COMMON SBR DESIGNS FOR REDUCED PROJECT DELIVERY AND PROCUREMENT COSTS

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ABSTRACT

Grampians Wimmera Mallee Water Corporation own and operate 26 Water Reclamation Plants (WRPs) in the state of Victoria, Australia. St Arnaud and Warracknabeal WRPs are two such sites which were identified as having business cases for renewal in 2009. The triggers for renewal were the age of the WRPs, ongoing maintenance issues, and growing uncertainty about reuse scheme availability. In 2010 AWT Water developed a preliminary and then detailed design to upgrade the two sites with a common sequencing batch reactor (SBR) design.

Because there are a number of similarities between the two catchments, and they are located approximately 100 km apart, a common design approach was selected. This article provides a summary of the design process for the two SBRs, and highlights the benefits and pitfalls of developing a common design for different WRPs.

The key benefits identified included:

- Lower design fees;
- Better equipment purchasing power;
- Reduced construction costs;
- Improved learning from design and construction changes;
- Simplified operation; and
- Performance benchmarking.

However it is important that sites are carefully assessed for commonality. This project highlighted the need to carry out detailed assessments of influent characterisation data, and network flow conditions, as these play a major role in selecting common designs.

KEYWORDS

Activated Sludge (AS), Common Design, Grampians Wimmera Mallee Water Corporation (GWMWater), Sequencing Batch Reactor (SBR).

1 INTRODUCTION

1.1 BACKGROUND

Grampians Wimmera Mallee Water Corporation (GWMWater) holds a corporate licence with the Environmental Protection Agency Victoria (EPA), for the operation of 26 Water Reclamation Plants (WRPs). The majority of these sites are lagoon based processes, but seven include forms of mechanical treatment. Two such sites which were identified as having business cases for renewal in 2009 were St Arnaud, and Warracknabeal.

In 2010, after a number of initial feasibility and options investigations, AWT Water was awarded the contract to develop a preliminary and then detailed designs to upgrade the two sites with a common sequencing batch reactor (SBR) process. This article provides a summary of benefits and pitfalls of developing a common design for different wastewater treatment plant sites.

1.2 ST ARNAUD

The township of St Arnaud is located approximately 200 km north west of Melbourne (Figure 1). It has a population of approximately 2,300. The St Arnaud WRP has a predominantly residential wastewater catchment, but does receive waste from a key trade waste contributor, Goldfields Turkey Abattoir. On occasion this site releases high volumes of high strength wastewater.

The existing system was built in the 1950's, and is now due for replacement. The existing treatment plant consists of a conventional trickling filter with Imhoff digester for sludge stabilisation prior to dewatering on drying beds. After a clarifier, maturation ponds provide disinfection prior to discharge to the winter storage ponds. Images of the old WRP are presented in Photograph 1.

Class C effluent is produced, and used by third party schemes for irrigation. These include a park, tennis club, golf course and a centre pivot irrigator.

Photograph 1: Old St Arnaud WRP
From left to right, trickling filter, Imhoff digesters, sludge lagoon

1.3 WARRACKNABEAL

The township of Warracknabeal is located approximately 300 km north west of Melbourne (Figure 1). The town has a population of approximately 2500. The Warracknabeal WRP has a predominantly residential catchment, although some small local industry is present. This is understood to have minimal impact on the wastewater volume and quality however.

The existing plant was built in the 1930's, and like the St Arnaud WRP, incorporates a trickling filter, with Imhoff digester for sludge stabilisation prior to delivery to two sludge lagoons. After a hummus tank, a maturation pond provides disinfection prior to discharge to the winter storage pond. Images of the old Warracknabeal WRP are presented in Photograph 2.

As with St Arnaud, Class C effluent is produced, and supplied to various third party reuse schemes for irrigation, including a racecourse and golf course.

Figure 1: Location of Warracknabeal and St Arnaud within the GWMWater service area

Photograph 2: Old Warracknabeal WRP
From left to right; inlet and splitting structure, trickling filter, sludge lagoon

1.4 CASE FOR UPGRADE

St Arnaud and Warracknabeal are small rural communities with significant water supply issues. GWMWater plays an important role in these towns by providing recycled water; especially to "not-for-profit" community assets such as the local race courses and golf courses. This focus on community support has seen GWMWater recycling over 95% of their treated wastewater – the highest proportion in the state of Victoria.

Aside from the age of the existing treatment systems (approximately 60 and 80 years old respectively), and ongoing maintenance issues, GWMWater had growing uncertainty about the future availability of reuse schemes in the region if the level of treatment for recycling was not improved. Withdrawal of these schemes would have a negative impact on the local community, and trigger the need to discharge into local waterways.

As the existing systems could not be upgraded to improve treatment, it was deemed necessary that the technology selected to replace the trickling filters and ponds should have the ability to be modified for this purpose when the need arose in the future.

Upgrading the treatment plants to high rate activated sludge processes provided the benefit of allowing potential improvement to the class of reclaimed water produced (allowing a broader range of reuse options), and by reducing the area of pond used for treatment saved large volumes of water through reduced evaporation (approximately 30 ML/year at St Arnaud). This goal had been planned by GWMWater for over 15 years, but the high construction costs meant that the business case would not stand. Designing and constructing a common design improved the business case.

1.5 OPTIONS CONSIDERED AND REUSE REQUIREMENTS

Both St Arnaud and Warracknabeal WRPs discharge 100% of their effluent as recycled water for irrigation. The Victoria EPA produces guidelines for the use of reclaimed water [Ref 1]. Class A reclaimed water corresponds to the most stringent treatment standard (to a tertiary level with multiple barriers) and allows flexible options for urban and industrial reuse. Class D corresponds to the minimum reuse standard (secondary treatment) and reuse on non-food crops only. The irrigation schemes at St Arnaud and Warracknabeal have been approved by the EPA to be deemed appropriate for Class C reclaimed water irrigation, requiring secondary treatment and pathogen reduction. The standards for biological treatment and pathogen reduction for Class C reclaimed water are summarised in Table 1 below.

Table 1: Class C reclaimed water quality objectives

Parameter	Unit	Median Water Quality Objective
E.coli	org/100mL	< 1,000
pH	units	6 – 9
BOD	mg/L	< 20
SS	mg/L	< 30

These limits had to be met by the two new treatment processes for GWMWater to satisfy the requirements of their irrigation licences with the EPA. Additional to the treatment requirements for Class C reclamation, nutrient limits were also applicable for irrigation, dependent upon the land area and crop type available. The selection of a process type was therefore crucial for this aspect of the effluent quality.

An initial investigation into a number of suitable technologies was undertaken. Treatment technologies investigated included:

- Trickling filters;
- Submerged aerated filters (SAF);
- Oxidation ditch;
- Conventional activated sludge (CAS);
- Sequencing batch reactor (SBR); and
- Membrane bioreactor (MBR).

Concept level cost assessments and the GWMWater operational requirements meant that only SAF and SBR technologies were suitable for further investigation.

SAF plants are a type of attached growth process, where aerated wastewater is treated by microorganisms supported on physical media. They are often used to remove Biochemical Oxygen Demand (BOD) and ammonia (NH_4) concentrations, but typically have limited ability to remove total nitrogen (TN).

SBR plants are suspended growth activated sludge process, generally run in batches with anoxic, aeration, and settling phases all taking place in the same reactor. They can be slightly more complicated to operate than SAF plants, but will remove greater quantities of nitrogen.

In order to determine the most effective treatment option, it was necessary to investigate the effluent nutrient concentrations required at each site, based on area of irrigation land available, and the EPA values for nutrient uptake of crops. It was determined that both sites would be able to discharge a maximum of 25 mgN/L from their storage ponds, based on the pre-design flow of 550 m^3/day. Likewise, effluent phosphorus concentrations of 5 mgP/L for St Arnaud, and 7 mgP/L for Warracknabeal were determined to be acceptable for the crop types.

With an allowance for evaporation in the storage ponds causing concentration of the effluent by approximately 5 mgN/L, a 20 mgN/L effluent quality was deemed necessary. SAF plants can typically treat to between 20-25 mgN/L and would have difficulty in regularly meeting this limit, whereas an SBR plant can effectively treat to these limits.

Operational costs for the two options were considered to be nearly identical, with higher aeration required for SAF plants, but mixing power required for SBRs. A multi-criteria assessment matrix was produced to compare the two options, and the SBR design emerged as the preferred option due to better effluent quality, smaller land requirements for irrigation (on a nutrient basis), smaller treatment plant footprint, and lower capital costs.

SBR was therefore carried forward for design with target effluent for Class C reuse, and the ability to adjust treatment to achieve nutrient levels of 20 mgN/L, and 5 mgP/L at a later date if required.

2 DESIGN CRITERIA

Early flow comparisons between the two sites indicated that the sites would be similar and therefore possibly benefit from a common design. As the development of design criteria progressed, it became clear that there were differences between the two catchments which would impact on the design.

2.1 FLOWS

For both of the catchments, it was identified that the populations were expected to gradually decline in the future. So no growth allowance was made in the design above the existing flows. However at the time of the design, Australia was emerging from a long drought period. The impact of this climatic change on water usage was unknown, but was expected to present an increase in usage as water restrictions in the catchment were lifted.

2.1.1 ST ARNAUD

The St Arnaud wastewater treatment plant is fed by gravity. Initial investigations into available inflow data at the St Arnaud site indicated that the inlet flow measurements were erroneous due to flumes becoming blocked and providing high readings. Careful screening of the data provided more accurate average flow information. In addition, the St Arnaud catchment includes a turkey abattoir, which was expected to grow by up to 30% in the short to medium term.

Average daily flows from municipal contributions and increasing abattoir discharges were estimated to be approximately 455 m^3/d. Investigating the turkey abattoir further revealed that on exceptionally high kill days, peak flows from the site could increase considerably.

2.1.2 WARRACKNABEAL

The Warracknabeal WRP by contrast is fed by a network pumping station, and therefore has a more uniform feed flowrate than the gravity system at St Arnaud (albeit more liable to step changes with high I&I storm flow changes). Two pumps (duty/assist) with maximum flowrates of 30 L/s and 36 L/s respectively feed the plant. Allowing to treat the total combined flow from both pumps would have required over sizing the plant for a very infrequent event, and would mean either a different reactor design than for St Arnaud, or similarly oversized reactor at that site.

It became apparent that the Warracknabeal network pumps could be modified by GWMWater to supply any preferred duty flow to the WRP, and then increase that flow during peak wet weather events. Assessment of a range of treatment flows highlighted that it was most cost effective to design for the peak wet weather flow conditions at St Arnaud, with a peak instantaneous flow of 22 L/s, and include a storm flow bypass (after the inlet works) for flows greater than this. The inlet works at Warracknabeal were therefore designed to have a peak instantaneous flow of 66 L/s (both network pumps in operation), and the remainder of the downstream processes a flow of 22 L/s (excluding recycles). Design flows are summarised in Table 2.

This presented a significant deviation from the intended common design. It was still possible to have the same SBR reactor design, but the size of the inlet works, and need for a storm bypass introduced a number of changes.

Table 2: Design flow criteria

Parameter	Unit	St Arnaud (future)	Warracknabeal	Common Design Criteria
ADF	m^3/day	455	404	500
Diurnal peaking factor		1.76		
Peak load day	m^3/day	604		604
PWWF	m^3/day	1,400	2,000	1,400
Instantaneous flow	L/s	22	36 (66 at inlet)	22 (66 at inlet)

The higher common design ADF of 500 m^3/d was selected to provide a 10% safety factor on the highest ADF to allow for the unknown impact of lifting water restrictions in the region. This implies a 20% safety factor on the Warracknabeal flows.

2.2 INFLUENT LOADS

As the Warracknabeal catchment is composed almost entirely of domestic connections, the influent pollutant concentrations were within the typical domestic ranges as expected. The St Arnaud pollutant load however, was significantly impacted by the turkey abattoir. In order to determine the extent of this impact, an online UV-vis spectrometer probe was installed at the inlet works to monitor concentrations for a number of weeks.

The information gathered demonstrated that the St Arnaud sewage had a considerably higher organics and solids load compared to the Warracknabeal catchment. For a common design to be feasible, the higher load had to be designed for, prompting the need for detailed modelling to ensure the Warracknabeal system would not be under-loaded. The design loads are summarised in Table 3.

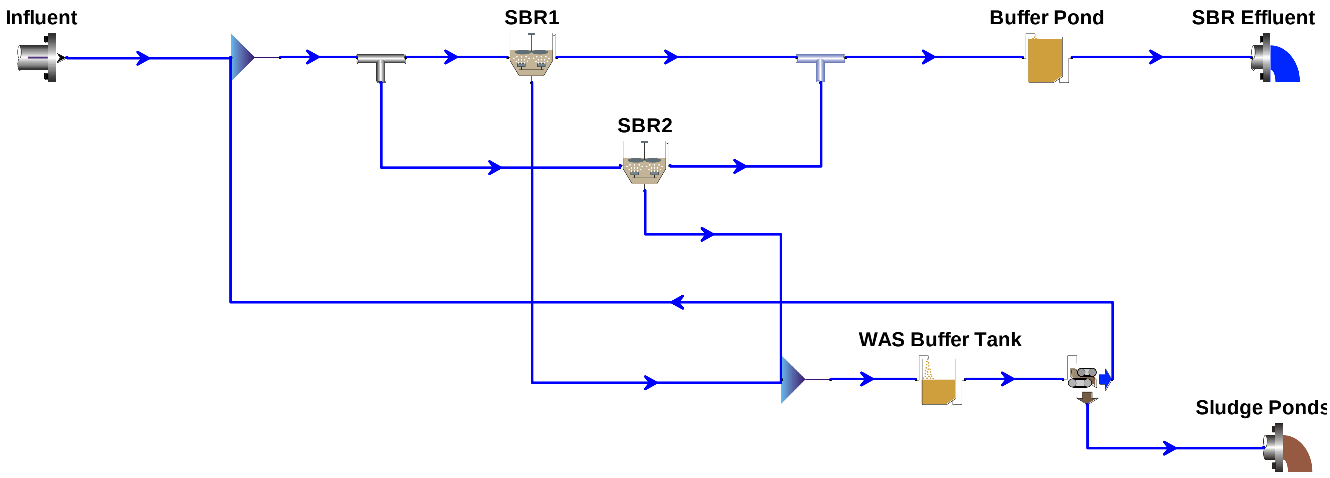
Table 3: Design influent characteristics

		St Arnaud		Warracknabeal	Common High Design Criteria	
		Current	Future	Current	Average	Peak Load
ADF	m³/d	438	455	404	500	604
BOD_5	mg/L	421	424	350	386	622
COD	mg/L	825	852	700	775	1,247
TKN	mg/L	90	89	88	81	136
NH_4	mg/L	54	55	66	53	66
TP	mg/L	13	13	14	12	13
SS	mg/L	436	461	345	420	906
BOD_5	kg/d	184	193	141	193	376
COD	kg/d	361	388	283	388	753
TKN	kg/d	39	40	36	40	82
NH_4	kg/d	24	25	27	27	40
TP	kg/d	6	6	6	6	8
SS	kg/d	191	210	139	210	547

2.3 DYNAMIC PROCESS SIMULATION MODELLING

A number of operating configurations were considered during the preliminary design of the SBRs. These included various cycle configurations, and batch/continuous modes. Models were developed in BioWin for each scenario, and the configurations evaluated to steady state for effluent quality performance. Figure 2 displays the layout of the model. The models were also tested for resilience to peak wet weather flow, and peak load day conditions as defined in the design criteria.

Figure 2: BioWin model layout



The average influent data developed in the design criteria was used as the model input. Examples of the BioWin outputs generated are shown in Figures 3 and 4 below.

Figure 3: Peak storm event – influent parameters

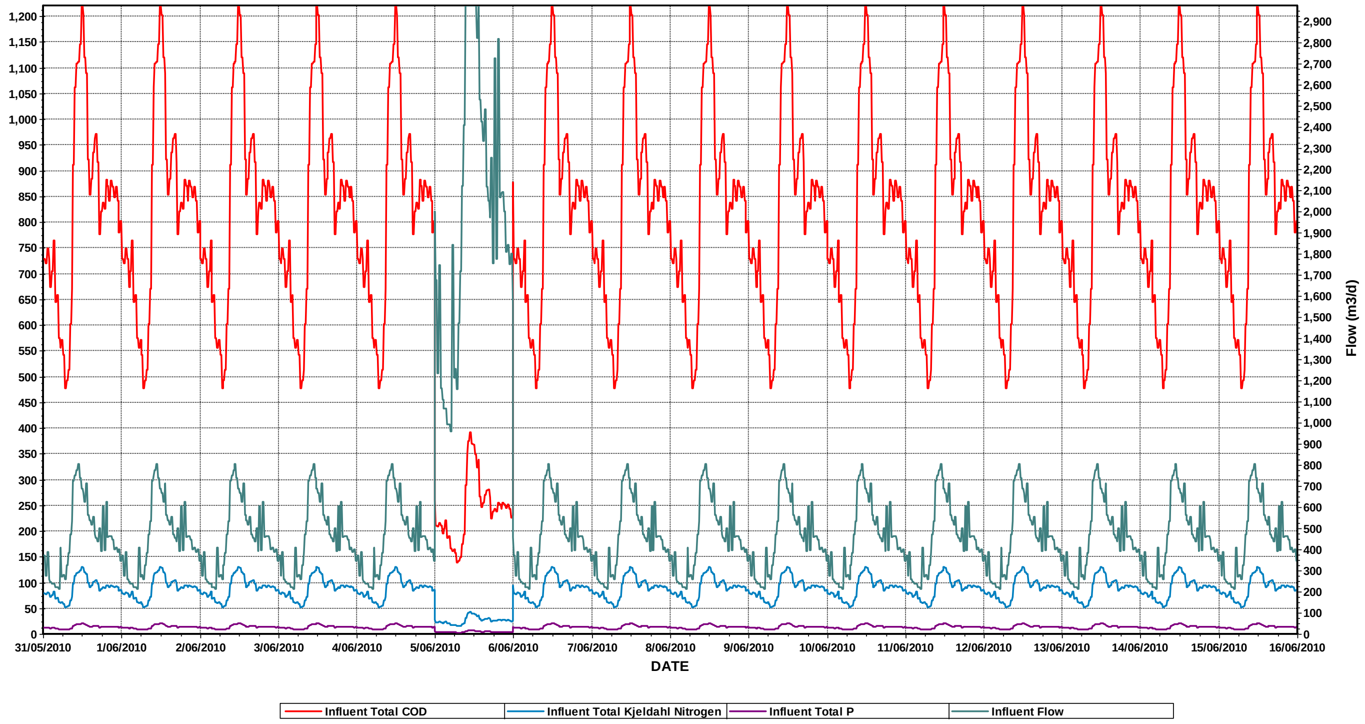
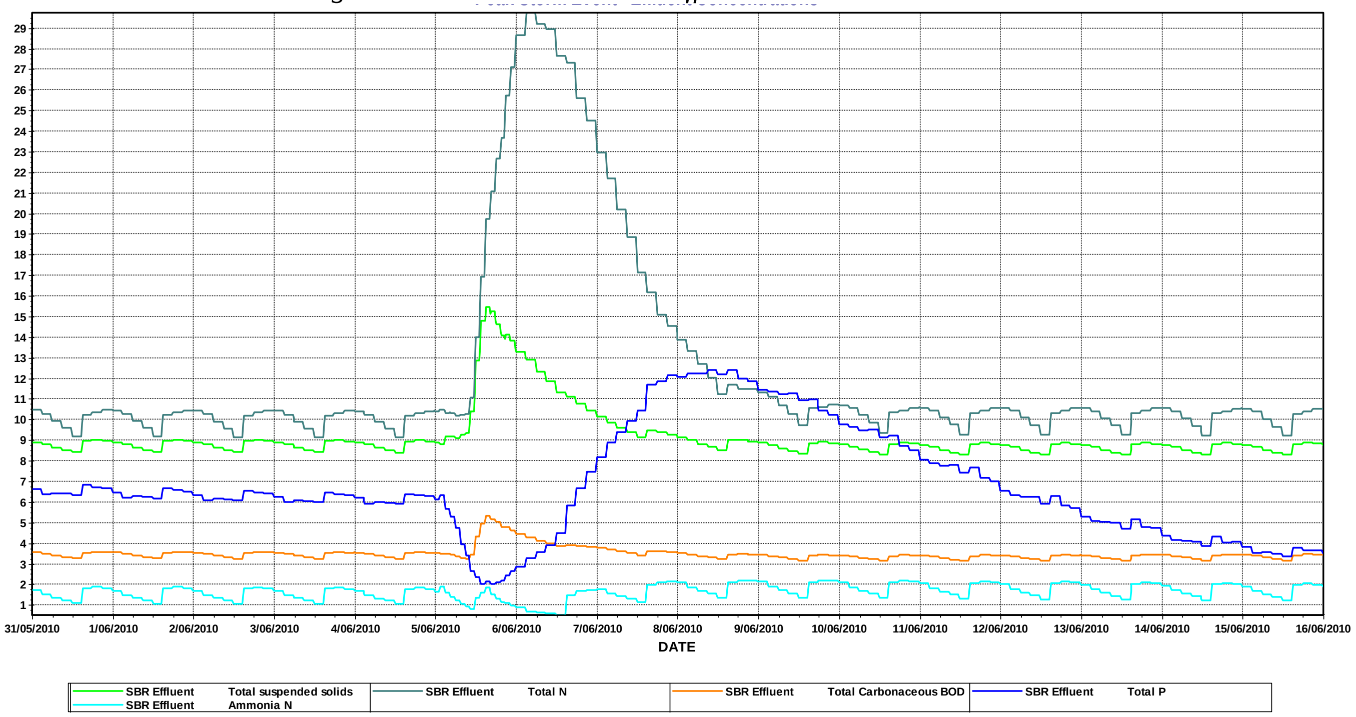


Figure 3, shows the influent conditions modelled to test for a peak storm event. The typical diurnal pattern is disrupted at around day 6, with flows increasing significantly and concentrations reducing. Figure 4, shows how the modelled plant responds to the event, with the selected patch operation, and anoxic/aerobic 6 our cycles. Effluent quality initially spikes, the plant then changes to storm cycle mode (shorter cycle times), and then recovers over the following days with normal cycle times.

Figure 4: Peak storm event – effluent concentrations



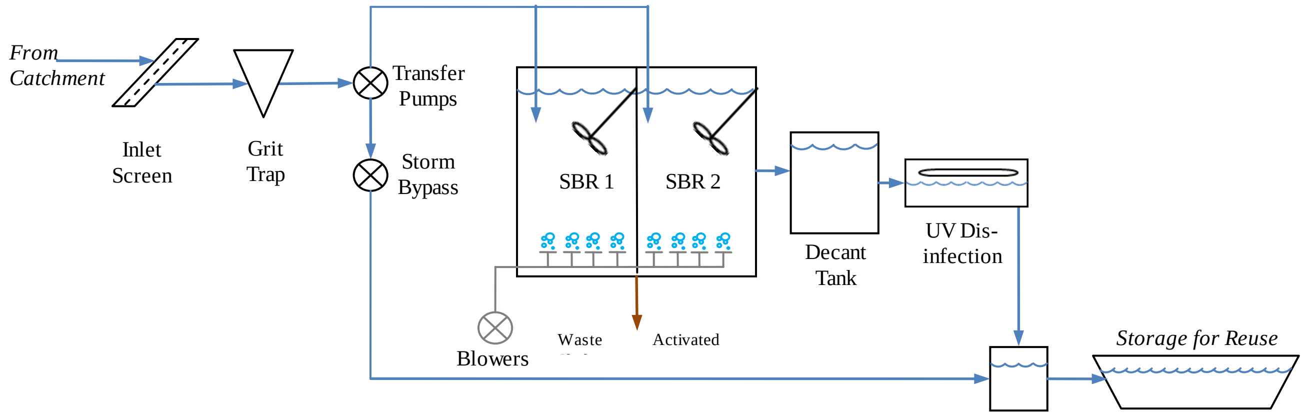
2.4 SELECTED DESIGN

As well as the common design features we typically expect in the New Zealand environment, a few local effects had to be catered for. These included blowers capable of operating effectively when ambient temperatures reach 45°C, and buildings protected against swarms of locusts.

The linear decanter system was also novel for the design. The system was first used in Australasia when installed at Pukekohe SBRs in New Zealand, but this was the first instance of their use in Australia.

The selected SBR process was developed based on a 6 hour standard cycle, with intermittent anoxic and aerobic phases. Generally the common design consisted of the unit processes described in Figure 5 below.

Figure 5: Schematic of common SBR design



3 COMMON DESIGN APPROACH

Because of the similarity in size for the two schemes, and their close proximity, GWMWater sought to develop common designs for the two sites. As discussed above, it was therefore necessary to design for the worst case flow scenario, including allowance for the industrial load at St Arnaud separately within the specific plant design, and then model the different design scenarios for the two sites. This approach presented many benefits, but also a few unforeseen hurdles.

3.1 COMMON DESIGN BENEFITS

Developing a common design for the two sites had the following benefits:

- **Lower design fees** – Once the common design parameters were set, AWT Water were able to deliver a lower cost design, with the majority of the components sharing the same parameters. The key process and most of the mechanical and structural designs were identical for the two sites. In addition, development of the design drawings was carried out in 3D-CAD models, with a common base design. This allowed for easy clash detection, and modification of only the parts of the design that diverged between the two sites (see Appendices A and B), saving considerable design time.

- **Improved purchasing power through bulk buying** – Buying larger packages of equipment at once allowed GWMWater to make significant equipment cost savings. GWMWater further improved their equipment costs by purchasing the major equipment items themselves, and free issuing these to the selected contractor.

- **Reduced construction costs through engagement of a single local contractor** – Similarly to equipment purchase savings, GWMWater were able to gain a very competitive fee for the construction of the two nearby plants, by bundling them into one contract. The contractor was able to have one team working on two nearly identical sites, and to mobilise to the second immediately after the first, resulting in cost savings being passed on to GWMWater.

- **Learning from changes** – As the construction of the two plants was staggered, any changes to the design or lessons learned during the construction of the first site were able to feed directly into improving the design and delivery of the second site. This included learning from the commissioning process, and allowing control programming changes to be easily made to the second plant before implementation.

- **Improved operational simplicity through common features** – Operational training requirements for GWMWater were significantly simplified with two identical sites. Operators made familiar with one site were easily able to operate the second.

- **Ability to benchmark performance between plants** – Similar plant design allows the performance and consumption of consumables (power, chemicals etc.) to be monitored, and compared between the sites. This will provide GWMWater with significant benefit throughout the life of the plants, a performance deviations can be easily investigated and remedied.

3.2 OBSTACLES TO THE COMMON DESIGN APPROACH

At initial glance, the two wastewater treatment plants appeared to be ideal for a common design approach. However as the work design proceeded, a number of significant differences became apparent, and resulted in a number of changes to the design in order to accommodate the variances that each site presented. Some of the key differences are highlighted below.

CATCHMENT WASTEWATER SOURCES

As described in earlier sections, the Warracknabeal catchment consists almost entirely of domestic wastewater from a declining population. Conversely the St Arnaud catchment includes an abattoir which is anticipated to expand in the future. This means that the St Arnaud WRP receives a greater organic and solids load than the Warracknabeal site, both now, and in the future. Ultimately this meant that by setting a common reactor size for both sites, the Warracknabeal WRP was oversized for the load it would receive. BioWin modelling of the two load scenarios was carried out to ensure that this would not cause significant issues. Additional design time was accrued to assess these scenarios.

PRESSURE AND GRAVITY NETWORKS

The early discovery of this significant difference between the two catchments resulted in the most significant deviation in the two designs. The pressurised rising main at Warracknabeal was capable of generating much higher instantaneous flows than the gravity sewer at St Arnaud, and at a higher delivery head. As a result, the inlet works and high flow by-pass arrangements were designed differently for the two sites. The St Arnaud inlet structure was designed for the peak instantaneous flow of 22 L/s, and installed at a low level in the ground to avoid additional pumping, and with separate screen a grit removal equipment.

The Warracknabeal inlet works however had to accommodate peak instantaneous of 66 L/s, which would be pulsed to the site by the network pumping station. Because of the pressurised rising main, the inlet structure had to be raised above ground level. This raised structure also required the selection of an alternative screen and grit removal package, and a greater flow capacity. The differences can be clearly seen in Appendices A and B.

STORM BYPASS ARRANGEMENTS

As a result of the higher instantaneous flows at Warracknabeal, it was necessary to design a bypass arrangement for peak wet weather conditions. The SBR reactors were designed for the lower peak instantaneous flow of 22 L/s (as experienced at St Arnaud, 24 L/s with recycles included) to maintain a common design. At flows greater than this, both sites incorporated a storm bypass arrangement which directed the excess dilute storm flows past the SBR reactors, and on to the HDPE lined maturation ponds.

For the St Arnaud WRP, this bypass was for in cases of emergency only, and expected to be used very infrequently. For Warracknabeal however, historical flow data indicated that bypasses could potentially occur each year during periods of high rainfall. It was necessary to carry out a significant amount of additional investigative work and determine the likely dilution of the bypass flows during these periods to demonstrate to the regulator that negligible effect would be expected. This case was aided by the fact that peak storm flows would be more dilute than dry weather flows, all flow would be screened with the majority of the flow biologically treated, and the maturation ponds would typically be at high levels when bypasses occurred.

Had the network arrangements been similar a common design would have been more easily achieved.

DISCHARGE PUMPING ARRANGEMENTS

Because the bypasses at each site were designed for different capacities, additional engineering of the treated effluent and storm bypass pumps was necessary to ensure that they could both discharge into the same discharge pipe without pumping against each other.

FLOOD PLAINS

Early site surveys indicated that both of the proposed construction sites were located within the flood plains of their respective nearby watercourses, and therefore at risk of inundation. While not a major issue, the different site survey levels meant that ideally the SBR reactors would be constructed at different depths.

In order to maintain a common design, it was necessary for both of the proposed WRP sites to be levelled for consistence, and raised above their respective 100 year flood levels.

4 SUMMARY AND CONCLUSIONS

The Warracknabeal site was commissioned in November 2012, and the St Arnaud plant in March 2013. Photographs of the completed treatment plants are included below.

Both plants were delivered at considerably lower costs than could be expected if they were stand-alone projects. The total construction cost for the two plants was approximately AU$5 million, with the total project cost estimated to be approximately AU$8 million (including all non-works costs, design, and client project management).

In this case, we estimate a saving of greater than 10% on the total project delivery cost, when compared against individually design treatment plants of a similar size (based on AWT Water's treatment plant costing database). If the design differences between the two treatment plants could be removed, greater savings could be expected.

This project demonstrated that if carefully managed, common WRP design and procurement can provide cost savings by:

- Lower design fees;
- Better equipment purchasing power;
- Reduced construction costs;
- Improved learning from design and construction changes;
- Simplified operation; and
- Performance benchmarking.

However it is important that sites are carefully assessed for commonality, especially carrying out detailed assessments influent characterisation data, and network flow conditions.

4.1 ST ARNAUD IMAGES

Photograph 3: UV system (left), inlet works (centre), SBR tanks (right)

Photograph 4: SBR tank aeration grids prior to commissioning tests

Photograph 5: Sludge drying lagoons

Photograph 6: SBR tanks in operation (aeration phase left, anoxic phase right)

Photograph 7: SBR (taller at rear) and decant tank (foreground)

Photograph 8: SBR tanks (left and centre), and sludge drying lagoons (right rear)

Photograph 9: Inlet works (foreground) and sludge drying lagoons (rear)

4.2 WARRACKNABEAL IMAGES

Photograph 10: Septage reception and pumping stations (septage, storm, and transfer)

Photograph 11: Sludge drying lagoons

Photograph 12: Blower sets

Photograph 13: Inlet works

ACKNOWLEDGEMENTS

Special thanks to GWMWater for their input and permission.

ABBREVIATIONS

AU$	Australian dollars
3D-CAD	Three dimensional computer aided design
BOD	Biochemical Oxygen Demand (mg/L)
EPA	Environment Protection Authority (State of Victoria)
GWMWater	Grampians Wimmera Mallee Water Corporation
I&I	Inflow and Infiltration
NH_4	Ammonia (mg/L)
SAF	Submerged Aerated Filter
SBR	Sequencing Batch Reactor
WRP	Water Reclamation Plant (Australian term for wastewater treatment plant with beneficial reuse)

REFERENCES

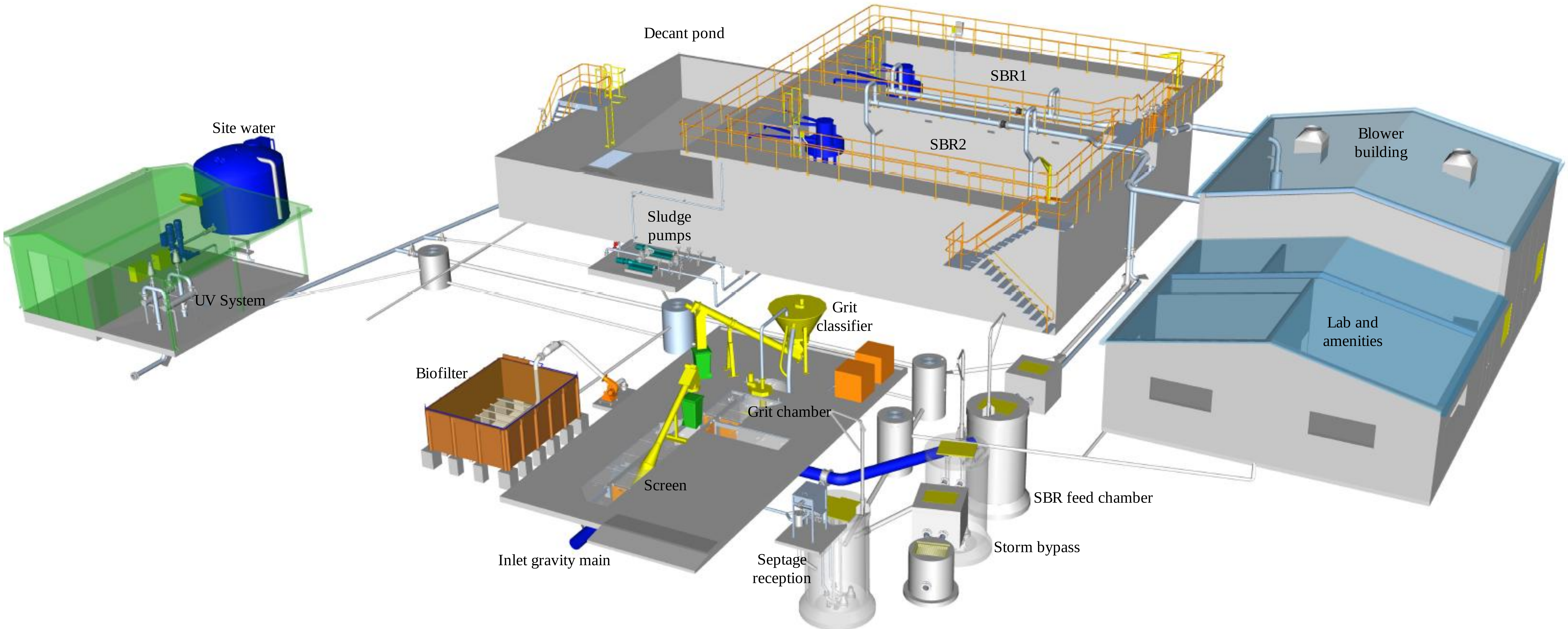
Ref 1 Guidelines for Environmental Management – Use of Reclaimed Water. Publication 464.2, EPA Victoria, June 2003.

APPENDICES

Appendix A 3D-CAD rendering of the St Arnaud WRP.

Appendix B 3D-CAD rendering of the Warracknabeal WRP.

APPENDIX A – 3D-CAD MODEL OF THE ST ARNAUD WRP.



APPENDIX B – 3D-CAD MODEL OF THE WARRACKNABEAL WRP