A Selective Hardness, Metals, and Sulphate Removal Plant Using an Innovative Approach to Ion Exchange

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SUMMARY

This paper details a 2MLD ion exchange water treatment plant which selectively removes arsenic, antimony, iron, hardness, and sulphate from mining water; designed to meet environmental quality indicators such as sulphates. The client, Fosterville Gold Mine Pty Ltd, is owned by Kirkland Lake Gold and is one of the world's highest grade gold mines. The site located near Melbourne, Australia had identified a risk of reduced mine water storage capacity due to surface run-off and increased sulphate rich dewatering of the underground mine at depth. Clean TeQ Water carried out the project management, process design, procurement, and commissioning for the plant, which was handed over in August 2020.

The plant uses Clean TeQ Water's CIF® (Continuous Ionic Filtration) technology, which uses both ion exchange chemistry and filtration to remove pollutants from water. Unlike conventional batch ion exchange (IX) systems which use static beds, CIF® uses a moving packed bed of ion exchange resin which provides the best kinetics (chemistry) and the ability to filter solids when needed. Unlike fixed bed batch ion exchange systems that move the water around, CIF uses air to move the resin around. There is a dedicated vessel for adsorption and a dedicated vessel for desorption which does away with the convention lead-lead-lag type batch ion exchange approach to provide robustness and a smaller footprint. Two CIF® modules were placed in series for the plant to form a DESALX® system. The first stage module removes multivalent cations (such as calcium, magnesium, and metals such as manganese and iron), and the second stage module removes multivalent anions (such as sulphate). During the treatment process, monovalent ions such as sodium and chloride pass through, and a gypsum-based brine is created which can be sent to existing lime precipitation systems for a zero liquid discharge solution.

The water produced by the DESALX® plant meets the performance criteria for sulphate, iron, arsenic, and antimony, with chemical usage below the design criteria. It also meets the quality indicators required by the State Environment Protection Policy for Waters; thereby potentially allowing the mine site to consider other water management best practices, such as Managed Aquifer Recharge (MAR). The MAR provides a good outcome to make this excess water available to future requirements and generations after the mine is closed.

1. Introduction

1.1. Mine Water Treatment

Mine water has some unique challenges, often being high in suspended solids, metals, high or low pH, and with varying water flowrates and qualities (Brown, Barley and Wood 2002). One of the most difficult mine water challenges is dealing with the brine left over from physical separation processes, such as reverse osmosis (RO). RO has long been accepted as the technology of choice for mine water treatment, however it is susceptible to scaling and fouling due to cations such as calcium, magnesium, strontium, barium, aluminium, iron, or manganese, reacting with anions such as sulphate, phosphate, carbonate, or silicate in the feed. Due to the presence of these species, water recovery is often limited to below 70% during treatment, producing a large volume of difficult to manage saline brine. The resultant brine ponds to manage this brine are often expensive to install, require large surface areas, can be unsightly, and are very expensive to decommission. In addition to low recovery, scaling and fouling results in low RO membrane life, increased costs due to membrane replacement, and additional downtime and chemical use due to CIP (Clean-In-Place).

1.2. Continuous Ion Exchange

Clean TeQ Water's CIF® (Continuous Ionic Filtration) technology is well suited to treat difficult mine water streams. It can selectively remove contaminants through ion exchange while simultaneously performing physical filtration, tolerating suspended solids in the feed, and allowing for cheaper reagents such as sulphuric acid and lime to be used. Since the resin is moved around, saturated conditions in the water don't present the same the issues that batch ion exchange cannot handle/tolerate. These usually cannot be used in conventional batch ion exchange systems since the precipitates that form cause the system to block up during desorption. CIF® is also more resistant to resin bed fouling compared to conventional ion exchange approaches since the ion exchange resin in periodically moved around the system. Higher removal efficiencies are also achieved in CIF® due to the counter-current movement between the feed solution and ion exchange resin. The system can also tolerate up to 150 mg/L of suspended solids in the feed and perform physical filtration if required.

In CIF®, ion exchange resin is continuously moved around the system for regeneration. Water treatment occurs in the adsorption column, which uses a moving packed bed of ion exchange resin. It can be likened to the continuous sand filtration process; however, the ion exchange resin continuously removes dissolved ions through ion exchange while simultaneously filtering solids if required. CIF® consists of a series of vertical columns, as seen in Figure 1, with one column treating the water, and the rest used to recondition the ion exchange resin as part of a continuous process.

1.3. DESALX® Technology

DESALX® combines two CIF® units in series, the first removes the divalent cations such as calcium, magnesium, and other metals, before the second stage removes multivalent anions such as sulphate. In the first stage, the strong acid cation resin in hydrogen form is regenerated using sulphuric acid, and in the second stage the weak base anion resin in free base form is regenerated using lime.

When calcium sulphate (gypsum) precipitation is expected during desorption, an additional agitated desorption column is used in the process to prevent blocking up. This column uses either physical mixing or air agitation in a pachuca column depending on the characteristics of the water. The gypsum formed is removed with the spent solution during the resin transfer step. This is a process that cannot be achieved with batch IX processes as solids block the system.

DESALX® selectively removes the multi-valent cation and anions, letting the majority of monovalent anions through. Using sulphuric acid and lime as reagents creates gypsum in both stages, allowing DESALX® brine to be dewatered or combined with high density sludge (HDS) systems to achieve a zero liquid discharge outcome.

DESALX® can be used to treat a variety of mine water types, including acid mine drainage, pit water, surface runoff, tailings water, excess water from underground mines, and process water. Hardness, metals, and sulphate are commonly present in mining wastewater as a result of processing, acid mine drainage, or the use of sulphuric acid on site.

1.4. DESALX® Pilots in South America

The DESALX® technology has previously been piloted at Barrick's Lagunas Norte site in Peru, and at Mina Invierno in Chile to test its sulphate removal capability. For Lagunas Norte, the site pilot treated a number of sulphate rich acid mine drainage streams and performed metals, sulphate, and TDS reduction. Feed streams also included RO brine and HDS clarifier overflow. The water was passed through the pilot plant either one, two, or three times depending on the sulphate removal extent required. A photo of the piloting equipment can be seen in Figure 2, and a table showing the results can be seen in Table 1.

At Mina Invierno, DESALX® was piloted to test the treatment efficiency of water from different sources on the mine. The primary objectives were to demonstrate the sulphate removal ability, and to determine whether the strict environmental discharge limits for the site could be met. For the full-scale plant, the gypsum-based brine produced by DESALX can be sent to the existing HDS lime precipitation system on site, creating a zero liquid discharge solution. The solids content leaving the desorption column was measured to determine the extent of gypsum precipitation during ion exchange resin regeneration. A render of the proposed full-scale plant can be seen in Figure 3, and a table of the pilot results can be seen in Table 2.

2. Water Treatment Plant for the Fosterville Gold Mine

2.1. Fosterville Gold Mine

The Fosterville gold mine is located two hours north of Melbourne, Australia. It is the state's largest gold producer and one of the highest-grade gold mines in the world. The underground mine has been in operation since 2005.

When mining started in 2005 there was an excess water problem. The excess water was initially stored in some of the old open cut pits, and as these started to fill up, the thinking moved to reinjecting the water back into the aquifer. The technology that first came to mind to reach the required quality for managed aquifer reinjection (MAR) was ultrafiltration (UF) followed by RO, however this approach was expected to only achieve 50% water recovery. Initial modelling of the system showed DESALX® offered lower operating cost and higher water recovery, reducing the volume of brine that would need to be stored on site. The ability to send the softened water to a reverse osmosis plant for polishing was also identified, achieving higher RO recovery, and reducing the potable water makeup required for the mine's processing circuits.

The management at Kirkland Lake Gold (now Agnico Eagle) saw the benefits that the DESALX® technology would bring and decided to proceed with the technology, making it the largest DESALX® installation to date. The contract was awarded in 2017 and design work and construction followed shortly after.

2.2. Design Phase

The flowsheet for Clean TeQ Water's scope can be seen in Figure 4, and a labelled render of the plant layout can be seen in Figure 5. The plant includes a ferric chloride precipitation system to reduce the arsenic and antimony in the feed water. The treated water then moves to the first stage of DESALX®, where cations such as iron, calcium, and magnesium are removed. The sulphate is then removed from the water in the second stage. Two modules consisting of adsorption, desorption and wash columns operate in parallel to accommodate the 2MLD flowrate.

2.2. Project Schedule

The project kicked off at the start of 2018 and included lab trials, a lab pilot, and a site pilot to optimize the design and verify the performance. Long lead items were ordered, and the fabrication of equipment continued in 2018. The final HAZOP / process review was completed, and construction finished in October 2019. Commissioning was completed in December 2019, with ongoing operations troubleshooting and support continuing, and the RO system being ramped up. Final handover of the plant occurred in August 2020. A photo of the completed plant can be seen in Figure 6.

2.2. Plant Performance

The design basis and performance of the plant is summarized in Table 3. The water produced by the DESALX® plant meets the performance criteria and the quality indicators required by the State Environment Protection Policy for Waters, making it of suitable quality where it can be reinjected into the aquifer. As at 15 April 2022 the mine is still a zero liquid discharge site, and water is sent to the downstream RO for process water reuse. The downstream RO is achieving a recovery of 85% given the reduced scaling risks and lower turbidity. The plant's resin flowrates can be adjusted if needed to increase and decrease the cation and anion removal extents.

2.2. Keys to Successful Project Delivery

Several factors contributed to the successful delivery of the project, including the:

- Strong relationship formed between Clean TeQ Water and all parties involved
- Openness to using new ion exchange technology for mine water treatment
- Two rounds of piloting (one on site and one in the lab) for the smooth scale up, and optimization of design parameters
- Collaborative engagement with the client and contractor to seamlessly integrate the plant with existing operations
- On the job training of operators allowing smooth operation beyond commissioning
- Remote access to the PLC allowing for quick assistance when required during the early days of the plant.

2.2. Lessons Learned

Being the first large scale installation of the technology for mine water treatment there were a number of lessons learned:

- A better understanding of the hydraulics of moving large resin beds between columns was obtained, and the forces that are exerted on various components.
- The design of the resin screens was improved early in the project following deeper collaboration with suppliers.
- Improvements to arsenic and antimony sludge management using seeding and recycling to further reduce footprint and maintenance requirements.
- Increasing the size of buffer storage between DESALX® and RO to ensure easy operation at higher capacities.

Looking ahead, Clean TeQ Water has already started:

- Further reducing acid consumption to near molar stoichiometric ratio
- Improving the in-column aeration design to optimize the air usage when resin is transferred

•Implementing high velocity columns to allow for a more compact system

3. Conclusions

The 2 MLD DESALX® plant at the Fosterville Gold Mine was successfully delivered to assist the client manage their excess water. The water produced by the DESALX® plant meets the performance criteria for sulphate, iron, arsenic, and antimony, meeting the quality indicators required by the State Environment Protection Policy for Waters and allowing the mine site to consider managed aquifer recharge. Conventional batch ion exchange systems have often struggled to find a place in mine water flowsheets, particularly when suspended solids and the risk of precipitation are present. This plant confirms Clean TeQ Water's moving bed technology as a viable and beneficial ion exchange based mine water treatment method.

References

Brown, M, B Barley, and H Wood. 2002. Minewater Treatment: Technology, Application and Policy. London: IWA Publishing.

Tables and Figures

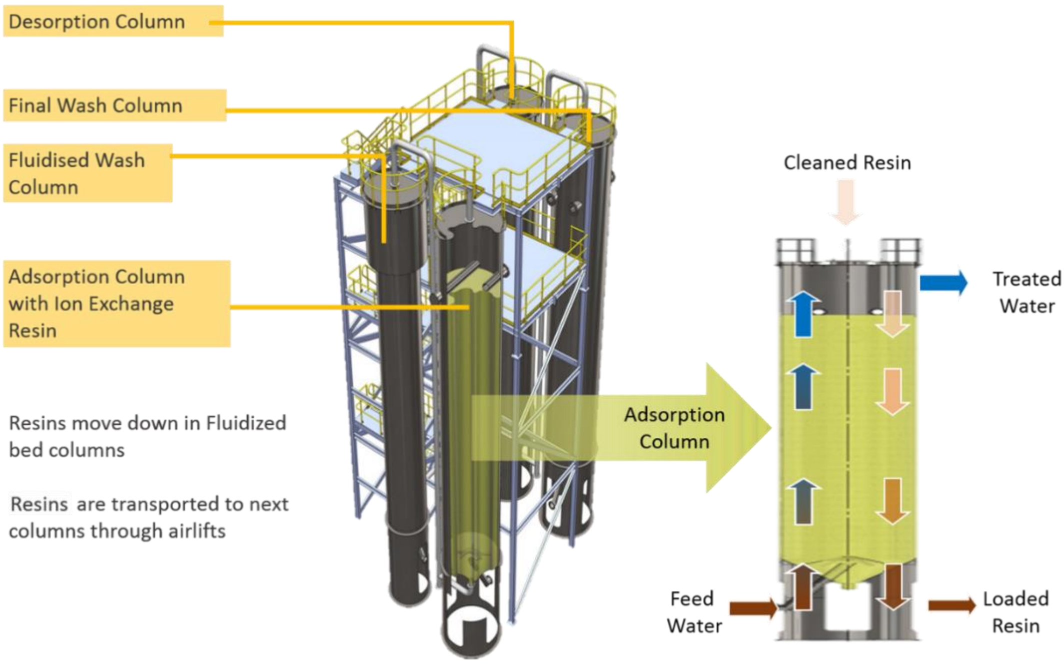

Figure 1. Diagram of a Typical CIF® System

Figure 2. DESALX Site piloting setup, Lagunas Norte, Peru

Table 1. Results from DESALX piloting, Lagunas Norte, Peru

Species	Units	Feed (sediment)	Treated (2 pass)	Feed (AMD)	Treated (3-pass)	Feed (RO Brine)	Treated (1-pass)	Feed (HDS overflow)	Treated (1-pass)
Sulphate	mg/L	3077	462.5	4490	19.62	6264	1920	1258	21.32
TDS	mg/L	3620	637	5334	42	8665	2815	1627	41
Aluminium	mg/L	108.8	0.001	162.3	0.142	0.001	0.001	1.432	0.522
Arsenic	mg/L	0.36	0.004	0.538	0	0.029	0	0	0.001
Barium	mg/L	0.019	0	0.012	0	0.117	0.004	0.025	0.001
Beryllium	mg/L	0.021	0	0.049	0	0	0	0	0
Cadmium	mg/L	0.074	0	0.139	0	0	0	0	0
Calcium	mg/L	128.8	10.31	179.7	5.4	945.4	49.03	327.1	3.84
Cobalt	mg/L	0.351	0	0.628	0	0.606	0.035	0.003	0.001
Copper	mg/L	23.9	0.004	28.78	0.013	0.299	0.008	0.007	0.037
Chromium	mg/L	0.041	0	0.078	0	0	0	0	0.001
Strontium	mg/L	0.901	0.023	1.959	0.01	1.972	0.272	0.759	0.008
Phosphorus	mg/L	0.941	0.004	1.475	0.004	0.901	0.062	0.004	0.004
Iron	mg/L	189.9	0.001	332.7	0.083	0.001	0.001	0.001	0.162
Lithium	mg/L	0.052	0.064	0.119	0.001	0.001	0.047	0.001	0.004
Magnesium	mg/L	30.41	25.8	45.49	4.092	2.909	109.4	16.11	3.813
Manganese	mg/L	10.7	0.002	17.66	0.03	0.097	0.009	0.847	0.05
Nickel	mg/L	0.483	0	1.194	0	0.057	0	0	0.002
Nitrate	mg/L	14.34	7.83	23.48	1.43	88.21	73.86	10.13	1.67
Lead	mg/L	0.041	0	0.007	0	0	0	0	0
Potassium	mg/L	0.455	3.618	0.11	0.295	56.31	6.526	1.191	0.463
Selenium	mg/L	0.025	0	0.047	0	0.719	0.319	0.004	0
Silicon	mg/L	17.86	13.1	25.2	4.39	5.53	3.34	0.02	1.03
Sodium	mg/L	10.59	114.1	14.14	6.29	1298	651.8	11.28	8.16
Uranium	mg/L	0.01	0	0.024	0	0	0	0	0
Zinc	mg/L	4.02	0.003	7.676	0.003	0.003	0.003	0.003	0.03
pH	-	2.75	10.2	2.75	10.25	9.21	10.2	8.98	10.2

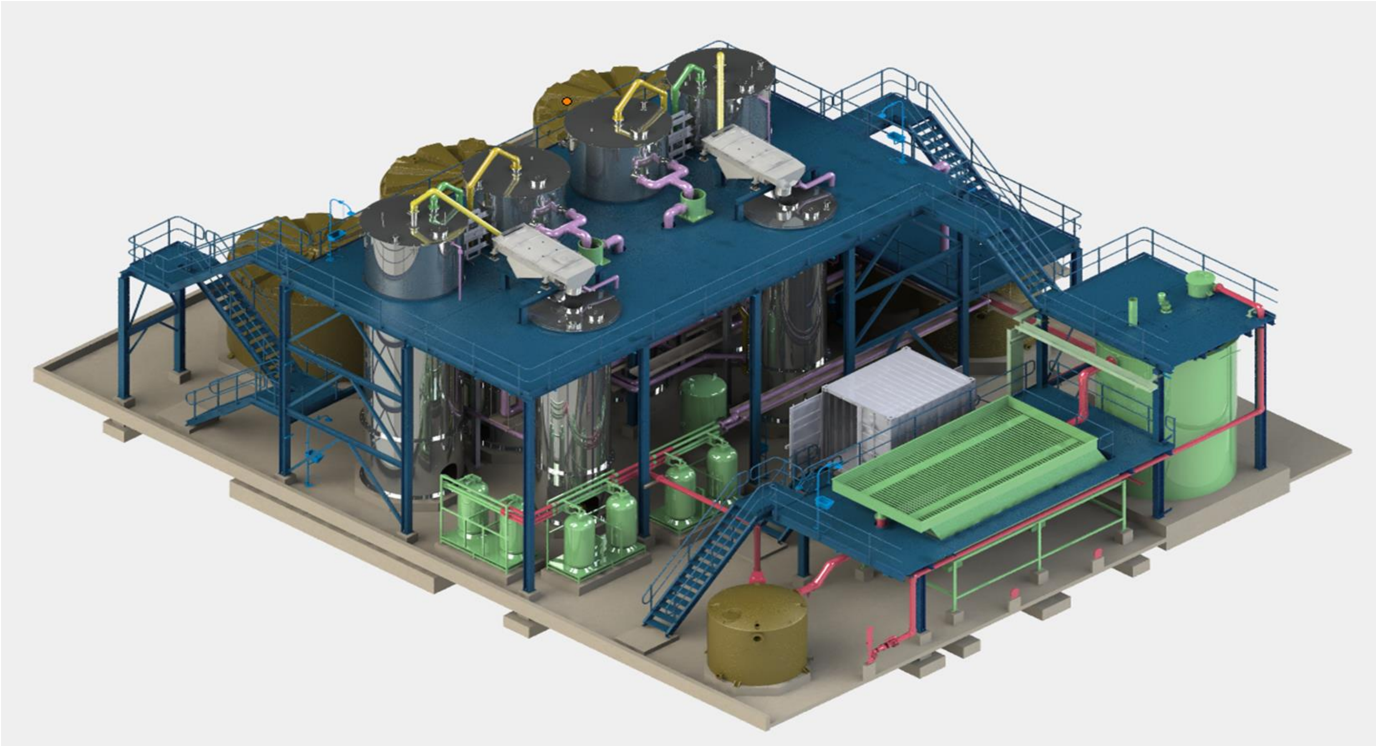

Figure 3. Render of proposed full-scale plant, Mina Invierno in Chile

Table 2. Results from DESALX piloting at Mina Invierno, Chile

Species	Unit	Feed 1	Treated 1	Feed 2	Treated 2	Feed 3	Treated 3	Discharge Limit	Gypsum Solids
Sulphate	mg/L	410.33	0.64	288.72	4.06	461.55	3.3	78	22,011
Total Dissolved Solids	mg/L	1003	255	616	165.18	903	255.11	303	
Chloride	mg/L	16.97	16.63	17.49	16.42	59.09	64.4	-	78.27
pH	-	8.45	7.51	7.9	7.41	6.68	8.02	6 - 9	7
Total Suspended Solids	mg/L	9	<3.00	<3.00	<3.00	10	5	896	
Solids	wt. %								3.3
Total Alkalinity	mg/L	244	9	123	12	36	20	> 15	
Aluminium	mg/L	0.34	0.11	0.05	0.02	0.05	0.06	1.53	
Iron	mg/L	0.48	0.09	0.06	0.03	0.05	0.03	1.83	0.26
Manganese	mg/L	0.11	0.01	0.11	0.01	0.48	0.01	0.51	0.81
Magnesium	mg/L	18.32	1.47	12.9	1.48	19.35	1.68	-	753.95
Sodium	mg/L	206.3	138.88	122.95	95.77	125.99	122.28	-	7,462
Electroconductivity	µS/cm	1440	425	931	247.93	1342	425.18	429	

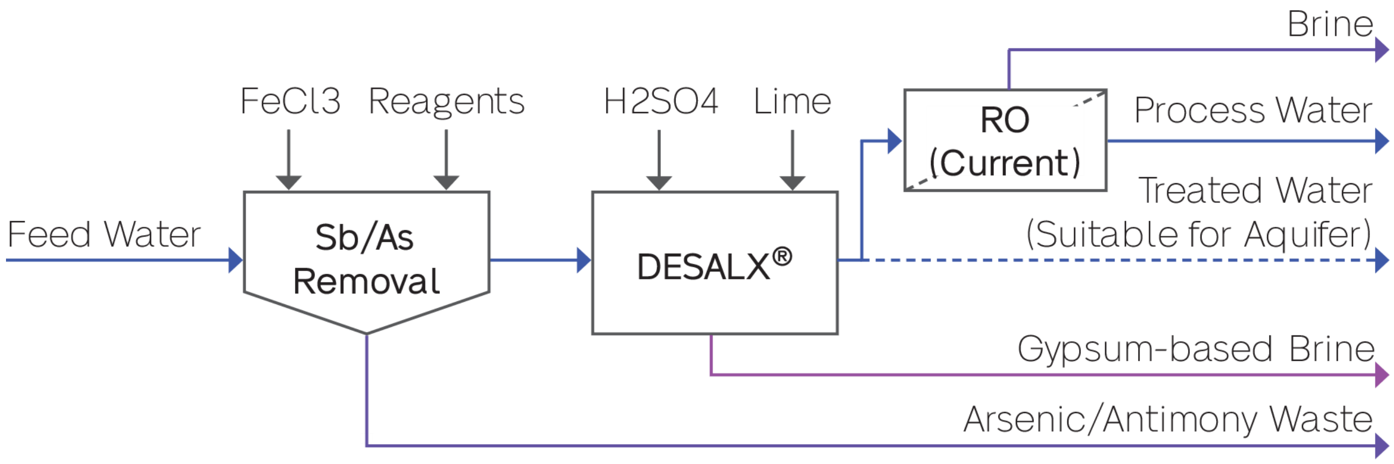

Figure 4. 2MLD Sulphate Removal Plant Flowsheet

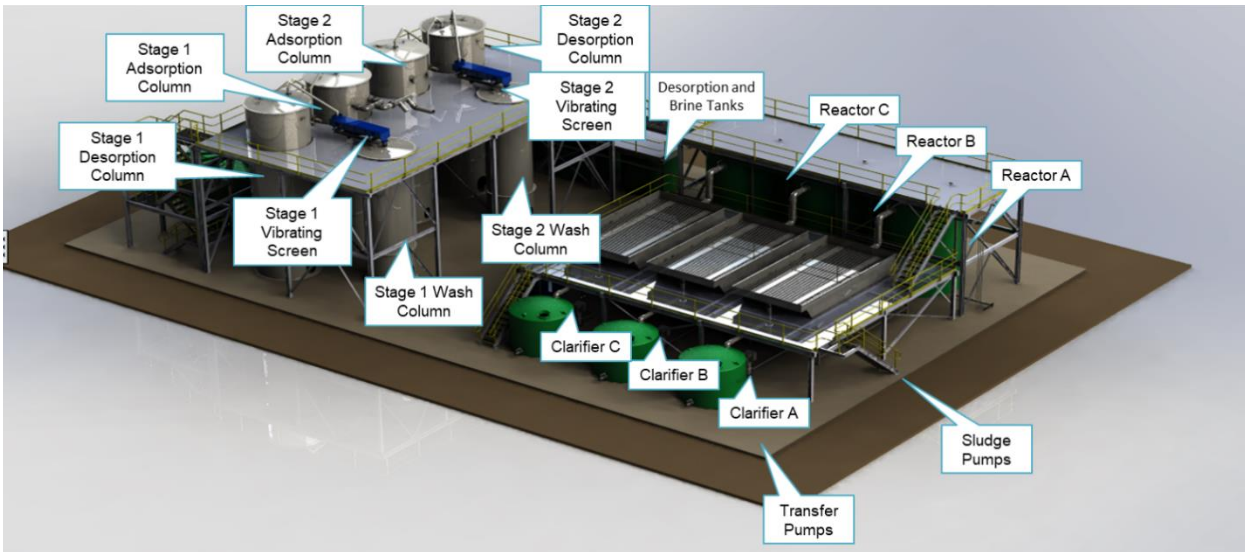

Figure 5. Layout of the Plant

Figure 6. Photo of the Completed Plant

Table 3. Design Basis and Plant Performance (bolded species indicate performance criteria).
Note: DESALX® can reduce sulphate to very low levels however this was not required by the client.

		Design Basis			Plant Performance
Species	**Unit**	**Before Precipitation**	**Before DESALX®**	**After DESALX®**	**After DESALX®**
Total Dissolved Solids	ppm	7,400	7,400	5,848	5,410
Calcium	ppm	300	300	85	107
Magnesium	ppm	321	321	96	223
Sulphate	**ppm**	**1515**	**1515**	**1000**	**790**
Iron (soluble)	**ppm**	**1**	**5**	**0.1**	**0.05**
Total Arsenic (soluble)	**ppm**	**0.5**	**0.03**	**0.03**	**0.001**
Antimony (soluble)	**ppm**	**13**	**0.05**	**0.05**	**0.025**

Author Profiles

Sivan Iswaran is the Business Development Manager for Clean TeQ Water. He has over 20 years' experience in Australia and Dubai working for companies including BHP, Nyrstar, WSP, Cleanaway, and Orica. Sivan has a Bachelor's Degree in Chemical Engineering from the University of Adelaide, and a Master of Business Administration degree from the University of New South Wales.

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