PAPER 7

COEGA KOP BIOFILTRATION PLANT

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ABSTRACT

The recent droughts around South Africa have highlighted the reality that the supply and availability of potable water is key to sustaining and growing the economy. Some studies have singled out shortages in water supply as one of the foremost threats to sustainable business today. With ongoing climate change and abnormal rainfall and evaporation patterns, some water supply authorities are seeking to reduce their dependence on surface water (i.e. large dams) by developing ground water schemes as a supplementary source of supply.

The Nelson Mandela Bay Municipality (NMBM) has embarked on an endeavour to diversify and supplement its existing water supply schemes. NMBM appointed Aurecon to provide professional engineering services for planning, design, procurement documentation and construction administration for a scheme to abstract and treat water sourced from the Coega Kop well-field; located about 30 km North-East of Port Elizabeth, adjacent to the existing Coega Kop Reservoir.

This groundwater contains relatively high levels of dissolved iron and manganese, which must be removed to make the water acceptable for public supply. This is usually done by physicochemical means, but in certain instances, such as at Coega Kop, biofiltration provides an economic, sustainable and more reliable alternative. The Coega Kop scheme will thus include a 20 ML/d biofiltration plant; this will be the second plant of its kind in South Africa, with a capacity twice the size of its10 ML/d predecessor.

A rigorous, collaborative and innovative design process, involving clients, engineers, geohydrologists, architects, 3D software modellers, virtual reality (VR) programmers and other professionals was undertaken to produce a well-integrated and operator centric design. The use of 3D modelling was used as a design collaboration tool for the various engineering and architectural disciplines. This was later built into a VR model, allowing technical and non-technical stakeholders to experience first-hand a lifelike representation of the plant before any construction activities commence. More than just being something nice to look at, the VR model serves as a tool to:

- discuss and obtain input and preferences from stakeholders such as future maintenance and operations staff;
- refine the design;
- undertake with clash detection;
- ensure adequate allowance for maintenance, dismantling, access, overhead lifting and so-on;
- allow for improvements in constructability considerations;
- aid the construction team in their planning and envisaging of the required product;
- facilitate early operator training; and
- explain the project to those providing funding.

Going forward it is envisaged that the VR model will be used during educational sessions or seminars at schools and tertiary institutions to raise more interest in engineering (i.e. maths and science) amongst young learners.

This paper focusses on the journey of learning to use 3D and VR modelling as a collaborative tool for planning, design, construction and future promotion of the proposed new water supply scheme and in particular the biofiltration plant.

INTRODUCTION

Background to water supply in Port Elizabeth

The sustainability of the water supply to the Nelson Mandela Bay Municipality (NMBM) has been regularly threatened for the past century through the combined impacts of increasing demands and potential reduction in the available yield from some of the existing surface water options. For this reason the NMBM need to consider additional sources to augment their supply. Options that have been considered include water demand management, river basin transfer schemes, desalination, reuse of wastewater and groundwater use.

Background to ground water exploration

Studies have been undertaken in recent years to establish the feasibility and conceptual plan of a groundwater supply scheme for the Nelson Mandela Bay Municipality (NMBM). Based on these studies, a decision was taken during 2015 to exploit groundwater resources from five boreholes in the Coega Kop Wellfield with an expected sustainable yield of up to 20 Mℓ/d.

These investigations also demonstrated that the borehole water is of good quality, but contains elevated concentrations of soluble iron and manganese. Typically this could be treated using physiochemical methods, however in this instance biofiltration is appropriate. Subsequentlyit was recommended that a biological filtration process would be the most suitable treatment process to deal with these high iron and manganese levels. A treatment plant incorporating this process together with stabilisation and disinfection would be required to produce acceptable water quality and achieve compliance with the South African National Standards for potable water (SANS 241:2015).

Details of the Wellfield

The Groot Winterhoek – Coega Ridge Table Mountain Group Aquifer is a fractured-rock aquifer which primarily consists of the Peninsula Formation of the Table Mountain Group (TMG). The geological structure of the aquifer is dominated by the Coega Fault System, a collection of semi-parallel faults of varying lengths and offsets, which runs along the entire length of the aquifer. Water from the aquifer gets trapped in and travels along fractures in the fault system and is under high pressure in the eastern reach of the fault.

The location of the well field near Coega Kop is ideal because the TMG outcrops at Coega Kop. The relatively shallow depth of the TMG makes the fault system easier to target from the surface for extracting groundwater. The location is also on municipal property which for obvious reasons simplifies legal matters.

A series of exploratory boreholes at Coega Kop have confirmed the feasibility of the scheme and established the expected yield. The production boreholes will be drilled through two formations to reach their target (the fault zone):

1) The Non-Peninsula Formation
2) The Peninsula Formation

The Non-Peninsula formation consists of the top layers of calcrete, clay, mud stone and sand stone, which confines the Peninsula Formation. This formation is between ±50 m and ±180 m thick at Coega Kop.

The Peninsula Formation is situated below the Non-Peninsula Formation and consists of quartzite and quartzitic conglomerates. This formation is considerably harder than the Non-Peninsula Formation and more challenging to drill through. The Coega Fault System, which the production boreholes are targeting, is situated in the Peninsula Formation.

It is important to note that this water supply is independent of drought periods as the water in the wellfield operates on much longer geohydrological water cycles.

DESIGN

Characterisation of the Coega Kop wellfield

The Coega Kop Wellfield water scheme has been designed for a maximum abstraction capacity of 20 Mℓ/d of groundwater from five boreholes. For practical purposes of equipment selection a turn-down minimum flow of 5 Ml/d is allowed.

The five boreholes will be equipped with pumping systems. Interconnecting pipework will feed the raw ground water to the water treatment plant (WTP). Once treated the water will be pumped to the existing Coega Kop reservoir.

The raw water quality adopted for the design is informed by results from samples taken between 2015 and 2016, with some allowance for uncertainty in results.The adopted basis assumes the following:

1) Water quality results of samples taken from temporarily accessible exploratory boreholes are suitable to serve as a proxy for the production boreholes which have not yet been drilled.
2) A conservative approach should be adopted, allowing for the following:
    a) Design values should be based on maximum concentrations measured
    b) A worst-case level of metal dissolution (>95%) should be considered

Based on the water characteristics listed in Table 1 the treatment scheme requires unit processes for adequate removal of particulates (turbidity and particulate aluminium), as well as for oxidation of soluble iron and manganese, and removal of the iron and manganese precipitate.

The raw water concentrations of iron and manganese are within the reference range for biological treatment using simultaneous oxidation/filtration on a silica sand media filter (Sharma, Petrusevski, & Schippers, 2005; Mouchet, 1992), but indicate much higher concentrations of dissolved manganese than what has typically been observed at other biological filtration plants globally, with the notable exception of the Preekstoel Biofilter which has successfully removed manganese in concentrations in the range of 2 mgMn/ℓ to 5 mgMn/ℓ (du Toit, et al 2015).

The low pH and low calcium carbonate precipitate also requires treatment processes to stabilise the treated water to reduce risks of aggressive action on downstream cementitious infrastructure.

While the water is sourced from a deep underground aquifer, and is not expected to contain pathogenic microbial organisms, provision has been made for disinfecting with a residual disinfectant to protect the water from downstream contamination in the distribution network.

Process design

The proposed treatment process primarily involves biological oxidation and filtration of iron and manganese, stabilisation and disinfection of groundwater from the Coega Kop Wellfield. A brief description of the design for the WTP is as follows:

The raw water from the boreholes is combined in a mixing chamber at the water treatment works where the pH is controlled using caustic soda. The water flows to a bank of rapid gravity sand filters, where favourable pH and redox potential conditions are maintained to allow iron removing bacteria colonising the filter media to oxidise the soluble iron. The oxidised iron precipitate is filtered from the water in the filter media and the iron filtrate is collected and pumped to a second bank of rapid gravity sand

Table 1: Adopted water quality design basis

Parameter	Unit	Value	Approach	Safety factor	SANS 241 (2015) limit / target
Iron (total)	mg Fe/l	7.50	95th %ile	+15%	0.3
Iron (dissolved)	mg Fe/l	7.50	Worst Case		0.3
Iron (% dissolved)	%	95%	Worst Case		
Manganese (total)	mg Mn/l	2.50	95th %ile	+15%	0.1
Manganese (dissolved)	mg Mn/l	2.50	Worst Case		0.1
Manganese (% dissolved)	%	95%	Worst Case		
Total aluminium	mg Al/l	4.80	95th %ile	+15%	0.3
Dissolved aluminium	mg Al/l	2.70	95th %ile	+15%	0.3
Ammonia	mg N/l	0.10	95th %ile	+15%	1.5
Dissolved oxygen*	mg O_2/l	4.10	Average		
Turbidity	NTU	16.00	95th %ile	+15%	1
Suspended solids at 105°C	mg/l	5.5	95th %ile	+15%	
Total alkalinity	mg $CaCO_3$/l	43.00	Minimum	-15%	
pH at 25°C		5.50	Minimum	-15%	5 – 9.7
ORP	mV	8.00	Average		
TDS	mg/l	49.00	Average		1 200
Ca	mg/l	4.20	Average		
Mg	mg/l	3.10	Average		
Zn	mg/l	0.00	Maximum	+15%	5

filters. Here conditions are maintained such that manganese removing bacteria colonised the filter media to oxidise the soluble manganese, which is similarly removed.

pH control is achieved by dosing caustic soda directly into the mixing chamber upstream of each filter bank. Dissolved oxygen levels and hence redox potential are maintained by controlling the portion of the water that flows over aeration weirs upstream of the iron and manganese filters as well as the amount of compressed air sparged into the mixing chambers upstream of the filter banks, if needed.

The filtrate flows by gravity through packed limestone bed contact stabilisation tanks into a treated water storage tank. A residual dose of chlorine (as calcium hypochlorite) is added into the treated water storage tank, controlled by a chip-feeder dosing system.The treated water is then pumped to the Coega Kop Reservoir.

The filters are backwashed with a combined water/air-scour system drawing water from the manganese filtrate tank, and supplying air from dedicated backwash blowers. The spent backwash water is fed to backwash water recovery ponds where the solid residue settles and the supernatant is pumped back to the head of the works. Settled solids are allowed to dry over time and are periodically removed for disposal offsite.

Anticipated costs of water production

Preliminary estimates of the scheme were generated. The prices are dated June 2018. The cost of installing the borehole field, equipping the boreholes and installing the required pipework is estimated at R60 million. The cost for construction and equipping of the Biofilter WT at 20 Mℓ/d capacity is estimated at R185 million. The OPEX costs, which include labour, chemical consumption, electricity and maintenance of capital infrastructure are estimated at R17 million/annum. These costs combined provide a unit return value (URV) to extract and treat the borehole water of approximately R4/m^3.

INNOVATION IN DESIGN

Integrated and Collaborative design process

The design team was relatively young (all design leads were under 35 years of age) with design oversight from a senior project director. This was recognised as an opportunity to experiment with the design process.

Four guiding principals were adopted to enable collaborative design.

- Firstly, it was recognised that all the design disciplines add equal value and were expected to educate the others on their design requirements and priorities such that they were aware of each other's design needs;
- Secondly, it was acknowledged that the detailed design phase would be iterative, complex, fluid and would take form slowly. This period is an inevitable and necessary part of multidisciplinary design. Designers accepted that they would have to make certain compromises in the interest of a holistically optimised design.
- Thirdly, inputs from all disciplines were welcomed from the beginning, however outputs from disciplines, in terms of drawings, reporting, etc. was limited to only when required in order to prevent designers doing abortive work before precursor design elements had been properly defined.
- Lastly, frequent design briefings/meetings were held to keep all disciplines informed of design changes as they were happening.

Operator-centric design

The objective of this design approach is to create an optimal environment for the process controllers on site so that they can carry out their day to day activities efficiently and comfortably.

An operator-centric design approach aims to assist process controllers by configuring equipment in a logical way, enabling effective control of each system. This is generally achieved by locating related equipment close together, by ensuring clear visibility for processes that require monitoring, and by facilitating simple circulation for normal routes taken by process controllers (minimising level changes, providing multiple routes within the building, limiting the need for exposure to wind/rain).

For this project, the operator-centric design focused on providing internal access to all main process and operation components, with significant visibility of key processes from areas the operators would be located in. For instance the upper Filter Gallery is visible from the Control Room, while the machine room is visible from both levels of the filter gallery.

In order to test assumptions the design team utilised the Water Institute of Southern Africa (WISA) Process Controllers social media channel to get broad input on operator requirements of novel equipment, materials handling, etc. Not only were queries answered, but often the enthusiastic operators would provide suggestions and advice on unsolicited aspects of the design.

Use of VR modelling as a design tool

Most modelling design work is currently undertaken using combinations of 3-dimensional modelling software. For this project Autodesk Revit and AutoCAD Civil 3D were used. As the models are already in a 3D format it is reasonably simple to then convert the models to be viewed in a virtual reality space for review purposes, albeit at basic quality level.

However, models can be refined further by rendering components of the model to provide additional information and texture to the model elements and then combine the elements in a gaming engine, which allows for a far more realistic, virtual reality experience for the user. This refined model is termed the VR model.

The VR model can incorporate elements such as sound, or interactive aspects such as allowing the user to get a real sense of the experience of being in the infrastructure. This has been used successfully to simulate operating procedures for an electrical switch station and a filter backwash for example.

In the authors experience the virtual reality experience, if rendered in sufficient, realistic detail, provokes the user to provide feedback. This would include what the user likes and doesn't like, concerns with the design, suggestions for maintenance, safety and trouble shooting.

Further, once the VR model has been created it is possible to generate promotional material for the project such as walk-throughs, or videos that can be distributed to stakeholders to keep them informed of the project. Further, an executable of the VR model can be created which would allow a client, contractor or other stakeholder to inspect the model at their leisure from their personal computer.

Figure 1: The Machine Room

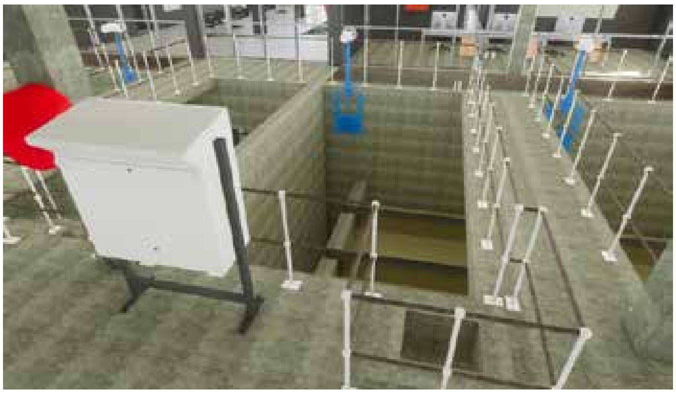

Figure 2: The rapid gravity sand filters

Figure 3: The contact stabilisation tanks

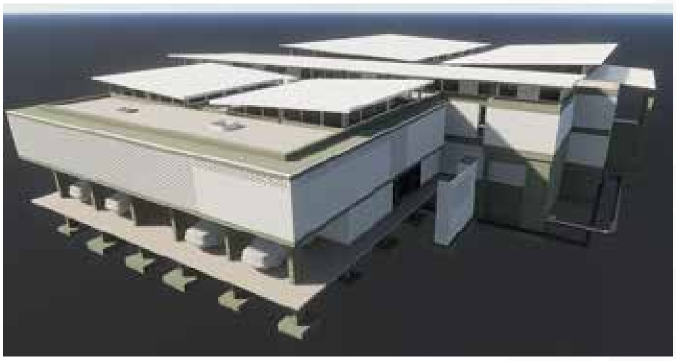

Figure 4: An overview of the structure, excluding the terrain model

CONCLUSIONS AND RECOMMENDATIONS

The Coega Kop Biofiltration Plant will be the second full scale biofiltration plant in South Africa to treat iron and manganese rich groundwaters. It will provide the NMBM with a necessary additional source of water which is independent of drought conditions.

The works has been designed with the end-user in mind and an experimental design approach was adopted to ensure a holistic design meeting the clients requirements could be achieved. Both social media and VR models were utilised to test the design and receive feedback during the design phase which provide both insightful and cost effective prototyping methods for the client.

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