PROCESS SIMULATION FOR DESIGN AND DE-RISKING OF A COMPLEX MINE AND POWER STATION WATER RE-USE AND BRINE PROJECT

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EXTENDED ABSTRACT

In recent years renewable energy sources have made significant headway into Australia's energy market, however coal fired power continues to provide >50% of Australia's power generation capacity [1]. Australian coal fired power stations are significant water consumers due to the large cooling water requirements. Therefore, sustainable water use is critical to ensuring the future of this industry, the coal industry that supplies it and Australia's economy. This paper details the outcomes of computerized process design and simulation investigations (utilizing EVS: Water Designer, formerly AqMB Designer) undertaken for one such coal fired power station to enable significant project risk reduction (ensuring compliance, reduction of costs and that timelines are met) through the optimized implementation of membrane desalination and thermal brine treatment technologies.
The process simulation software allowed construction of a design "digital twin" which was used in each phase of the project, from planning, concept design, vendor selection, execution, commissioning and ongoing operations. It has enabled troubleshooting of ongoing operational issues, identification of reference design for vendor engagement and selection of the optimal design offered by vendors. Process simulation of the various scenarios involved all pertinent analytes (>30), including their interaction via speciation modelling, whilst simulating system designs of up to 50-90 process units (up to a total of 9 stages of reverse osmosis), with multiple recycle and feed streams. A key automated output from the software is the lifecycle cost evaluation which allows cost optimization and design selection. Ultimately the vendor design which was selected had significantly reduced energy requirements due to the use of a membrane concentration process, enabled operation of the existing plant during construction and moved the system to sodium carbonate dominated chemistry which reduced chemical usage and was advantageous for co-disposal of brine and salt with power station derived ash. Discussions are taking place, for which the design "digital twin" to potentially be transferred to the operations phase where predictive analytics and forecasting can be employed to ensure compliance and optimized operations.

Keywords: Cooling water, brine management, process simulation, digitization, digital twin

1. INTRODUCTION

Although renewable energy sources have in recent years made significant headway into Australia's energy market, coal fired power continues to provide >40% of Australia's generation capacity [1]. Resultingly, the cooling water requirements of Australian coal fired power stations make them significant water consumers. Therefore, sustainable water use is critical to ensuring the future of this industry, the coal industry that supplies them and Australia's economy. This paper details the outcomes of process simulation investigations undertaken for one such coal fired power station to enable significant project risk reduction (i.e. costs and timeline) through the optimized implementation of membrane desalination and thermal brine treatment technologies.

1.1 General Project Background

The coal-fired power station for where this project is located is within proximity to a large population centre within Australia. Coal for the power station (PS) is predominately sourced from a nearby mine. Water supply used in the cooling circuits of the power station is from a nearby lake which is within the tributary of the city's water supply catchment. Groundwater discharges from the coal mine also feed into the same catchment. Due to this the power station operator has observed over recent years a deterioration in its cooling water makeup quality which can detrimentally affect future operations.

To undertake operations at the nearby coalmine, water is extracted from underground workings at a rate of 36 to 42 ML/d. Prior to treatment plant commissioning, raw water was treated to remove suspended solids (up to 100 mg/L) and discharged into the local catchment at a licensed discharge point at a salinity of approximately 1200 µS/cm electrical conductivity (EC). The coal mine was granted development consent to expand the mine with conditions requiring discharge salinity of 500 µS/cm EC (90^{th} %ile) and to eliminate acute and chronic toxicity to aquatic species in any water discharged from the mine. Therefore, significant reduction of the raw water salinity is required prior to discharge.

1.2 Water & Brine Treatment Process

To achieve the salinity discharge limits and to prevent future make-up water problems, the mine and PS have worked collaboratively to implement water and brine treatment solutions which are mutually beneficial to both parties and the environment. The solution involves transfer of dewatered minewater to the PS and augmentation of the plant's existing water and brine treatment facilities to treat and utilize the water and to treat the resultant brine i.e. this has been termed here the PSWTP (power station water treatment plant). Details of the final selected process at PSWTP and a simplified block flow diagram is presented in Section II.

1.3 Process Simulation for Project De-Risking

GHD, as the Client Engineer for both parties, has extensively used process design and simulation software for project de-risking at each phase the project; from initial feasibility assessment through concept definition, through tender evaluation and into final plant operation. Table 1 outlines the activities included within this process.

Table 1: Design phases and associated activities

Phase	Activity
Planning Phase	Forecasting the impact of deteriorating cooling water make-up on the power station
Concept Design Phase	Simulated / designed multiple alternative mine water desalination schemes for cooling tower make-up water with direct input into costing
Concept Design Phase	Simulated / designed multiple alternative cooling tower blowdown RO concentrate treatment schemes
Concept Design Phase	Simulated and evaluated integrated mine water treatment, cooling tower and RO concentrate treatment schemes
Vendor Selection Phase	Simulated and evaluated offers from vendors for mine water desalination and cooling tower blowdown RO concentrate treatment schemes
Execution, Commissioning & Operational Phases	Forecast, via simulations, the impact of various scenarios upon the power station / water treatment plant operations and licensed discharge points water quality e.g. impact of delays to commissioning, scenario planning for supply of different mine water quality feeds, ash repository planning etc.

1.4 Process Simulation Software

The process simulation software utilized is "EVS: Water Designer" (abbreviated to "EVS: Water" and formerly known as "AqMB Designer"). EVS: Water is a web-based process modelling platform for simulation of water and brine treatment facilities and incorporates all common conventional, membrane, electrolytic, thermal process units. It also includes an in-built water chemistry/speciation modelling engine which is customized for water treatment and allows prediction of coagulation, precipitation, adsorption, scale/corrosion potential, antiscalant performance etc. Given the above capabilities of the process design software has been successfully used in for the simulation and design of industrial water treatment processes [2, 3]. Figure 1 provides an overview of the results interface where engineering deliverables may be exported and results interrogated.

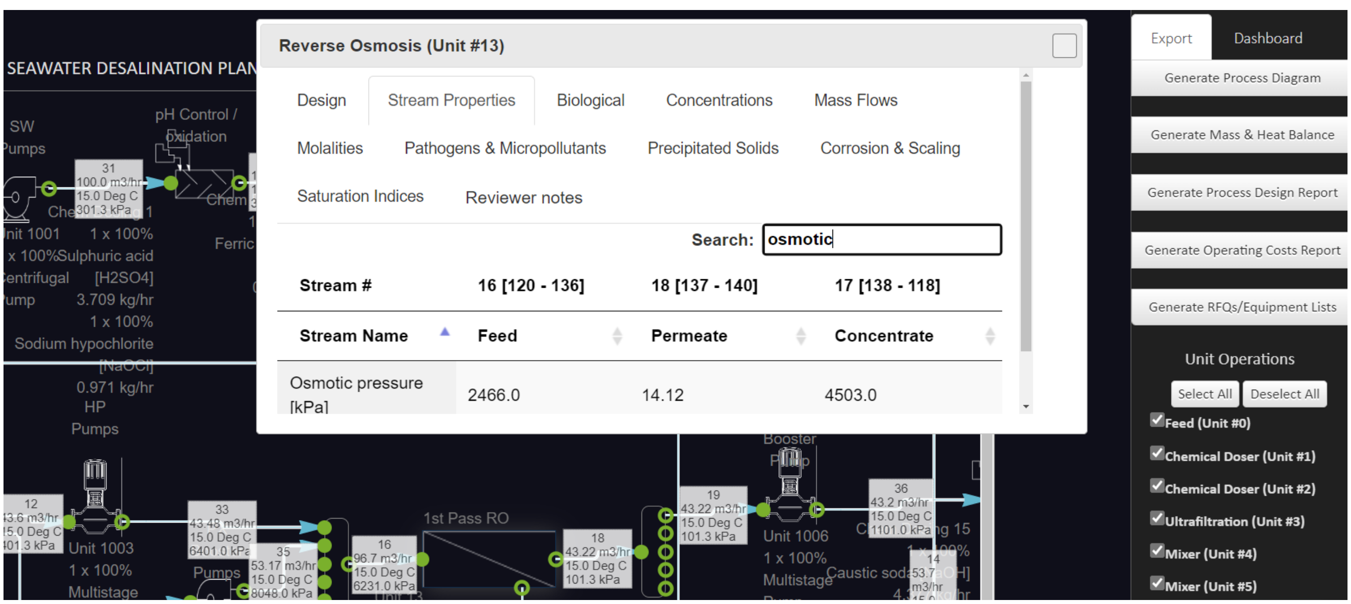

Figure 1: EVS: Water Designer results interface example for a SWRO design

EVS: Water allowed construction of a “digital twin for design” (i.e. concept design and tender evaluation) which has subsequently been transferred into a “digital twin for operations” (i.e. simulation of multiple commissioning and operational phases). A key benefit of the software is that it allows integrated process modelling of multiple process designs and feed scenarios on a single flowsheet. Process design simulation of an integrated process allowed investigations of many scenarios in a relatively short amount of time and enabled significant reduction in risk, implementation timeline and cost for the PSWTP project. A key automated output from the software which enables cost optimization and de-risking, is the lifecycle cost evaluation, where the electrical load list, chemical dosing list etc are automatically calculated and entered into a whole-life cost estimate which incorporates capital costs etc.

II. PROCESS SIMULATION INVESTIGATIONS & RESULTS

As noted above, EVS: Water was utilized for a range of water and brine treatment simulation and design applications on this project. The following sub-sections provide an overview of these investigations with pertinent results.

2.1 Planning Phase: Forecasted the impact of deteriorating cooling water make-up quality

The PS has observed an increase in salinity of the main cooling tower make-up source which had been exacerbated by several years of drought. To further understand the impact of the deteriorating make-up water, GHD and the PS utilized process simulation to predict the impact upon the existing cooling tower and blowdown treatment system. This assisted the PS to determine the optimal timing of the PSWTP Project implementation and the actions (i.e. operational and process modifications) necessary to ensure continued operation of the power station.

The pre-existing process incorporated a relatively common cooling tower blowdown treatment scheme (i.e. MF/RO of approximately 6 ML/d capacity followed by thermal brine concentration) and is summarized in the simplified block flow diagram presented in Figure 2 below. Ultimately, this system has been replaced by the new PSWTP shown later in this paper in Figure 5.

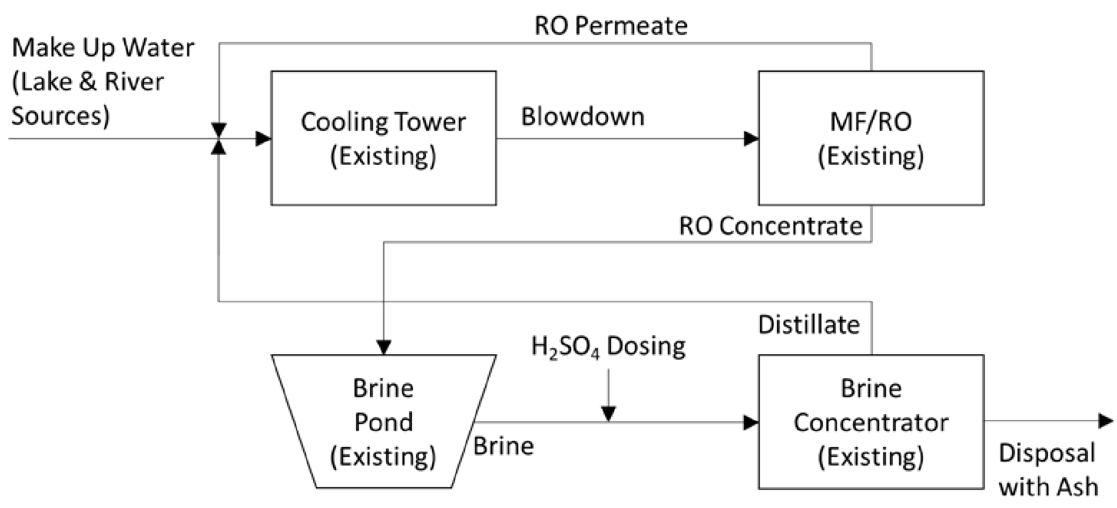

Figure 2: Simplified Block Flow Diagram of Existing PSWTP Water & Brine Treatment System

The process presented in Figure 2 was replicated in EVS: Water using approximately 50 process units (the above main process units and mixers, splitters, chemical dosing etc.) with various process recycles. The make-up water quality was extrapolated 2 years into the future and covered a reduced suite of ~20 water quality analytes (including TDS, TSS, conductivity, pH, temperature, total alkalinity, Al, ammonia, Ba, HCO_3, Ca, CO_3, Cl, Fe, Mg, NO_3, NO_2, O_2, P, K, Na, SiO_2, SO_4) for each make-up stream. The number of analytes were reduced due to the extended length of time that the simulations are modelled for; typically all analytes of concern are modelled including heavy metals and metalloids and totaled to over 30.

GHD undertook time series process simulations to predict when cooling tower blowdown design constraints were to be exceeded (i.e. pH, Langelier Saturation Index (LSI), Ca, SO_4, SiO_2, NH_4, TDS, conductivity, Ca & SO_4 product, Mg and SiO_2 product, sulphuric acid dosing pump limits etc), the operational actions required to address these design constraint exceedances and ultimately to determine the required timing of process equipment replacement or upgrade if all operational actions had been exhausted. Figure 3 shows key outputs from the process simulations. This figure shows that the make-up water sulphuric acid dosing system was predicted to be undersized on various occasions. Acid dosing is used to ensure that the cooling tower blowdown water remains within total alkalinity and LSI limits such that scaling does not become problematic for the cooling water circuit and the existing downstream blowdown WTP RO system. Figure 3 also shows that the lower TDS (and more expensive) river make-up water (extracted from higher up in the catchment) would also eventually be required as the lake TDS continued to rise. A key impact of rising TDS is that the number of cycles of the cooling tower would need to be reduced, thus increasing the blowdown volumes and exceeding the volumetric capacity of the downstream existing RO and BC systems.

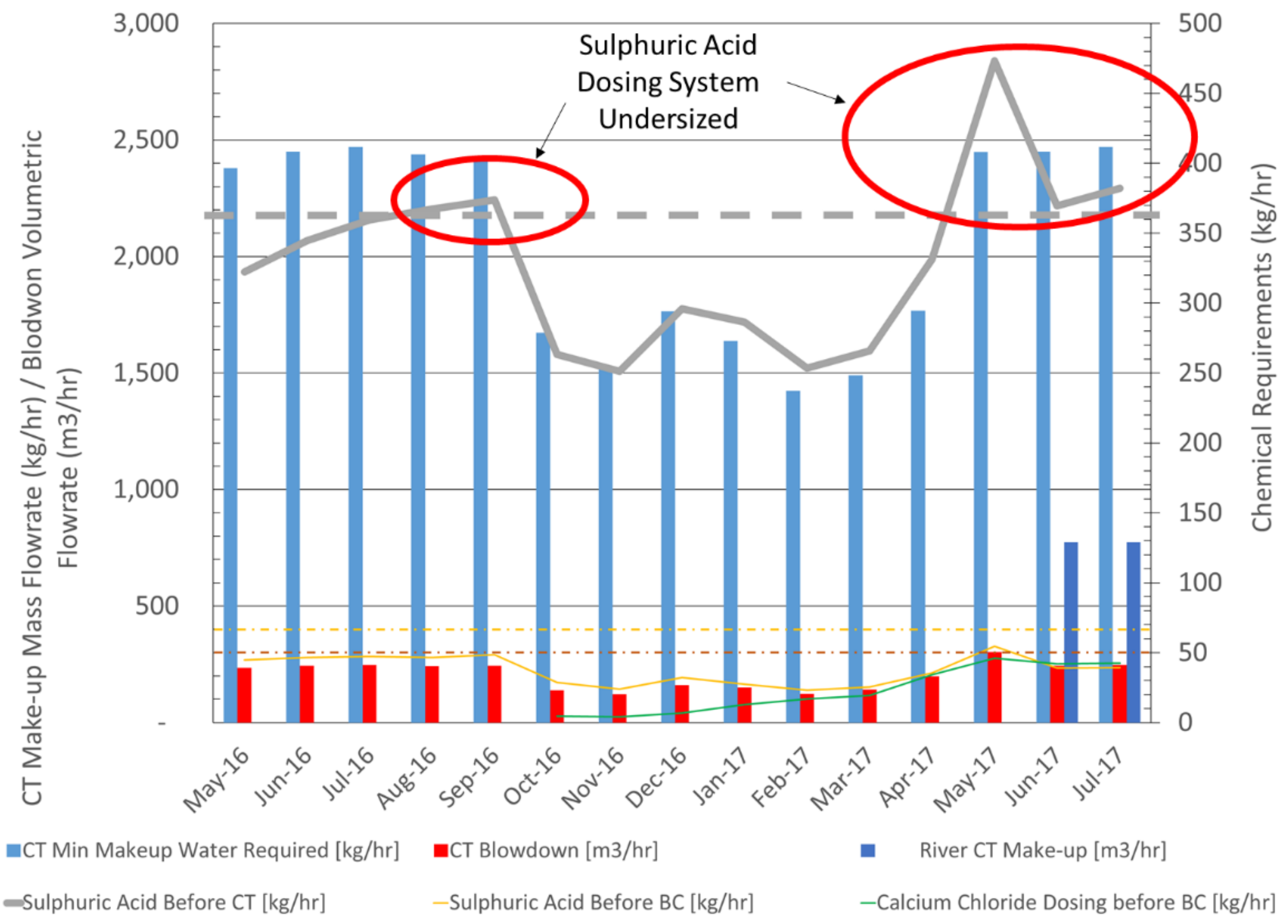

Figure 3: Key Output of Process Simulation Make-Up/Blowdown Flowrates & Chemical Dosing Requirements

2.2 Concept Design Phase: Modelled multiple cooling tower blowdown RO concentrate schemes

To provide accurate information before seeking market participation, the coal mine and PS needed to evaluate different treatment options. GHD undertook simulation of different treatment schemes using EVS: Water to ensure compliance with the EPA consent whilst allowing evaluation of whole-life costs. The software allows automated production of process engineering deliverables (PFD, mass and heat balance, design report) including lifecycle costs covering power requirements, consumable requirements and chemical consumption rates. In addition, as these can be exported into excel format, customization of costings such as labour, individual chemical agreements and consumable prices can be adjusted dependent upon specific agreements in place. This enabled quick determination of a preferred concept design via life cycle cost assessment to inform each client of the scale of the project, then enable business case formulation and approval to move forward to the next phase of the project. The process schemes examined included various upgrades to the existing system and evaluation of current and more novel / emerging process technologies including electrodialysis metathesis (EDM).

The selected reference design resulting from process simulation, which was used for subsequent vendor engagement, is outlined in Figure 4. The reference design is predominantly based on the existing system with upgrades to the BC feed sulphuric acid dosing system (to address the large additional load of alkalinity from the mine water RO concentrate), refurbishment of the existing BCs and installation of a brine crystallizer. The advantages of this treatment scheme included minimal change to the existing process and the ability to maintain continued operation of the brine system, as it was critical to ensure uninterrupted operation of the power generation facility. The process also ensured similar dominating chemistry i.e. sodium sulphate chemistry predominates due to destruction (using sulphuric acid) of mine water alkalinity which was significantly dominated by sodium bicarbonate. The disadvantage is the significant chemical requirements and the continued use of older equipment.

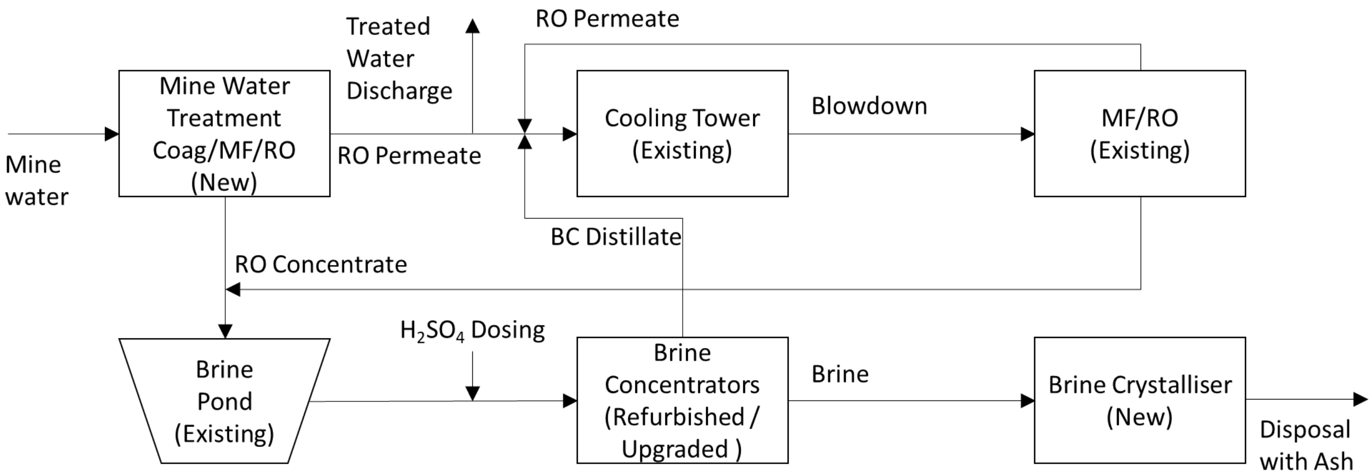

Figure 4: Simplified Block Flow Diagram of Selected Reference Design for Vendor Engagement

2.3 Vendor Evaluation Phase: Evaluated alternative offers from vendors

GHD also used EVS: Water to evaluate alternative concept designs proposed by vendors and to provide plant performance, water quality and lifecycle cost information to narrow down potential treatment schemes. Potential desalination and RO concentrate treatment schemes were assessed before a suitable scheme was selected.

The selected vendor design was an alternative process offered by a vendor which was based on a softening / RO brine concentration / thermal crystallization treatment system and operated in the sodium carbonate chemistry regime (as opposed to sodium sulphate). A simplified block flow diagram of the process (approximately 90 process units as represented in the process design software) is presented in Figure 5 with the key process areas being:

- Mine Water Treatment – Coagulation, membrane filtration, 4-stage RO
- Cooling Tower and Cooling Tower Blowdown MF/RO (2-stage) Treatment (existing processes, out of vendor scope)
- Brine Treatment – Cold lime softening (CLS), membrane filtration (MF), weak-acid cation ion exchange (WAC-IX), 3-stage reverse osmosis (RO), forced circulation brine crystalliser

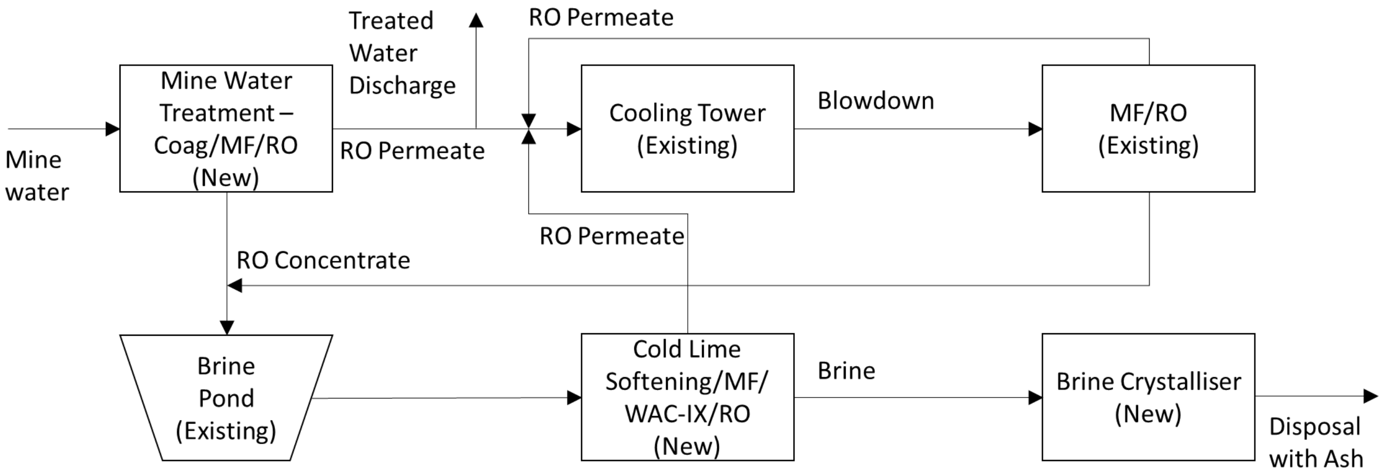

Figure 5: Simplified Block Flow Diagram of the New PSWTP

This process, as evaluated by GHD with the assistance of EVS: Water and in collaboration with our client, has advantages in terms of allowing continued operation of the existing brine concentrators during construction, reduction of energy requirements due to the use of a softening and membrane concentration process (i.e. cold lime softening, WAC-IX and RO) and change over to sodium carbonate brine chemistry. The change to sodium carbonate chemistry is advantageous for brine co-disposal with ash due to the higher pH further reducing the mobility of potential contaminants within the ash repository [4, 5]. Disadvantages include significant changes to the existing process and the chemistry requiring a steep learning curve in terms of operation and leading to potential risks of interruption to PS operations during the chemistry transition.

III. CONCLUSIONS

This paper demonstrates the benefits of utilizing a "digital twin" software for the operations, design and commissioning phases of complex desalination and brine management systems involving numerous feed streams, process units and recycle streams. The EVS: Water software allowed rapid assessment of multiple designs via lifecycle cost assessment and ultimately project cost and delivery optimization and therefore project de-risking.

Utilizing the software resulted in an improved outcome for our client via savings of costs through the confirmed benefit of moving to a different chemistry regime (i.e. sulphate-based chemistry to carbonate-based chemistry), allowed more efficient vendor engagement and ensured that a large number of options were assessed for the benefit of all stakeholders (e.g. the coal mine, the power station, downstream water users and improved regulator engagement).

Due to the success of the "design digital twin", discussions are taking place regarding its transfer to the operations phase where predictive analytics and forecasting will be employed to ensure compliance and operations optimization.

VI. REFERENCES

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