3 GHG emissions (transport + disposal)	Estimate Most likely	Estimate Low	Estimate High
Sludge production TSS	mg/L	20	16	28	kg/d TSS dry	434	334	598											
This sludge will be returned to the WWTP in this option					kg/d wet cake, 18% d.s.	2413	1854	3322	10	ton	km	25	10	100	Tra	tonnes CO2-e/ annum	7	2	38
The calcs here are indicative of the AWTP contribution to sludge production					Wet cake kg/ML product water	121	93	166							Dis	tonnes CO2-e/ annum	881	677	1212
(in the absence of the AWTP the solids produced by the AWTP would have been disccharged to rec. waters)																**Sub-total**	**888**	**679**	**1,251**

Appendix H – Life Cycle Inventories Summary

Results of Combined Uncertainty Analysis (Monte Carlo) - ALL PRODUCT WATER FLOWS = 120 ML/d

Option:	1 - SWRO			2 - IPR			3 - DPR			4 - Dual Pipe		
Percentile	50%ile	5%ile	95%ile	50%ile	5%ile	95%ile	50%ile	5%ile	95%ile	50%ile	5%ile	95%ile
OPERATIONS												
Flows (or Multiplier)	1			2			2			6		
Product Water Recovery, %	42%	41%	44%	82%	81%	83%	82%	81%	83%	94%	92%	96%
Feed, ML/d	284	271	295	146	144	149	146	144	149	128	125	131
Product, ML/d	120	120	120	120	120	120	120	120	120	120	120	120
Power, Average MW (Total)	**20.2**	**18.9**	**22.1**	**11.7**	**10.8**	**12.6**	**8.0**	**7.2**	**8.9**	**3.6**	**2.6**	**4.8**
Raw Water Intake	1.3	1.1	1.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Production	17.1	15.9	18.9	5.9	5.1	6.6	5.9	5.1	6.7	2.2	1.3	3.5
Product Water Distribution	1.8	1.4	2.2	5.5	5.0	6.0	1.8	1.4	2.2	1.0	0.8	1.3
Power Use, Average MWh/annum (Total)	**485**	**454**	**530**	**281**	**259**	**302**	**192**	**172**	**213**	**85**	**63**	**116**
Raw Water Intake	31	26	37	7.2	6.5	7.9	7.2	6.5	7.9	7.2	6.5	7.9
Production	410	381	454	141	123	160	141	123	160	53.0	31.6	83.4
Product Water Distribution	44	35	53	132	121	143	44	35	53	24.8	20.0	30.9
Specific Power Use, Average kWh/ML product water (Total)	**4,045**	**3,782**	**4,417**	**2,338**	**2,160**	**2,517**	**1,604**	**1,432**	**1,774**	**711**	**526**	**967**
Raw Water Intake	256	216	307	60	54	66	60	54	66	60	54	66
Production	3,420	3,176	3,784	1,178	1,026	1,329	1,179	1,026	1,330	442	264	695
Product Water Distribution	364	290	445	1,100	1,007	1,193	364	290	445	206	166	257
Materials Use (Total), tonnes/ annum total product delivered	**6,234**	**5,613**	**6,900**	**6,303**	**5,737**	**6,893**	**6,301**	**5,741**	**6,895**	**10,830**	**1,486**	**2,231**
Chemicals	6,170	5,570	6,815	6,269	5,705	6,858	6,268	5,709	6,860	10,813	1,483	2,228
Membrane module replacement	64	43	85	34	32	35	34	32	35	16.6	2.5	3.1
Sludge Disposed (to landfill) tonnes/ annum												
Dry solids	1,089	777	1,484	2,551	2,212	2,982	2,551	2,210	2,983	969	806	1,162
Wet cake	**3,890**	**2,775**	**5,300**	**12,753**	**11,059**	**14,911**	**12,754**	**11,048**	**14,916**	**5,382**	**4,479**	**6,455**
Greenhouse gas emissions (Total), ktonnes CO2-e/ annum	**175**	**119**	**225**	**114**	**82**	**142**	**84**	**61**	**104**	**43**	**32**	**58**
Raw Water Intake (Scopes 2 + 3)	10	6	15	2	2	3	2	2	3	2.5	1.5	3.3
Scope 2	9.1	5.5	13	2.1	1.3	2.9	2.1	1.3	2.9	2.1	1.3	2.9
Scope 3	1.3	0.8	1.9	0.3	0.2	0.4	0.3	0.2	0.4	0.3	0.2	0.4
Production (Scopes 2 + 3)	150	94	199	66	45	87	66	45	87	32	21	49
Scope 2	123	76	164	42	26	57	42	26	57	15	8	27
Scope 3 (Electricity)	18	11	24	6.1	3.7	8.3	6.1	3.7	8.3	2.2	1.1	3.9
Scope 3 (Chemicals)	4.8	4.1	5.4	5.3	4.7	5.9	5.3	4.7	5.9	9.0	7.3	11.3
Scope 3 (Membranes)	0.3	0.2	0.5	0.2	0.1	0.4	0.2	0.1	0.4	0.04	0.04	0.1
Scope 3 (Sludge Disposal)	3.9	2.8	5.3	12.8	11.1	15.0	12.8	11.1	15.0	5.4	4.5	6.5
Product Water Distribution (Scopes 2 + 3)	15	9	21	45	28	60	15	9	21	8	5	12
Scope 2	13	7.7	18	39	24	52	13	8	18	7	4	11
Scope 3	2	1.1	3	5.8	3.4	7.6	1.9	1.1	2.7	1.1	0.6	1.5
Specific greenhouse gas emissions (Total), tonnes CO2-e/ ML product water	**4.00**	**2.72**	**5.13**	**2.60**	**1.86**	**3.25**	**1.91**	**1.40**	**2.38**	**0.99**	**0.73**	**1.33**
CONSTRUCTION												
Materials Use (Total), tonnes	**29,822**	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Pipelines & Valves	18,322			56,122			15,231			76,313		
Raw Water Intake	2,339			802			802			216		
ROC or other waste discharge	2,339			793			793			52		
Product Water Distribution	13,644			54,527			13,635			76,045		
Treatment Plant	11,500			no data			no data			no data		
Emodied greenhouse gas emissions (ktonnes)	**31**	no data	no data	no data	no data	no data	no data	no data	no data	no data		
Pipelines & Valves	26			80			22			55		
Treatment Plant	5			no data			no data			no data		

Appendix I – Design Basis Assumptions for Costing

Table 3 Design basis for Option 1 - Desalination

ATSE/AWRCoE Recycled Water Project	Overview of Option		
Option Number	1		
Process Description	Desalination		
Treated Water Quality	• Potable water meeting ADWG • Introduction to existing reticulation network		
	Feed Flow (ML/d)	**Recovery (%)**	**Treated Water Production (ML/d)**
Key Design Assumptions	267	45	120
Annual Production (GL/yr)	40 GL/yr (based on 334 days operation per year)		
Point of Connection to Supply	Potable Water Storage (pre-existing within Reticulation Network)		
Distance to Point of Connection	50 km, pipeline assumed to travel through city zoning extending into rural zoning		
Elevation at Point of Connection	50 m, then assumed gravity flow to reticulation network		
Core Process	**Key Process Assumptions**		
Ocean Inlet + Seawater Pumping + Seawater Screening + Brine Outlet			
Coagulant Dosing + Clarification Process	• Coagulant dosing comprised of Alum dosing, pH correction • Clarification Process		
Fine Screens	• Fine screenings disposed to Ocean		
Ultrafiltration (UF)	• Ultrafiltration Plant comprised of Multiple UF Trains with , backwash facilities and chemical cleaning storage and dosing systems. • Backwash water treated in Sludge Thickener and disposed to Landfill. (Alternatively could be disposed to Ocean). • CIP Cleaning chemicals neutralised then added to the brine.		
RO	• Two-stage SWRO comprised of multiple trains with chemical cleaning storage and dosing systems • RO Brine disposed to Ocean		
Lime/CO_2	• Required for stabilisation and pH correction of final treated water to meet ADWG requirements		
Cl_2 /NH_2Cl	• Required for disinfection of final treated water • Chlorine or chloramine could be used for this purpose		
Water Storage	• Required to provide sufficient contact time for disinfection and for balancing treated water supply prior to pumping to distribution network		
Sludge Treatment: Thickening & Dewatering	• Assumed to comprise sludge thickener and dewatering (centrifuge) to allow for disposal to Landfill		
Ancillary (including Power Supply)	• Typically allows for components including service water, air, power.		

ATSE/AWRCoE Recycled Water Project	Overview of Option
Examples of Similar Plants used for Benchmarking	• Perth 2 (150 ML/d) constructed 2011 • Plant Overall Cost benchmarked against Australian desalinations plant located in coastal cities including (Perth 1, Perth 2, Gold Coast, Sydney, Victoria, Adelaide)
CAPEX ($M)	$730 M
OPEX ($M)	Not available
NPV ($M)	Not available

Table 4 Design basis for Option 2 – Indirect Potable Reuse

ATSE/AWRCoE Recycled Water Project	Overview of Option		
Option Number	2		
Process Description	Indirect Potable Reuse		
Treated Water Quality	• Potable water meeting limits in ADWG {Noting the current ADWG may not apply to this option}. • Introduction to existing reticulation network • Potable water to supply new developments only		
	Feed Flow (ML/d)	**Recovery (%)**	**Treated Water Production (ML/d)**
Key Design Assumptions	141	85	120
Annual Production (GL/yr)	40 GL/yr (based on 334 days operation per year)		
Point of Connection to Supply	Potable Water Storage (pre-existing within Reticulation Network)		
Distance to Point of Connection	100 km, pipeline assumed to travel through city zoning extending into rural zoning		
Elevation at Point of Connection	150 m, then assumed gravity flow to reticulation network		
Core Process	**Key Process Assumptions**		
Raw Supply Pipeline + Pump + Coarse Screening	• Screenings disposed to Landfill		
Coagulant Dosing + Clarification Process	• Coagulant dosing comprised of Alum dosing, pH correction • Clarification Process		
Fine Screens	• Screenings disposed to Landfill		
Ultrafiltration (UF)	• Ultrafiltration Plant comprised of Multiple UF Trains with air scour, backwash facilities and chemical cleaning storage and dosing systems (Clean in Place (CIP)) • Backwash water treated in Sludge Thickener and disposed to Landfill.		
RO	• Single-stage SWRO comprised of multiple trains with chemical cleaning storage and dosing systems • RO Brine disposed to outfall due to close proximity of plant to coast		
UV + Peroxide	• Required for disinfection and destruction of pharmaceuticals compounds and other micro-contaminants		
Lime/CO_2	• Required for stabilisation and pH correction of final treated water to meet ADWG requirements		
Cl_2 /NH_2Cl	• Required for disinfection of final treated water • Chlorine or chloramine could be used for this purpose		
Water Storage	• Required to provide sufficient contact time for disinfection and for balancing treated water supply prior to pumping to distribution network		
Sludge Treatment: Thickening & Dewatering	• Assumed to comprise sludge thickener and dewatering (centrifuge) to allow for disposal to Landfill		
Ancillary (including Power Supply)	• Typically allows for components including service water, air, power.		

ATSE/AWRCoE Recycled Water Project	Overview of Option
Examples of Similar Plants used for Benchmarking	• Bundamba AWTP, Western Corridor Project in QLD, 60 ML/d (2008-9)
CAPEX ($M)	$387 M
OPEX ($M)	Not available
NPV ($M)	Not available

Table 5 Design basis for Option 3 - Direct Potable Reuse

ATSE/AWRCoE Recycled Water Project	Overview of Option		
Option Number	3		
Process Description	Direct Potable Reuse		
Treated Water Quality	• Potable water generally meeting ADWG limits {This idea is not contemplated by the current ADWG, see note above regarding this process}. • Introduction to existing reticulation network • Potable water to supply new developments only		
	Feed Flow (ML/d)	**Recovery (%)**	**Treated Water Production (ML/d)**
Key Design Assumptions	141	85	120
Annual Production (GL/yr)	40 GL/yr (based on 334 days operation per year)		
Point of Connection to Supply	Potable Water Storage (pre-existing within Reticulation Network)		
Distance to Point of Connection	50 km, pipeline assumed to travel through city zoning extending into rural zoning		
Elevation at Point of Connection	50 m, then assumed gravity flow to reticulation network		
Number of Properties to be served			
Core Process	**Key Process Assumptions**		
Raw Supply Pipeline + Pump + Coarse Screening	• Screenings disposed to Landfill		
Coagulant Dosing + Clarification Process	• Coagulant dosing comprised of Alum dosing, pH correction • Clarification Process (Lamella Clarifier)		
Fine Screens	• Screenings disposed to Landfill		
Ultrafiltration (UF)	• Ultrafiltration Plant comprised of Multiple UF Trains with air scour, backwash facilities and chemical cleaning storage and dosing systems (Clean in Place (CIP)) • Backwash water treated in Sludge Thickener and disposed to Landfill. CIP Cleaning chemicals disposed to Outfall.		
RO	• Single-stage SWRO comprised of multiple trains with chemical cleaning storage and dosing systems • RO Brine disposed to Outfall due to close proximity of plant to coast		
UV + Peroxide	• Required for disinfection and destruction of pharmaceuticals compounds and other micro-contaminants		
Lime/CO_2	• Required for stabilisation and pH correction of final treated water to meet ADWG requirements		
Cl_2 /NH_2Cl	• Required for disinfection of final treated water • Chlorine or chloramine could be used for this purpose		
Water Storage	• Required to provide sufficient contact time for disinfection and for balancing treated water supply prior to pumping to distribution network		
Sludge Treatment: Thickening & Dewatering	• Assumed to comprise sludge thickener and dewatering (centrifuge) to allow for disposal to Landfill		

ATSE/AWRCoE Recycled Water Project	Overview of Option
Ancillary (including Power Supply)	• Components including service water, air, power.
Examples of Similar Plants used for Benchmarking	• Based on Bundamba AWTP (as for Option 2)
CAPEX ($M)	$387 M
OPEX ($M)	Not available
NPV ($M)	Not available

Table 6 Design basis for Option 4 – Dual Pipe Reuse

ATSE/AWRCoE Recycled Water Project	Overview of Option		
Option Number	4		
Process Description	Dual Pipe Reuse		
Treated Water Quality	• Class A (or A+) water meeting NHMRC Recycled Water Requirements • Introduction to existing reticulation network • Recycled water to supply new developments dual pipe use only		
	Feed Flow (ML/d)	**Recovery (%)**	**Treated Water Production (ML/d)**
Key Design Assumptions	141 (6 x 23.5 ML/d plants)	85	120 (6 x 20ML/d)
Annual Production (GL/yr)	40 GL/yr (based on 334 days operation per year)		
Point of Connection to Supply	4 x 5ML New Recycled Water Storages 2 x PS to High Level Tanks		
Distance to Point of Connection	8 km, pipeline assumed to travel through city zoning		
Elevation at Point of Connection	30 m		
Number of Properties to be served	Approximately 480,000 properties connected to dual pipe (assumed 250 L per household per day)		
Core Process	**Key Process Assumptions**		
Raw Supply Pipeline + Pump + Coarse Screening	• Screenings disposed to Landfill		
Coagulant Dosing + Clarification Process	• Coagulant dosing comprised of Alum dosing, pH correction • Clarification Process (Lamella Clarifier)		
Dual Media Filtration	• Dual media filter comprised of sand and anthracite media with air scour and backwash facilities		
Fine Screens			
Ultrafiltration (UF)	• Ultrafiltration Plant comprised of Multiple UF Trains with air scour, backwash facilities and chemical cleaning storage and dosing systems (Clean in Place (CIP)) • Backwash water treated in Sludge Thickener and disposed to Landfill.		
UV	• Required for disinfection		
Lime/CO_2	• Required for stabilisation and pH correction of final treated water to meet ADWG requirements		
Cl_2/NH_2Cl	• Required for disinfection of final treated water • Chlorine		
Water Storage	• Required to provide sufficient contact time for disinfection and for balancing treated water supply prior to pumping to distribution network		
Winter Storage	• Required only for Dual Pipe Reuse Option due to requirement for storage of recycled water during Winter period when demand for recycled water is reduced • Assume 6 x 80ML storages (1 per 20 ML/d plant)		
Sludge Treatment: Thickening & Dewatering	• Assumed to comprise sludge thickener and dewatering (centrifuge) to allow for disposal to Landfill		

Ancillary (including Power Supply)	• Components including service water, air, power.
Examples of Similar Plants used for Benchmarking	• Pimpana Coomera Dual Pipe system (17 ML/d) • There are few examples of Recycled WTP for Dual Reuse in the order of 120 ML/d capacity
CAPEX ($M)	$289 M
OPEX ($M)	Not available
NPV ($M)	Not available

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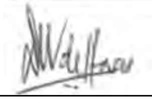
1	D de Haas	S Khan (UNSW)		D de Haas		3.7.13

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