Appendix A

UNSW

DR STUART KHAN
SENIOR LECTURER
School of Civil
and Environmental Engineering

26 October, 2012

National Parks Association of NSW
Macarthur Branch

PO Box 792
Campbelltown NSW 2560
AUSTRALIA

To whom it may concern,

RE: Expert Report: Water Management Options for West Cliff Colliery, EPL 2504

I have considered the request for advice on this matter as outlined in a letter to me from EDO NSW, dated 16th October 2012. I am pleased to provide the advice outlined below as my response to that request. As I have understood it, the advice requested from me is to identify realistic options for treatment of a coal mine wastewater prior to discharge to the aquatic environment.

I received various accompanying background documents from EDO NSW including a draft copy of the report "Investigation of Water Quality in the Georges River: Focus on the influence of Brennans Creek Coalmine Wastewater Discharge" by Dr Ian Wright. I have now read this draft report in detail and have based my advice on the water quality issues described therein.

Dr Wright's report indicates that "…Brennans Creek and Georges River, in the Appin to Airds area, suffered water quality impairment as a direct consequence of the inflow of Brennans Creek into the Georges River" and that "the majority of flow in Brennans Ck is from a coalmine wastewater discharge…".

Dr Wright's report further indicates that "the water quality contaminants of most concern in the upper Georges River and Brennans Creek are salt, measured as electrical conductivity, and its constituent major anions and cations and heavy-metals (Aluminium, Arsenic, Copper, Nickel, Zinc, and Lead)". However, the report also identified considerably elevated pH and turbidity levels in Brennans Creek and downstream in the Georges River, both of which can have significant ecological impacts in aquatic systems.

Given the findings of Dr Wright's report, the advice that I have prepared is focused on treatment processes which may be considered for the effective treatment of inorganic anions, cations and heavy metals (Eg. Aluminium, Arsenic, Copper, Nickel, Zinc, and Lead) as well as pH and turbidity.

Since a wide variety of approaches is commonly used to treat various contaminants and various types of wastewaters, I have provided my advice as a short appraisal of the various approaches used.

ADJUSTMENT OF pH CONDITIONS

Adjustment of water pH can be achieved relatively simply and with minimal expense. Elevated pH can be neutralised by the careful addition of suitable acidic substances. This could include a range of week and strong acids, as well chemical mixtures designed to provide a buffering (pH stabilising) effect. While the approach is relatively simple and inexpensive, initial testing and on-going monitoring would be required to properly tailor the approach to the specific water requiring treatment.

However, it should be noted that pH adjustment by chemical addition will have little or no effect on most of the dissolved inorganic anions and cations of concern.

Furthermore, pH adjustment may exacerbate turbidity levels due to precipitation of some substances or may lead to elevated dissolved concentrations of some substances due to the solubilisation of some suspended particulates. It may be possible to incorporate careful pH adjustment with granular filtration or membrane filtration (see below) to achieve some level of removal of some key inorganic contaminants. However, careful process assessment and optimisation would be required to achieve this.

CHEMICAL OXIDATION AND REDUCTION

In water treatment, chemical oxidation and reduction processes are used for the treatment of specific inorganic and organic species. Some inorganic metal species (most commonly iron and manganese) may be oxidised to insoluble forms and subsequently removed by precipitation. These processes may also oxidise odorous sulphide and break down metal-organic complexes.

However, chemical oxidation will not lead to the precipitation of most of the inorganic anions and cations of concern in the current case and is also not effective for already-oxidised forms of iron or manganese. It is unlikely to produce a reduction in electrical conductivity (and may in-fact lead to an increase).

Conventional oxidation processes use such oxidants as chlorine, chlorine dioxide, hydrogen peroxide, or potassium permanganate. These processes also tend to involve reactions with dissolved organic matter and may lead to the formation of byproducts. Chlorine-based oxidants commonly lead to the formation of chlorinated byproducts, some of which are known to be toxic and/or environmentally persistent.

COAGULATION AND FLOCCULATION

Coagulation and flocculation are commonly used in water treatment for the removal of small suspended and colloidal particulate matter as well as some fraction of dissolved organic matter. Chemical coagulants such as alum, ferric chloride or ferric sulphate are added to the water where they are rapidly hydrolysed forming insoluble precipitates. These precipitates destabilise particle suspensions by adsorbing to surfaces and neutralising surface charges. Flocculation involves gentle mixing to cause particle aggregation which facilitates sedimentation and removal.

These processes may be used to treat elevated turbidity levels in water. However, they are generally not effective for the removal of dissolved inorganic anions and cations.

GRANULAR FILTRATION
Filtration using granular material such as sand or charcoal is widely used for removing particles from water. This is an effective and relatively inexpensive process for treating elevated turbidity. However, is not effective for removing highly soluble inorganic anions and cations.

MEMBRANE FILTRATION – INCLUDING REVERSE OSMOSIS
Synthetic (polymeric) membranes are increasingly being used in a diverse range of water treatment applications. Four general types of pressure-driven membranes are currently widely used: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The distinction between these types of membranes is somewhat arbitrary and subject to differing interpretations, but the membranes are loosely identified by the types of materials rejected, operating pressures, and nominal pore size.

MF and UF membranes are relatively porous and only really effective for the removal of suspended particulate and colloidal materials. Accordingly, these are employed for the treatment of particles, sediment, and algae. They are increasingly used as an alternative to granular filtration for treating elevated turbidity.

NF membranes can be highly effective for the removal of divalent cations such as Ca^{2+} and Mg^{2+} and therefore are increasingly widely used in water softening plants. NF is likely to be useful for the removal of some of the specific inorganic ions (eg. Aluminium) identified in Dr Wright's report.

However only RO membranes are effective for the removal of a wider range of monovalent and non-charged inorganic species. Accordingly, RO is likely to be required in order to achieve a significant reduction in electrical conductivity by membrane filtration.

Reverse osmosis (and to some degree nanofiltration) can be used to achieve a significant reduction in the concentrations of most ionic cations and anions. Precise performance depends on membrane selection, process design and operational conditions, but conductivity removal of 90-99% can be routinely achieved.
The primary disadvantages of using high pressure membranes such as RO for water treatment generally include relatively high capital and operational costs and relatively high energy requirements (hence carbon footprint).

Furthermore, these processes also produce a concentrated waste stream known as a 'concentrate' or 'brine'. While the volume of this concentrate may be significantly reduced (70-90%) from the original wastewater volume, it must ultimately still be disposed of. This concentrate disposal often presents a new suite of challenges. The relevant issues and the broad range of approaches adopted have previously been reviewed in detail by myself and co-authors. I have attached a copy of this review (titled "Management of Concentrated Waste Streams from High-Pressure Membrane Water Treatment Systems" by Khan et al, 2009) for your further information on this topic.

ADSORPTION

Some inorganic water contaminants such as arsenic and lead can be removed from water by adsorption to a solid material. The primary adsorbent materials used in water treatment are powdered activated carbon (PAC) and granular activated carbon (GAC). PAC is added directly to the water and is usually removed by sedimentation or filtration. GAC is most commonly operated as a fixed filtration bed, through which the water is drawn under gravity or with assisted head pressure.

While there are a number of mechanisms involved, the GAC and PAC adsorption processes rely upon a relatively high 'hydrophobicity' of the contaminants to be adsorbed. Therefore, while they can be used for treatment of some forms of arsenic and some heavy metals, they are not generally effective for most inorganic anions and cations. They would be expected to have negligible impact on the overall electrical conductivity of most wastewaters.

Furthermore, adsorption materials require intermittent regeneration and ultimate disposal. These processes produce waste streams, which will contain any removed arsenic or heavy metal substances.

ION EXCHANGE

Ion exchange is a process used in water treatment to remove dissolved ionic constituents that can cause aesthetic, health or ecological impacts. It is considered to be a non-conventional process because it is not widely used in large-scale plants. In drinking water applications, ion exchange is primarily used for water softening and demineralisation (eg, removal of Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}) or to target specific local problem chemicals such as barium, radium, arsenic, perchlorate and chromate.

Synthetic polymeric resins are most commonly used for ion exchange water treatment processes. Such resins can be designed to selectively remove either cations or anions. The resins can be regenerated using various salt or acid solutions, depending on the particular application. Resins known as 'strong acid exchangers' and 'strong base exchangers' can be used to exchange a wide variety of ionic substances with hydrogen ions (H^{+}) or hydroxide ions (OH^{-}), respectively. These hydrogen ions or hydroxide ions may be subsequently neutralised by further pH adjustment.

While ion exchange is useful for targeting specific problem substances, it remains ultimately an 'exchange' process where one chemical species is replaced by another. Even where exchange takes place with neutralisable hydrogen ions or hydroxide ions, there will always be counter-ions associated with the neutralisation process, such that the water will not be truly 'purified'. Furthermore, like adsorption processes, ion exchange resins require regeneration, leading to concentrated waste streams, which must be ultimately disposed of.

CONCLUSION

The summary provided here describes the most obvious approaches to water treatment that may be variously considered to target some of the water contaminants highlighted in Dr Wright's report. There are other common processes, which are clearly not suitable (such as biological treatment and air stripping), which have not been described. There are also a number of 'emerging' technologies (eg, forward osmosis and membrane distillation), which may provide great opportunities in the future, but are generally not considered to be ready for industrial application at this time.

It is my assessment that the only currently available technology with the capacity to significantly treat all of the identified inorganic anions, cations and heavy metals (Eg. Aluminium, Arsenic, Copper, Nickel, Zinc, and Lead) and the overall electrical conductivity is reverse osmosis. This would normally need to be applied in conjunction with appropriate pre-treatment, which may include filtration (eg, microfiltration) and pH adjustment. Final pH adjustment and/or remineralisation subsequent to reverse osmosis treatment may also be necessary to achieve optimal final water quality.

As a rule, water treatment processes are best designed with close attention to the specific characteristics of the water to be treated and it is therefore difficult to generalise further without detailed assessment of the particular case. Comprehensive laboratory analysis and validation of a pilot plant performance are both recommended prior to the identification of the most suitable process train and operational conditions.

While reverse osmosis can certainly achieve very high water quality, I wish to emphasise the importance of also carefully considering the issues associated with the management and disposal of the concentrated waste streams produced by these high pressure membranes. I trust that the attached literature review will assist in that consideration.

I hope you will find the advice that I have provided to be useful. I would be very happy to provide any clarification or further information that you may require.

Yours sincerely,

Dr Stuart Khan

Senior Lecturer,
School of Civil & Environmental Engineering.

Phone: (02) 93855070
Email: s.khan@unsw.edu.au

ATTACHMENT:

Khan SJ, Murchland D, Rhodes M and Waite TD (2009) Management of concentrated waste streams from high pressure membrane water treatment systems. *Critical Reviews in Environmental Science & Technology*, **39**(5) 367-415.