Seawater desalination as an option to alleviate water scarcity in South Africa: the need for a strategic approach to planning and environmental decision-making

G. O. Schreiner, R. C. van Ballegooyen and W. Osman

ABSTRACT

In the last decade, seawater reverse osmosis (SWRO) has come to be seen by policy-makers as a novel technology that will significantly advance water security in South African coastal regions. Water purveyors, from the private sector, local/district municipalities and provincial authorities, are undertaking studies to explore the feasibility of SWRO to meet growing demand and relieve mounting pressure on current bulk water supply infrastructure. With this in mind, it is suggested that national strategic planning should be introduced to present the opportunities and constraints of the desalination option within the national water and energy policy. In absence of this, piece-meal decisions will be made at local authority levels and the construction of SWRO plants will be determined by regional circumstances (e.g. drought) as opposed to national water policy agenda. This paper explores the value of such a strategy by considering the drivers of SWRO in South Africa, the risk of unplanned large-scale SWRO implementation (with a focus on environmental impacts) and the initial steps that could be taken toward a Strategic Environmental Assessment for SWRO in South Africa.

Key words | environmental impacts, informed decision-making, national water policy, seawater reverse osmosis, Strategic Environmental Assessment

G. O. Schreiner (corresponding author)
W. Osman
CSIR – Environmental Management Services,
Box 320 Stellenbosch 7599,
South Africa
E-mail: *gschreiner@csir.co.za*

R. C. van Ballegooyen
CSIR – Natural Resources and Environment,
Box 320 Stellenbosch 7599,
South Africa

INTRODUCTION

The National Treasury's 2012 Budget Review suggested that South Africa would start running out of water within the next 20 years. The document concluded that based on current projections, South Africa's water demand will outstrip available supply around 2030. To counteract these forecasts, the government allocated R 75-billion to the augmentation of existing and construction of new bulk water supply schemes across the country (Treasury 2012).

In addition to these traditional water supply schemes, national water policy has encouraged public water purveyors in coastal regions to explore the potential for the creation of new water resources from the sea. The South African National Water Resource Strategy (DWAF 2004) and the Draft South African National Water Resource Strategy 2 (DWA 2012), suggest that the nation will face severe challenges in the future as traditional water resources approach their full-yield potential. Climate change is also expected to increase the risks associated with security of supply. Consequently, attention in South Africa could become sharply focused on seawater reverse osmosis (SWRO) as a potential solution to water scarcity in coastal regions.

The decreasing costs of SWRO, together with the fact that SWRO could provide a more environmentally-acceptable solution than traditional supply schemes, such as dams, could result in SWRO projects being implemented prior to some of the conventional water resource schemes. The technology used in SWRO is increasingly being refined and options to use renewable energy sources to power SWRO plants are also under investigation (Gilau & Small 2006).

SWRO is a membrane filtration process used to reduce the salinity of seawater. The process works by applying pressure to overcome the natural osmotic pressure of seawater by pumping

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it through a semi-permeable membrane. 'Pure' water will move through the membrane from a region of high salinity to a region of low salinity. This creates a processed permeate stream that can be used as potable water. Salts and minerals unable to pass through pores in the membrane will be retained in a concentrate stream known as 'brine'. The brine concentrate on the upstream side of the membrane comprises a high salinity effluent. Traditional brine concentrations are approximately 1.7 times the salinity of seawater. This equates to a salt concentration of 60 g/L versus 35 g/L (the salinity concentration mean of South African coastal waters) of pure seawater (DWAF 2007).

There are numerous international case studies that suggest environmental and technical criteria to be considered in the planning and construction of sustainable SWRO plants. National projects such as Membrane Based Desalination – an Integrated Approach (Enrico 2011) funded by the European Union, the National Centre of Excellence in Desalination (Furukawa 2011) based in Australia, and the California Coastal Commission and Coastal Act (CCA) in the United States (2004) have contributed to a growing global awareness of the need to regulate the SWRO industry from a planning and environmental perspective given the expected rapid growth in the market.

SWRO plants are multifaceted: they cross or impact upon the social, economic and ecological spheres. The combination of marine infrastructure, extensive coastal zone development, vast terrestrial pipeline corridors, operational wastes of brine and sludge, and energy consumption make SWRO plants dynamic and potentially 'high impact' industrial operations. While SWRO is mentioned through the South African national water policy, including the most recent National Water Resource Strategy 2, what is currently lacking is a strategic understanding of how SWRO could be understood as part of a holistic national approach to water supply, energy consumption and environmental impacts within the sensitive coastal zone.

DRIVERS OF SWRO IN SOUTH AFRICA

Technology and market drivers

Notable advances in SWRO over the last two decades have positioned it as a water source competitive with traditional supply schemes. While the water production costs of SWRO are higher than those associated with natural freshwater resources, the efficiency of the membrane technology and energy saving devices continue to improve (Voutchkov *et al*. 2010). Over the years, many countries and regions have been at the forefront of SWRO development and presently the Arabian Gulf, Red Sea, North Africa, Australia, the west coast of the United States and some Mediterranean countries rely on substantial proportions of freshwater processed through SWRO plants (Cotruvo & Abouzaid 2010).

In the South African context, the global research-based management consulting firm TechSci Research recently published a report entitled 'South Africa Desalination Market Forecast and Opportunities, 2017' (Slabbert 2012). The report suggests that the country's desalination market (including SWRO) has substantial growth potential and states that this market is expected to grow at a compound annual growth rate of 28% within the next 5 years (Slabbert 2012). While there are varying interpretations of the growth path for SWRO in South Africa, the undeniable trend is that significant sector growth is expected in the future.

Climate change and water demand drivers

Rainfall in South Africa is highly variable in spatial distribution and is unpredictable, both within and between years. Much of the country is arid or semi-arid and the whole country is subject to droughts and floods (DWAF 2004). Bulk water supplies are largely provided via a system of large storage dams and inter-basin water transfer schemes. Thus, a reduction in the amount or reliability of rainfall, or an increase in evaporation as a result of climate change, may exacerbate the already seriously limited surface and ground water resources in South Africa (DWAF 2004).

Current population projections in South Africa estimate that the population will grow to 53 million by 2025 and with it water demand will rise (DWAF 2009). Rapid rates of urbanisation will place stress on existing water infrastructure. New and developing business nodes with limited infrastructure will also require water supplies to be sustainable in the future. These patterns of urban settlement are not driven by regional planning and as a result are generally unsupported by sufficient water service infrastructure (DWAF 2009).

Water policy drivers

In the Water for Growth and Development Framework (2009), the Department of Water Affairs (DWA) suggests that in addition to the traditional water supply schemes, SWRO should be used to supplement existing resources. A key principle behind ensuring continuous supply is to limit the financial expense of transporting water by keeping the source as close to the end-user as possible. This would suggest that traditional large-scale inter-basin transfer schemes and similar strategies will be supplemented by smaller-scale, point-of-source water augmentation alternatives in coastal regions. In this respect, the South African National Water Resource Strategy (DWAF 2004) and the Draft South African National Water Resource Strategy 2 (DWA 2012) both envisage the long-term application of SWRO in coastal regions of the country.

The DWA has also embarked upon regional water supply assessments in order to 'reconcile' water demand versus supply alternatives. The studies are continuously being undertaken for most of the 26 key national growth points as identified by the National Spatial Development Plan for South Africa (particularly in water scarce regions and those areas experiencing the highest projected demands). The objective of the reconciliation studies is to develop future water requirement scenarios, investigate all the possible water sources and provide recommendations for interventions and actions. Based on the reconciliation studies undertaken for coastal areas thus far, the DWA has suggested that full feasibility investigations be undertaken to establish the potential of SWRO as an alternative water supply source.

The other water supply options that are under investigation include infrastructure development and management, groundwater development and management, water resources system operations in addition to climate change and disaster management strategies (DWA 2012). Of the six strategies mentioned in the South African National Water Resource Strategy 2 (DWA 2012), only two actively examine alternative water sources, i.e. groundwater and seawater using SWRO.

The remaining four strategies focus on addressing issues of efficiency, adaptation, research and operations for available water sources. The first strategy addresses infrastructure development and management by examining the macro infrastructure needed for a water secure future. The second strategy addresses the challenge of climate change by integrating resilience in water sector planning. The disaster management strategy aims to respond effectively and so minimise sector-losses during vulnerable times. Water resource operations are addressed to ensure the efficient supply of water. The extent to which these alternative water supply strategies could be employed to meet water demands needs to be properly evaluated against the SWRO option in coastal regions. However, from a local water agency and purveyor perspective, a steadily rising interest in SWRO has been observed. This is largely as a result of the desire to reduce reliance on imported potable water supplies; and desalinated seawater is viewed as more reliable than traditional water sources due to increased competition at local water purveyor levels.

ENVIRONMENTAL RISKS OF SWRO IMPLEMENTATION

The United Nations has realised the importance of the development of sustainable SWRO planning criteria that offer governments in water-stressed regions a viable opportunity to respond to both population growth and the impacts of climate change. While the United Nations Environment Programme (2008), the World Health Organization (2011) and the World Wide Fund for Nature (2007) have published reports on the environmental impacts of SWRO, the actual impacts are still subject to considerable debate (Latteman 2010). Considering the complexity of the environmental impacts relating to marine and terrestrial pipeline corridors, seawater intakes, brine outfalls, the operational footprint in the coastal zone and other indirect impacts (e.g. energy consumption and CO_2 emissions); there are understandably a number of risks to be considered when planning for SWRO plants. Here, the authors discuss what are considered to be the most pertinent environmental risks and impacts.

Discharge of brine into the marine environment

Brine streams will generally contain the natural constituents of seawater in a concentrated form. In addition, the pre-treatment of seawater involves chemical additives such as biocides (to inhibit biological growth on the membranes and pipes), coagulants (to remove suspended materials before filtration) and anti-scalants (to prevent scale formation, i.e. calcium carbonate accretion). Heavy metal contamination from corrosion of the pipelines over time can also be found in the brine concentrate (Latteman 2010).

The potential biological and ecological impacts of brine and chemical additives the marine environment are relatively unknown. The US National Research Council suggests that a considerable amount of uncertainty of the ecological impacts of SWRO exist; and consequently, concern over the potential impacts remain prevalent (Latteman 2010). Hoepner & Latteman (2002), UNEP (2008) and Latteman (2010) suggest that some of the following are the key marine impacts that may be associated with brine disposal in the marine environment.

- Impacts on seawater quality and sediments:
  - changes in salinity and temperature in the mixing zone;
  - sinking of the brine plume and the formation of a dense bottom water layer;
  - increases in turbidity and decreases in light penetration in the mixing zone;
  - reductions in the dissolved oxygen associated with the decay of organic matter; and
  - changes in sedimentation and erosion patterns along the beach (where there is a shoreline crossing for the intake and outfall infrastructure, there may be a disturbance of local sediment transport patterns that may in turn result in shoreline impacts such as erosion and accretion. In general, these are avoided through appropriate engineering design of pipelines, i.e. burying pipelines through the surf-zone).
- Impacts on marine macrofauna:
  - increased salinity and residual chlorine may affect algae and seagrass meadows. Coagulants may also impair photosynthesis that can lead to a die off of these organisms.
- Impacts on marine plankton and nekton:
  - residual chlorine by-products may have toxic impacts on plankton organisms in the mixing zone.
- Impacts on marine benthic invertebrate fauna:
  - increased salinity may create an osmotic environment hostile to the benthos;
  - chemical 'blanketing' may be toxic to sessile species; and
  - toxic and salinity impacts can change species abundance at the discharge site.

'High impact' industrial developments within the coastal zone

The coastal zone at the interface of the sea and the land is ecologically and socially unique. It serves both human and non-human interests. The South African coastline is over 3,000 km in length, more than 80% of which consists of sandy beaches and dunes containing diverse and threatened plant species and vegetation units (DWAF 2007). The regions immediately inland of the highwater mark are increasingly subject to anthropogenic pressure. In recent years, industry, coastal ribbon developments, commercial and recreational activities have placed increasing environmental pressures on these sensitive zones.

The long-term ecological impacts during the operation of SWRO plants are likely to be the fragmentation of ecological and coastal connectivity, facilitation of the spread of alien invasive organisms, soil compaction and erosion, various impacts on nutrient cycling, sediment accretion and many more. In addition, dune areas that form crucial barriers between the coast and inland ecological communities may be compromised.

From a social and economic perspective, recreation, tourism and public access can be adversely affected by SWRO plants. Public access to the coast will include both perpendicular and horizontal access routes, depending on the location, size and nature of the SWRO plant. It may have a high impact on lower income local communities living adjacent to the site. In addition to restricting physical access, new developments often change the 'sense of place' of the area; it can affect the communities' cultural heritage and traditions (especially communes that rely on the coast for subsistence).

Energy consumption and greenhouse gas emission

The specific energy demand of SWRO plants depends on a range of factors such as energy recovery devices, pre-treatment design, the type of membranes, the efficiency of pumps and motors, the type and efficiency of energy recovery systems and environmental conditions. Modern SWRO plants can achieve a specific energy demand (i.e. the plant only) of <2.5 kWh per 1,000 L and a total energy demand (i.e. the plant and auxiliary pumps) of <3.5 kWh per 1,000 L by using state of the art equipment. The real energy demand may be higher under less favourable conditions, i.e. high fouling potential, low temperature, high salinity, etc. (Latteman 2010).

The total energy requirement of SWRO plants is generally between 4–5 kWh per 1,000 L of potable water including pretreatment and auxiliary equipment. Assuming a 4.5 kWh mean total energy demand, approximately 1 kWh will be used in the production of 221 L of freshwater in a modern SWRO plant. In the South African context, according to Eskom's 2012 Annual Integrated Report, the power utility generally requires 1.42 L of freshwater to produce 1 kWh (ESKOM 2012) and during this process approximately 1.03 kg of CO_2 will be emitted equating to approximately 1.07 kg of CO_2-equivalents (CO_2-equivelent estimates the global warming potential of all greenhouse gases by transforming the non-CO_2 emissions into an equivalent amount of CO_2 emissions that would have the same global warming potential) (Latteman 2010). However, these data do not take account of transmission losses. Monitoring at the Sydney SWRO plant shows that a significantly higher value of 2.3 CO_2-equivalents per 1,000 L of processed water can be expected when transmission losses are considered (Latteman 2010).

The total energy demand of SWRO plants that will be constructed in South Africa is generally uncertain. While the operational energy requirements will be considerably higher than those associated with traditional bulk water supply schemes, SWRO offers the government and environmental planners a suite of alternatives than can be used to offset environmental impacts associated with water catchment management strategies such as damming. It is evident that in the South African context, further research into energy requirements and the associated CO_2-equivelents need to be determined at a higher planning level, if the relationship of energy demand and water supply in the context of SWRO plants is to be fully understood.

A NATIONAL STRATEGY FOR SWRO

While desalination of seawater has been mentioned in South African water policy documentation and many of the reconciliation studies have proposed investigation into SWRO, all of these studies have been undertaken in isolation that have investigated regional water requirements. In other words, they will not be informed by a strategic national view on the viability of SWRO as a sufficiently environmentally and economically sustainable solution to meeting South Africa's long-term water needs.

Further research needs of relevance to desalination of seawater in Australia, the United States and other parts of the world have been presented by Furukwa (2011), the CCA (2004) and Latteman (2010), respectively. Based on these and existing local research thus far (e.g. Swartz *et al.* (2006); DWAF 2007), focal areas for increased alignment of water policy exist for the development of a national policy on deployment and performance monitoring of SWRO plants with an emphasis on the technological and environmental lessons learned. This would require an implementation strategy that responded to at least some of the following requirements.

A situational assessment of SWRO in South Africa

- A nation-wide inventory of small-scale plants currently operating around the South African coast with a focus on research and lessons learned. Monitoring data to measure performance, e.g. energy consumption, permeate water quality etc. all need to be assessed and evaluated.
- An extensive national legal and policy review of SWRO within water, coastal, air quality emission, energy, marine legislation, etc. to determine the full extent of how SWRO must be approached within the ambit of all applicable legislation.
- A description and explanation of the relevant environmental legislation applicable to Environmental Impact Assessment (EIA) and the development of the aforementioned and monitoring protocols so that development permits can be obtained (and stream lined if required) and the national inventory can be suitably monitored.

Development of an overarching national policy on deployment

- A national level screening study of suitable locations, plant sizes and technologies for SWRO facilities considering water demand in the region and environmental opportunities (e.g. high sea current energy at outfall location) and constraints (e.g. poor intake water quality, rare marine or terrestrial species, etc.).

- The determination of a strategic life-cycle assessment of SWRO against other alternative supply schemes such as dams, reclamation of wastewater, water restrictions, water pricing, subsidy removal and development controls on resource and land use (WWF 2007).
- The extent to which energy requirements are likely to place constraints on the adoption of SWRO plants in line with national commitments to carbon emission reduction. This would form a component of a more aligned approach to energy and water planning. Further to this, there is a fundamental need to understand the energy/water nexus and coupling SWRO water production with renewable energies is an important component of this debate (IEA-ETSAP & IRENA 2012).
- The development of policy incentives governing SWRO such as funding mechanisms and interactions for engagement of local authorities with national departments. This would include guidance on the required and most feasible contracting conditions and development plans. These would need to ensure the integration and integrity of the financial planning phases, the engineering process, environmental authorisation and other regulatory processes of relevance.
- An indication of the options that exist for operational procedures of SWRO plants to alleviate peak seasonal demands and/or provide a temporary base water supply for a region that corresponds to shortage of rainfall and available supply.
- The formulation of an international policy and guidelines review should be undertaken which discusses the application of SWRO plants within international best practice guidelines. A technological and financial review of best available technology for SWRO by referring to international case studies in similar environmental conditions (Latteman 2010). An overview of the economics and running costs (where possible) of the various SWRO technologies under consideration would be desirable for decision-making.

Guidelines for operational roll-out and monitoring performance

- Direction on the most relevant contracting conditions and development plans. These would need to ensure both the integration and integrity of the financial planning, the engineering process and environmental processes (guidelines for ensuring timeous information flows between design, the EIA process and decision-making) and other regulatory procedures of relevance.
- Examples of how environmental feasibility and monitoring protocols should be executed. In addition, detailed guidance on issues such as water quality monitoring programmes is required, and sufficient experimental data is needed, including field investigations, laboratory toxicity tests and modelling studies.
- Guidelines on capacity building of water purveyors to operate and monitor SWRO plants; and the strategies best suited to engaging the public at large in the discussion about SWRO implementation.

CONCLUSIONS

While some perceive SWRO as a panacea to water supply in the face of population growth and climate change, there are some people who perceive it as a technocratic, expensive and ultimately harmful approach to addressing increasing water demand and facilitating climate change adaptation. Having said that, putting the cost of water as well as increasing demand and climate changes variables into perspective, it has to be considered that when the alternative is no water (or inadequate water supply) and when significant harm to human health and social welfare could occur, greater economic and environmental costs may be tolerated in some circumstances (Latteman 2010).

It is likely that SWRO may come to form a substantial portion of potable water supply in the coastal regions of South Africa. As the need for water accelerates, national policy will need to be guided by a framework where water supply from SWRO is considered within the national environmental and economic planning contexts. Currently there is no co-ordinated approach on a national scale. Given the complexity and far-reaching footprint of these plants, SWRO must form part of a holistic national approach to water supply, resource usage and environmental sustainability. This would require a strategic approach to decision-making to counter the seemingly ad-hoc approach to SWRO currently being undertaken by water purveyors. At the very least, a co-ordinated response to permitting requirements and marine discharge inventory of current operations must be established in the short term.

Outcomes that meet the objectives of water purveyors, SWRO advocates and those concerned with sustainability may flow from an improved and consistent process to assess water needs and the optimum mix of both supply and demand side measures set against the background of an overarching SWRO strategy. Where SWRO is established to be an integral part of meeting a real water need at local levels in the most cost effective and least environmentally harmful way, SWRO plants need to be sited, constructed and operated to minimise unacceptable environmental impacts and ensure long-term water supply and sustainability (WWF 2007). This will only be achieved through a strategic planning approach to SWRO implementation which can be used to underpin informed and defensible decision-making about water planning for the future.

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