A GUIDELINE TO COMPARE THE FEASIBILITY OF GRAVITATING SEWAGE VIA A TUNNEL WITH RISING MAINS

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ABSTRACT

The sustainability of infrastructure is an increasing challenge as the operation and maintenance of these facilities become more expensive each year. This is especially true in municipal infrastructure designed and built for the conveyance of waste water.

Electrically driven systems are also increasingly at risk with power supply constraints and there is an increasing need to reduce operational costs. With rising energy costs, and the resultant impact on operating costs, there can be cost advantages in gravitating sewage through tunnels between catchments, rather than pumping. The use of Tunnel Boring Machines, TBMs, makes it feasible to tunnel through many different geotechnical conditions and they have been used successfully in South Africa for hard rock tunnels, as well as tunnels in sand and clay beneath sea level.

This paper investigates the project lifecycle present worth of costs of pumping sewage between adjacent catchments versus the project lifecycle present worth of costs for gravitating sewage via a tunnel for various flows, lengths and pumping heads. The results provide a first order tool to indicate whether tunnelling may be preferable to overland pumping.

INTRODUCTION

Life cycle costs of basic public infrastructure are a key decision tool when comparing various alternatives. In particular an alternative with a lower initial capital cost but with high maintenance and operational costs may not be the most cost effective solution over the desired service life. In addition, the energy consumption and the reliability of the energy source should be considered, not only from the cost point of view but also from an environmental impact point of view.

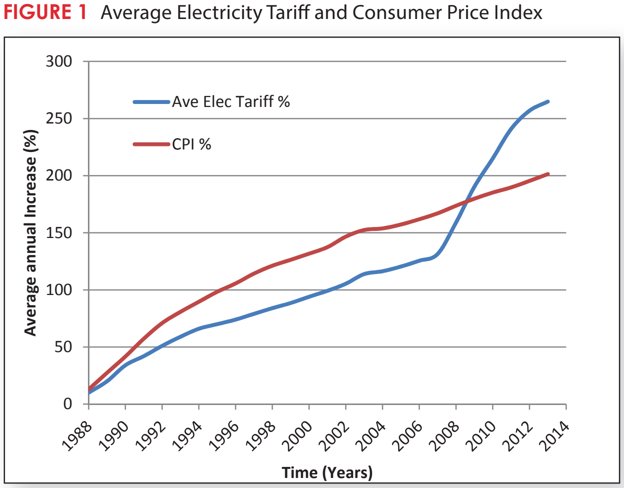
In South Africa, as is common in most countries, urbanization continues to gain momentum with concomitant pressure placed on existing basic infrastructure. The need to expand and replace existing aging infrastructure is ever-present. A fully functional sewage system is not only required from a human rights point of view but also to ensure the environment is not detrimentally affected. Furthermore, the cost of maintaining a sewer network should not exceed the rates generated by the population served by the said infrastructure. While service providers, primarily municipalities, often subsidize infrastructure capital costs and operational costs from funding from central government, once costs exceed income and/or subsidies available, the operational effectiveness of the infrastructure is compromised, possibly also leading to environmental damage.

The average cost of electricity has risen and is placing financial strain on maintaining effective operation of sewer rising mains. Coupled with the rising cost of electricity, there is currently also a shortage of generating capacity in South Africa which has forced ESKOM to institute "load shedding". A further challenge is the fact that many sewer pump stations are located in secluded and/or remote areas and as a result the electrical wiring and pumps are easy targets for theft and vandalism.

Tunnelling is an alternative option to rising mains. While it eliminates the need for energy consumption during operation and has substantially lower operating costs, it generally requires a higher initial capital investment.

This paper analyses the life cycle costs of pumping sewage from one catchment over a spur to the adjacent catchment, at a lower level, and compares this to life cycle costs of gravity tunnels. This provides a first order indication of where sewer tunnels could be a viable alternative to the pumping of sewage.

FIGURE 1 Average Electricity Tariff and Consumer Price Index



VARIABLES CONSIDERED

There are a number of variables that affect the comparison of pumping sewage versus gravitating sewage via a tunnel. The variables considered for the pumped alternatives include future electricity costs, pumping head, and pump station requirements. Those considered for the tunnelling include topography, geology, tunnelling method, pipe sizes, tunnel size, tunnelling hydraulic requirements and tunnel infrastructure requirements. Variables which affect both pumping and tunnelling include outfall lengths, flow rates, pipe material, foreign currency exchange rates, discount rates, and discounted return period. These are discussed in more detail below.

Pumping Variables

Electricity Costs

As demonstrated later, this is one of the most significant factors in the analysis. Since 2007 the price of electricity has risen over one hundred (100) percent (1), an average of 10,5% per annum, as depicted graphically in Figure 1.

It is difficult to predict the future average increase in electricity tariffs over the analysis period as ESKOM indicates that they require an average increase in the order of thirteen (13) percent for the next five (5) years while the energy regulator of South Africa awarded average increases of sixteen (16) percent and eight(8) percent in 2012 and 2013 respectively, down from a high of approximately thirty (30) percent in 2009.

TABLE 1 Average Electricity Tariff Increase and Consumer Price Index

Year	Average approved tariff increase %	CPI %
2007	5.9	5.2
2008	27.5	6.6
2009	31.3	6.2
2010	24.8	5.4
2011	25.8	4.5
2012	16	5.7
2013	8	6

Table 1 lists the average tariff increase percentage against the Consumer Price Index (CPI) between 2007 and 2013 (1).

A number of power stations are nearing the end of their service life, and the drive to reduce our carbon footprint means that ESKOM is currently looking at possible nuclear power to eliminate the power shortages in the long term. The capital cost of developing new power stations is high and therefore it is unlikely that South Africa will return to the state where excess power was generated, resulting in the historical low electricity tariffs.

Figure 2 shows the average electricity price, in USD cents per kilowatt hour (c/kWh) for a number of countries with large economies(2). In the article, all conversions are done at a rate of rate of USD 1 = ZAR 13.96. South Africa's current average cost of electricity at 8.46 USD c/kWh is just over half the cost of the average price of electricity in Italy (15.7 USD c/kWh). The average cost of the top three counties, namely Italy, Germany and United Kingdom, is approximately 15.03 USD c/kWh which is roughly 77,5% higher than South Africa.

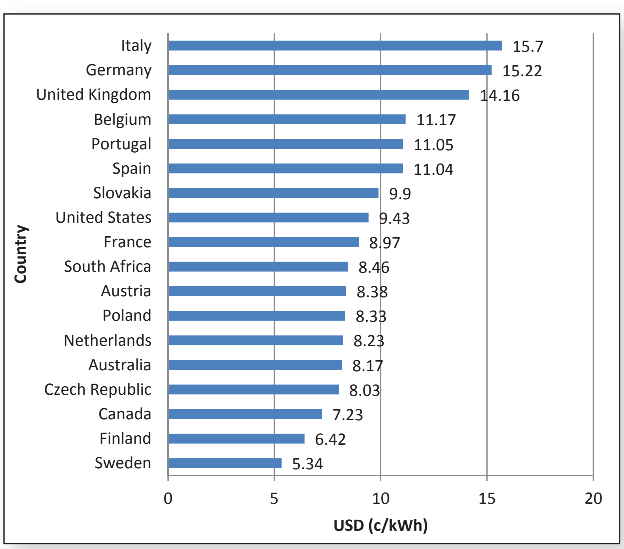
Currently South Africa is experiencing an annual inflation rate of roughly 6% which is within the Reserve Bank's inflation target rate of between 3% and 6% per annum and therefore monetary policy is expected to remain relatively unchanged. The average future electricity cost increases are likely to be in excess of inflation to enable ESKOM to pay for the capital costs of future power stations. If one considers future average electricity price increases of approximately 8,0% per annum, it effectively means that on average the real price of electricity is growing at 2,0% per annum.

Using a 2,0% per annum real increase in cost for electricity tariffs, it will take South Africa just over 29 years to reach the current average electricity costs of 15.03 USD c/kWh. Using an annual increase of 10,0% (4% real increase) per annum it would take just over 14,5 years to reach the same current rate.

The current average electricity prices listed in Figure 2 will change with time due, amongst other influences, to inflation and so the duration until South Africa's average electricity tariffs match those of other leading economies is unknown but it is a real possibility that the tariffs will reach these limits.

Figure 3 (3), UrbanEarth predicts that, at least up until 2017, an average tariff increase of at least eight (8) percent may be expected. This is deemed to be prudent.

FIGURE 2 Average Electricity Price (2015) of selected countries with large economies



Pumping Head

It is assumed that there is a spur between the collection point of the sewage in one catchment and the delivery point in the adjacent catchment. Pumping heads of twenty five, fifty, seventy five and one hundred (100m) metres are considered.

Pump Station Requirements

The costs of the pumping options are based on the Average Dry Weather Flow (ADWF) with a minimum storage capacity of twenty four (24) hours , including a generator capable of meeting the average annual dry weather flow.

Tunnelling Variables

Topography

A tunnel is only viable if the inlet is higher than the discharge and there is a spur separating the inlet from the discharge.

Geology

The type of material through which a tunnel is excavated has a direct bearing on the complexity of the tunnelling equipment and methods required and ultimately the costs associated with the excavation of the tunnel.

The Karoo formation, which includes sedimentary rock, is found over large areas of South Africa. This exercise only looks at the costs for tunnelling through sedimentary rock. It must however be emphasized that even in sedimentary rock, one can expect a wide range of materials as sedimentary rock varies from sandstone to mudstone and shale with varying degrees of hardness and jointing and bedding, and may contain various igneous intrusions.

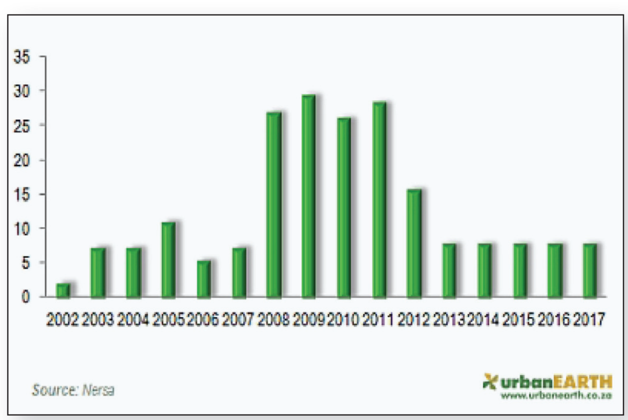
Tunnelling Method

The costs for tunnelling are based on using a TBM, tunnelling through sedimentary rock. Sedimentary rock typically has jointing and bedding which tends to result in the rock breaking out in blocks. In a drill and blast type of tunnel operation the amount of overbreak as a result of the jointing and bedding is difficult to control which may result in costly overruns. The preferred method of tunnelling is using a TBM which not only reduces the overbreak but also enables rock bolts to be placed immediately in areas where required.

Pipe Sizes

The required pipe sizes for the various flow rates for the tunnelling option are based on maintaining the velocity of the effluent between 0,7 and 2,5m/s, with an average velocity of 1.5m/s (9).

FIGURE 3 Electricity Price Increase in South Africa (%) – 2002-2017



Tunnel Size
All effluent is conveyed through the tunnel in a closed pipe system. This means the tunnel must be able to accommodate the pipes as well as allowing access for maintenance purposes. The required tunnel sizes therefore vary in diameter from 2,9m to 4,2m. Figure 4 shows the typical tunnel arrangement with a closed pipe system on each side, restrained in pipe chairs and a walk way down the centre for access.

Tunnelling Hydraulic Requirements
As the effluent is conveyed via a closed pipe system within the tunnel, it is vital that all effluent is screened and excess grit removed from the flow prior to entry into the tunnel to minimize the chance of blockages. The cost of a screening chamber and a grit chamber is included in the tunnel costs.

Tunnelling Infrastructure Requirements
The cost for an inlet structure and outlet structure to control access to the tunnel and provide ventilation is included. Provision is also made for ventilation shafts as required.

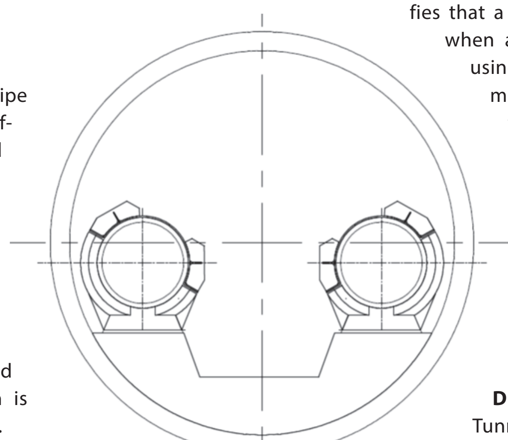


FIGURE 4 Typical Cross Section of Tunnel

Common Variables

Outfall Length
Four different outfall lengths are considered, namely one - , two-, three- and four thousand metres. For the pump options, fifty percent (50%) of the length of the outfall has been taken as a rising main and fifty percent (50%) as a gravity outfall, for each of the analysed lengths, to simulate pumping up and over a spur. In the tunnelling option the full length is naturally under gravity flow.

Flow Rates
Four different peak wet weather flow rates are considered, namely five hundred (500), seven hundred and fifty (750), one thousand (1000) and two thousand (2000) litres per second.

A peak factor of 2,5 (8) has been applied to the Average Dry Weather Flow (ADWF) to calculate the Peak Dry Weather Flow (PDWF). A fifteen (15%) percent (8) allowance has been made to the PDWF, for storm water ingress, to calculate the Peak Wet Weather Flow (PWWF), as indicated in the Guidelines for Human Settlement Planning and Design Volume 2.

Pipe Material
Pipes conveying effluent are generally subjected to chemical attack and abrasion from grit. High Density Polyethylene (HDPe) pipes have been used in both the pumping option and the tunnelling option due to their high resistance to chemical attack and abrasion.

Foreign Currency Exchange Rate
The acquisition of a Tunnel Boring Machine (TBM) constitutes a significant part of the overall cost of tunnelling and as they are imported, the fluctuations in the South African Rand impact on the final cost of the tunnel. The calculations in the analysis are based on an exchange rate of fifteen rand twenty (R15.20) to the Euro (€).

Discount Rates
In general a discount rate in a present worth of costs (PWOC) analysis must account for not just the time value of money, but also the risk or uncertainty of future cash flows. The greater this uncertainty, the higher the discount rate. A paper titled Capital Projects (4) outlined the possible contributions actuaries could make when evaluating infrastructure. One of the aspects discussed was the selection of an appropriate discount rate. In general the paper concluded that the discount rate could be as low as six (6) percent for capital projects undertaken by government in the United Kingdom (UK) but in general eight (8) percent is seen as the average discount rate generally used.

The South African National Road Agency (SANRAL) (5) specifies that a discount rate of eight (8) percent be used when analyzing alternative infrastructure options using the Highway Development and Management (HDM-4) Software(6). The Guidelines for the Development of Water and Sanitation Infrastructure (7) recommends a discount rate of 8% percent per annum or the official Government discount rate. A sensitivity analysis using 6% and 10% is however also recommended.

A discount rate of eight (8) percent has been used in the present worth of costs (PWOC) calculations.

Discounted Return Period
Tunnels are generally robust structures and many over one hundred (100) years old are still operational. A discount period of fifty (50) years has been chosen which does result in the requirement that pumps need to be refurbished during the analysis period.

ANALYSIS METHODOLOGY

Based on the various assumptions listed above, a conceptual sizing was made for each option, that is for each (Δh), namely 25m, 50m, 75m and 100m; each (Δl) 1000m through to 4000m in increments of 1000m and each PWWF (ΔQ) of 500l/s, 750l/s, 1000l/s and 2000l/s. The estimated capital cost and the operation and maintenance costs were calculated for a 50-year discounted return period The project lifecycle present worth of costs (PWOC) of each option was then determined. An overview of the key components is presented below.

Capital Costs

The capital costs associated with the various infrastructure elements are generic project costs. These costs are based on information from existing projects and/or portions of existing projects escalated to 2015 prices. The project costs are inclusive of direct construction costs and indirect costs including design costs, project management costs and 14% VAT.

Electricity Costs

The average current electricity cost of R0.8206 per kilowatt hour, as per Buffalo City Metropolitan Municipality Electricity Tariffs and Charges(10), is applied for all the various options. The annual electrical costs were then escalated at 8% per annum.

Maintenance Costs

Generic maintenance rates (7), have been applied to all the infrastructure components. Annual maintenance costs to the value of 0,5% of the pipeline capital cost has been allowed for pipelines, 0,25% for the civils component and 4,0% per annum for the mechanical and electrical components based on current capital costs. These costs were then escalated at an inflation rate of 6% per annum.

Project lifecycle present worth of costs

The capital project costs, based on empirical data, together with annual maintenance and operational costs were calculated annually for the 50-year analysis period and then discounted to a present day value using the following formula:

$$PWOC = \sum_{n=0}^{N} {}^{FC}/_{(1+i)^n} \tag{1}$$

Where
PWOC = Present Worth of Costs
FC = Future Cost
i = Discount Rate
n = Years (Discount Period)

FIGURE 5 Project Life Cycle Present Worth of Costs for Tunnel & Rising Main with a 25m pumping head

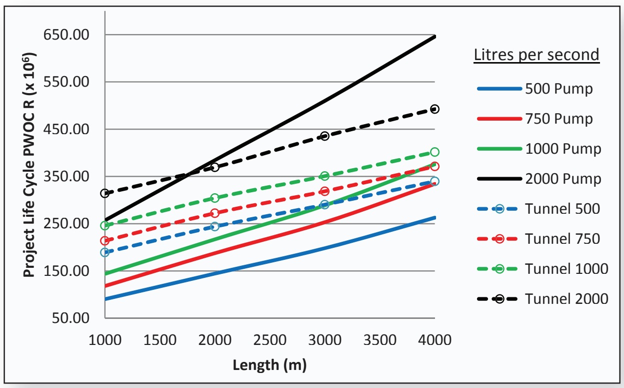


FIGURE 6 Project Life Cycle Present Worth of Costs for Tunnel & Rising Main with a 50m pumping head

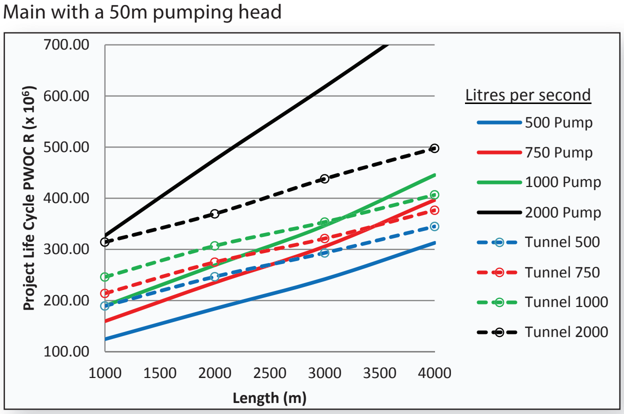
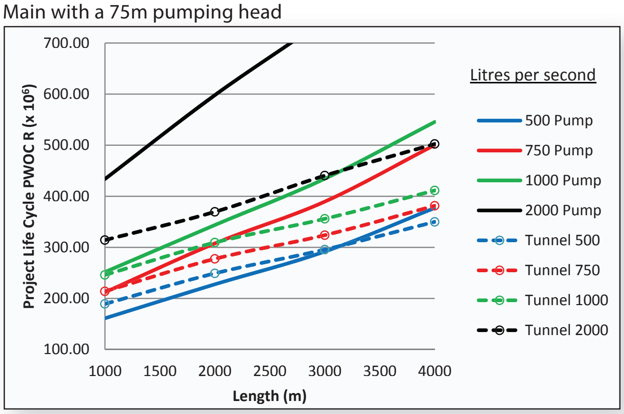


FIGURE 7 Project Life Cycle Present Worth of Costs for Tunnel & Rising Main with a 75m pumping head



RESULTS

The project lifecycle present worth of costs (PWOC) for the various lengths and flow rates are presented together for each pumping head in Figures 5 to 8. The legend denotes whether the data is for a pumped option or tunnel option for the four different flow rates (PWWF) from 500 to 2000l/s.

With a pumping head of 25m, pumping is more economical for PWWF flow rates up 1000l/s for all lengths. For PWWF flow rates of 2000l/s at a length of approximately 1700m tunnelling becomes more economical.

At a pumping head of 50m, pumping is more economical for PWWF flow rates up 500 l/s for all pipe lengths analysed. For PWWF flow rates of 1000l/s and 750l/s, tunnelling becomes more economical at lengths of 3200m and 3500m respectively. For PWWF flow rates of 2000l/s, tunnelling is more economical than pumping over all the analysed lengths.

For PWWF flow rate of 500l/s and a pumping head of 75m at a length of 3200m or more tunnelling becomes more economical. For PWWF flow rates of greater than 500l/s, tunnelling is more economical than pumping over all the analysed lengths.

Once a pumping head of 100m is reached all the tunnelling project lifecycle present worth of costs are lower than their concomitant pumping project lifecycle present worth of costs and therefore tunnelling is cheaper over the full range of PWWF flows and lengths.

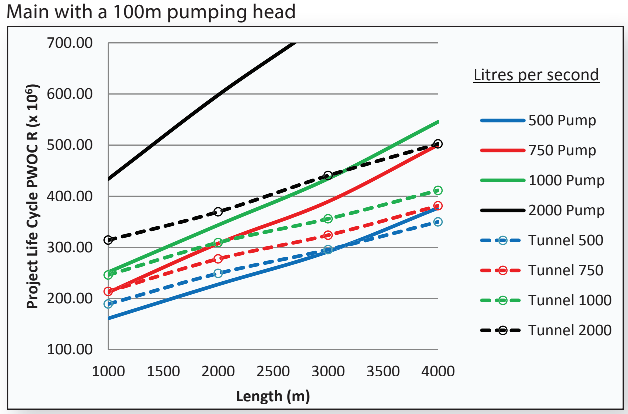
CONCLUSIONS

Tunnelling is viable in certain circumstances. Generally, as the PWWF flow rates increase the viability of tunnelling increases. The variable with the largest impact is that of the pumping head. As the pumping head is increased, the viability of tunnelling increases even for the lower flow rates.

The increased costs for the greater pumping heads are directly correlated to the high energy consumption. Therefore the largest influence on the viability of tunnelling is directly related to the future increase in electricity tariffs.

The project lifecycle present worth of costs calculated for the various scenarios are based on generic data and therefore it must be emphasised that this only produces a first order analysis for the viability of tunnelling. The indication that tunnelling may be a viable option will require further investigation which should include more site specific investigations, such as the drilling of boreholes to confirm the geology. Due to the many variants involved, the actual costs of both the pumping option and the tunnelling option should be calculated to determine the most cost effective solution.

FIGURE 8 Project Life Cycle Present Worth of Costs for Tunnel & Rising Main with a 100m pumping head



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ENVIRONMENTAL AUTHORISATION OF LAND-BASED EFFLUENT DISCHARGES INTO THE COASTAL ENVIRONMENT: SYNCHRONISING ENGINEERING DESIGN, ENVIRONMENTAL IMPACT ASSESSMENT & REGULATORY APPROVAL PROCESSES TO MINIMISE THE RISK OF PROJECT DELAYS

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ABSTRACT

A significantly changed landscape with respect to environmental policy, legislation and the authorisation of land-based wastewater discharges into coastal environments, suggests that it is timeous to provide municipal authorities and coastal industries with a renewed insight into the requirements and likely time-scales associated with infrastructure developments related to the disposal of land-based effluents to coastal environments.

A change in the regulatory authority responsible for the issuing of Coastal Water Discharge Permits and General Authorisations for land-based wastewater discharges into coastal environments has precipitated a sequence of events that has included a review the associated policy, legislation and operational guidelines and their implementation, as well as both recent and pending reviews of water and sediment quality guidelines. A concurrent change in the legislation governing the Environmental Impact Assessment process, together with trend of change in the type and nature of proposed wastewater discharges into coastal environments, has highlighted some existing and potential future challenges associated with the successful execution of infrastructure development projects related to the disposal of land-based effluents to coastal environments.

This paper addresses these challenges by providing a detailed description of the three key processes involved in such discharge infrastructure development projects (engineering design, environmental design/impact assessment and environmental authorisation/permitting processes), the information requirements for each of these processes and the most probable timelines for their execution based on past experience as well as the requirements of some of the recent regulatory changes. Highlighted are potential vulnerabilities (e.g. poor synchronisation of information flows between the processes) that could lead to significant project delays and/or increased costs. Also discussed is the role of improved assessment techniques and the potential use of novel construction methods in expediting and providing greater flexibility in the planning and execution of proposed wastewater management infrastructure development projects.

INTRODUCTION

Cost-effective processing, management and ultimate disposal of wastewater effluents is an important enabling factor in the delivery of municipal services related to water and sanitation, and in allowing appropriate industrial development and the associated socio-economic opportunities that this brings. One of the options in this regard is the disposal of partially treated or fully treated effluents through discharges into coastal environments. For such an option to be viable requires that the capital and operational costs are minimised while ensuring an environmentally sustainable solution. The engineering design process typically is focussed on ensuring a cost-effective and efficient processing, management and, if necessary, disposal of wastewater effluents, whereas it is the role of the regulatory authorities (supported by those undertaking the environmental design and impact assessment studies) to ensure the environmental acceptability and sustainability of the proposed wastewater management infrastructure.

In the recent past some significant changes have taken place with respect to the environmental policy, legislation and authorisation of proposed effluent discharges to the marine environment. This has included:

- changes in the regulatory authority responsible for the issuing of Coastal Water Discharge Permits and General Authorisations for land-based wastewater discharges into coastal environments;
- a review of the policy, legislation and operational guidelines associated with the discharge of land-based wastewater to the marine environment and the implementation thereof;
- recent and pending reviews of water and sediment quality guidelines;
- changes in the legislation governing the Environmental Impact Assessment process.

These changes, together with a changing landscape with respect to the type and nature of wastewater discharges, have highlighted some existing and potential future challenges. These include a need for a number of changes in the execution of effluent management infrastructure development projects, as well as the consideration of improved techniques for scientific and technical assessments and the use of novel construction methods to expedite and provide greater flexibility in the planning and execution of wastewater management infrastructure developments projects.

Environmental policy and authorisation processes

Prior to the promulgation of the Integrated Coastal Management Act, 2008 (Act No. 24 of 2008) (ICMA), the disposal of land-derived effluent