

# DESIGN, CONSTRUCTION, OPERATION AND EFFECTIVENESS OF A PILOT ARTIFICIAL WETLAND SYSTEM TO REMOVE STORMWATER AND SEWAGE POLLUTANTS ENTERING THE SWARTKOPS RIVER ESTUARY VIA THE MOTHERWELL CANAL, NELSON MANDELA BAY, SOUTH AFRICA

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## ABSTRACT

SRK Consulting conceptualised, designed and supervised the development of a R 7,5-m artificial wetland for the Nelson Mandela Bay Municipality in the Eastern Cape, which may herald a new approach to the natural cleaning of polluted water entering South African rivers and estuaries. The pilot scheme is believed to potentially be the first of its kind in South Africa.

The Motherwell stormwater canal was designed to discharge stormwater into the Swartkops River estuary, but becomes contaminated at times with sewerage spills emanating from the Motherwell residential area. The Swartkops River estuary is ranked as the top temperate estuary in terms of subsistence value and the eleventh most important estuary in South Africa (Turpie & Clark, 2007). Prior to the commissioning of the artificial wetland system, the quality of the water entering the Swartkops River estuary from the Motherwell Canal exceeded the Department of Water Affairs general guideline for recreational use by between ten and five hundred-fold.

The construction of the wetland included a rock-filled reinforced concrete structure 65 m long by 8 m wide as the primary element in the cleaning process. Water percolates through the aggregate and begins the biological polishing process. It then flows under gravity through two reed beds planted with *Typha capensis* reeds.

To date, the artificial wetland system has resulted in a marked reduction in the concentration of *Escherichia coli*, faecal coliforms and total coliforms.

## INTRODUCTION

The Nelson Mandela Bay Municipality is responsible for the management of the Motherwell Canal, a stormwater canal designed to discharge stormwater into the Swartkops River estuary. However, the canal becomes contaminated at times with sewerage spills emanating from the Motherwell residential area due to blocked sewers and pump station electrical failures. A substantial volume of litter also enters the canal on a continual basis. All of this pollution was entering the Swartkops River estuary via the canal. The Swartkops River estuary is ranked as the top temperate estuary in terms of subsistence value and the eleventh most important estuary in South Africa (Turpie & Clark, 2007), but is threatened by pollution and other impacts. Prior to the commissioning of the artificial wetland system, the quality of the water entering the Swartkops River estuary from the Motherwell Canal exceeded the Department of Water Affairs general guideline for recreational use by between ten and five hundred-fold.

SRK Consulting (South Africa) (Pty) Ltd. was appointed by the Nelson Mandela Metropolitan Municipality in January 2006 to prepare designs for the implementation of a pilot artificial wetland at the end of the Motherwell canal to scrub the stormwater passing through the Motherwell canal and reduce ongoing pollution of the estuary. A portion of land of 0.8 ha along the western side of the stormwater canal was immediately available for the construction of the wetland. The size of the necessary wetland to adequately address the pollution levels (Chemical Oxygen Demand (CODs) and Biological Oxygen Demand (BoDs)) and hydraulic requirements was determined at 4.5 ha. Due to the site space constraints, the development of a pilot wetland as a precursor to a potential future series of such wetlands was agreed to by the Municipality. The pilot wetland was designed to filter low flows diverted from the stormwater canal through a series of ponds prior to diversion back into the river (SRK Consulting, 2008).

## **METHODOLOGY**

### **CONCEPTUAL DESIGN**

A constructed wetland system is envisaged to operate as a low maintenance system due to its long hydraulic detention times and low overall activity i.e. no mechanical parts other than the valves and transfer pumps (dry weather conditions).

Constructed wetlands aim to systematically control and optimise the ability of a wetland system to remove or transform waste-water pollutants and in many cases to also create an aesthetic environment for wildlife and social objectives. Constructed wetlands can mimic natural systems in that water flows over the bed surface and is filtered through the dense stand of aquatic plants, Free Water Surface systems (FWS), or the system can promote subsurface flow through shallow, permeable media in which the plants are established, Subsurface Flow systems (SF). Surface flow marshes are popular in the USA for large waste-water flows and polishing (cleaning) of nutrients, whilst subsurface flow systems are widely accepted throughout Europe, Australia and South Africa. Provision of a permeable media in relation to the hydraulic loading to obviate surface ponding tends to be an expensive component of the subsurface flow systems, and the factor responsible for the majority of problems when permeability is not adequately catered for. The land area and engineering required to establish a Constructed Wetland arrangement is largely related to the degree of treatment required from the system in relation to the social and aesthetic objectives and topography of the site available. The units may operate as surface or subsurface filtration systems to optimise physico-chemical pollutant removal mechanisms and to balance aerobic and anaerobic biological degradation reactions, evapotranspiration and infiltration.

FWS systems usually receive pre-treated or secondary wastewaters, while the SF wetlands tend to receive primary wastewaters and are often a component of integrated systems where their discharge passes to a FWS for polishing. The water depth in FWS systems is generally shallow, < 500 mm, to encourage plant growth in the free water interface. Consequently, FWS systems tend to require larger surface areas than the equivalent SF system, requiring additional hydraulic consideration to ensure that water optimally flows through the open water areas. Long retention times and an extensive plant material surface area, provide for filtration removal of particulate and organic matter. The sediment, plant biomass and plant litter surfaces are also where most of the microbial activity affecting water quality occurs, including oxidation of organic matter and transformation of nutrients. The slow decomposition of plant matter accumulating on the bed surface, also provides a matrix media of low bulk density, high water holding and cation exchange capacity and thereby a high potential to transform organic material and nutrients through the wealth of resident microbes.

SF wetland systems receiving domestic sewage generally function as little more than anaerobic in-situ contact chambers and attached growth biofilters. The media provides the attachment surface for micro-organisms able to anaerobically and / or anoxically (if nitrate is present), reduce organic pollutants into CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>S etc. and new microbes. The media also acts as a filter for the retention of suspended solids and microbial solids, which can be degraded and stabilised over an extended period within the bed, so that outflow suspended solids levels are generally low.

Where low organic and hydraulic loads are applied to a wetland, a SF system can become a low rate nitrification biofilter, whereby nitrifying bacteria are able to compete for sites on the media with the aerobic

heterotrophs. Adequate oxygen to support a degree of nitrification can then be supplied via direct diffusion from the atmosphere as well as that produced by the plants themselves.

In order to meet the various objectives, the Motherwell Canal Artificial Wetland System was designed to enable both FWS and an SF and ensure that very limited maintenance would be required.

### **DETAILED DESIGN**

A pilot debris control system (PDCS) was designed and commissioned in the Motherwell Canal to trap and enable the removal of litter, prior to its entry into the wetland. The design of the wetland included a primary (SF) and two secondary cells (FWS) (see Figure 1). A cut-off was installed in the canal to intercept the low flows, diverting flows into the primary cell. A silt trap was included in the primary cell structure.

Contaminated water is retained in the cells for a period of time and ultimately discharges at a new outlet at the lower end of the second secondary cell. The second and lower secondary cell is protected by gabions.



Figure 1: The artificial wetland includes a primary reinforced concrete containment cell (right) and two secondary reedbed cells (centre A and left B) for treatment.

The primary cell consists of a reinforced concrete containment structure with plan dimensions of approximately 65 m long by 8 m wide. The steep gradient of the site and the limited site area available dictated that the structure be partly buried in the slope above the site with excavation depths varying between 1.5 m on the downslope side and 3.5 m on the upslope side. At design stage it was recognised that the silt carried in the incoming flow would be problematic in terms of eventual blockage of the rockfill pore spaces. The primary cell inlet structure therefore included a silt trap. Take off from the canal was achieved by installing a deflector plate that diverted flows from the canal into a 400 mm diameter pipe inserted into the wall at the canal at invert level. A trash screen at this location provided additional protection against litter and debris entering the system. Flow to the primary cell was controlled by adjustment of a valve in the 400 mm delivery line. A distribution channel was constructed to ensure an even flow into the primary cell. A calibrated V notch plate was installed between the silt trap and the distribution channel to provide accurate flow data. Water quality improvement can then be referenced against varying throughputs with a view to optimising the system. The primary cell outlet structure included eight outlet pipes positioned vertically in pairs. The floor of the containment structure was sealed with a high plasticity index clay layer sourced on site. Stone ballast of nominal size 40 mm was used as the rockfill and the structure was filled to 100 mm below the top of the structure walls. During the initial flooding of the cell all outlet pipes were closed. The top pair was then opened. This provided the best environment for bacteria to develop in contact with the rockfill. A by-pass pipe system was installed to ensure that during periods of maintenance water supply to the secondary cells could be ensured (see Figure 2).



Earth berms were constructed to form secondary cells A and B. These berms included a clay core. The cell bases and side slopes were sealed with a compacted layer of high plasticity index clay. A layer of topsoil, previously stockpiled on site during the site preparation phase, was spread over the clay. A brick and concrete chamber was constructed at the inlet to secondary cell A to receive flows from the primary cell. A distribution pipe was installed to ensure even flows into the cell. Two overflow weirs were constructed in the berm separating secondary cells A and B. These weirs included provisions for adjustments to the overflow level which would serve two purposes: firstly to maintain water depth as the reed biomass increased; and secondly as a means of disturbing any preferred flow paths that could develop that would reduce the retention time within the cell. Scour outlet structures and drain pipes were installed in each cell. Each cell can thus be drained individually whilst ensuring that the remaining cell still receives sufficient water to support the reeds. An outlet structure and discharge pipe were installed in secondary cell B, discharging directly into the Swartkops River estuary. The invert of the discharge pipe was set above spring high tide level.

Once construction of the primary cell and secondary cells was complete, reeds were harvested from local wetlands and planted in the secondary cells. *Typha capensis* (bulrush) reeds were chosen as the preferred reed due to availability and their rapid response to increased nutrient load. Sudden increases in leaf growth would be a useful indicator of increased pollution. The reeds were harvested and planted by hand at approximately 300 mm centres. At the end of the 12 month maintenance period, a survey showed almost 100% survival rates and no replacement plants were required.

The wetland does not require substantial maintenance. Maintenance of the primary cell is limited to periodic clearance of primary cell silt trap as well as clearance of litter and debris that enters the system and accumulates on the surface of the rockfill. The secondary cell weir overflow levels need to be raised if it is noticed that the water depth has become inadequate and if preferential flow paths have developed. Harvesting of the reed leaf growth stimulates growth and increases water polishing capacity. Consideration has been given to engaging local communities in these activities. This would generate employment and the harvested vegetable matter could be used in the production of compost for use in vegetable gardens that have been established in the Motherwell area.

## RESULTS

Prior to the commissioning of the artificial wetland system, the quality of the water entering the Swartkops River estuary from the Motherwell Canal exceeded the Department of Water Affairs general guideline for recreational use by between ten and five hundred-fold.

To assess the efficacy of the artificial wetland system, water quality monitoring was undertaken on a weekly basis for 11 months, which commenced upon initial intake into the system on 19 February 2010 (see Figure 3 and Figure 4). During the evaluation period a marked reduction in the concentration of *Escherichia coli*, faecal coliforms and total coliforms being discharged from the wetland system in relation to intake water was observed.

The wetland illustrated increasing effectiveness over the initial four month period, which was attributed to increased microbial and reed colonisation. However, during month four of discharge, the Municipality increased the rate of intake water into the system, which resulted in a moderate reduction in the effectiveness of the system due to reduced residence time.

For a six week period from 2 September 2010, the intake water quality was particularly poor, which coupled with the high intake rate, could not be adequately processed by the wetland. However, upon minor improvement in the intake water quality, the system responded positively with an associated improvement in discharge water quality from the wetland system and a return to near 2 September 2010 discharge water quality by 4 November 2010.

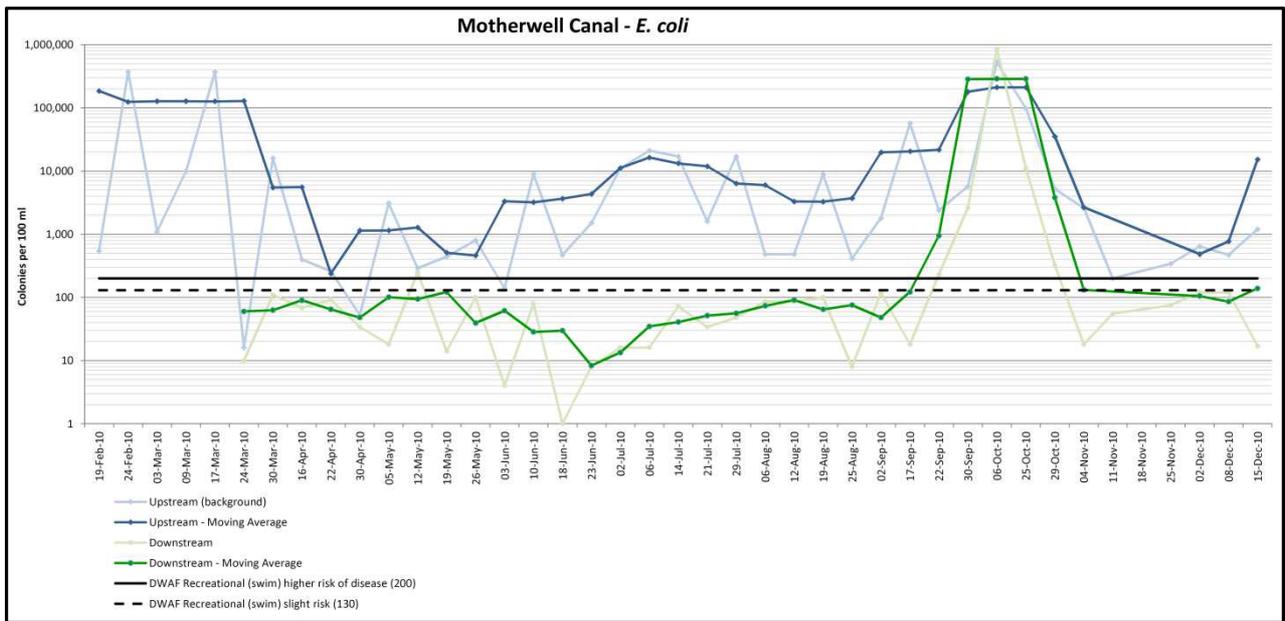


Figure 3 Water quality measured as *E. coli* concentrations entering and being discharged from the artificial wetland during the monitoring period.

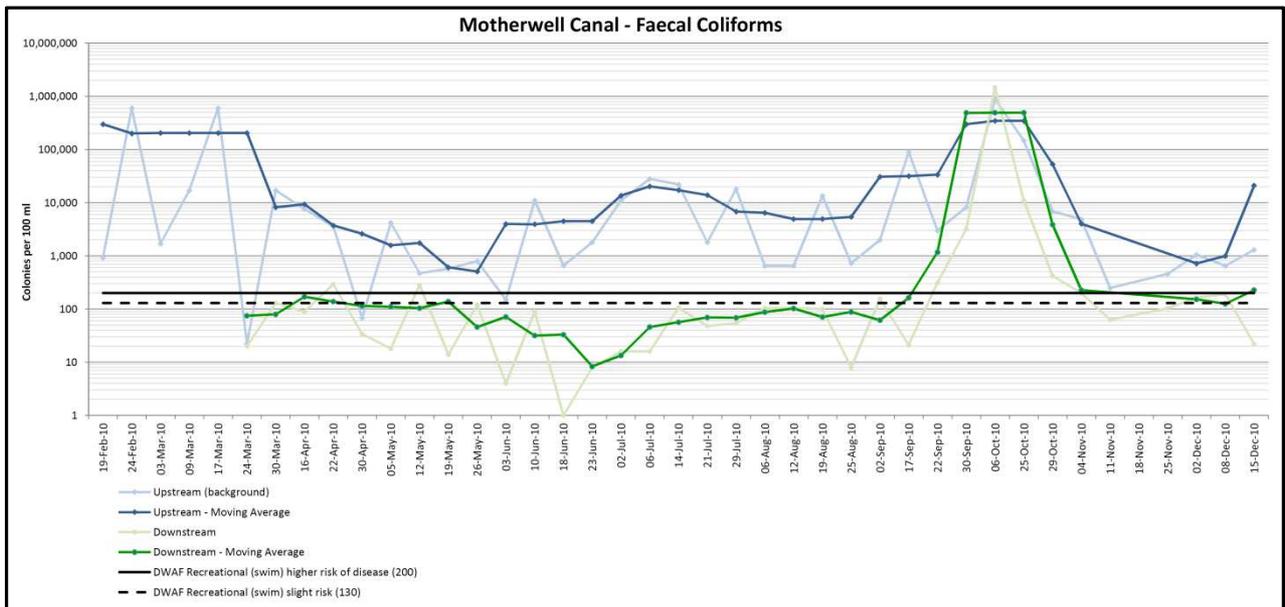


Figure 4: Water quality measured as Total Coliform concentrations entering and being discharged from the artificial wetland during the monitoring period.

## CONCLUSIONS

Due to space constraints of available land, a portion of land of only 0.8 ha was available, whereas the hydraulic requirements of the Motherwell canal were determined at 4.5 ha. The system was therefore designed as a pilot, as a precursor to a potential future series of such wetlands.

The Motherwell Canal Artificial Wetland System was designed to enabled both free water surface and subsurface flows, which has optimise the potential to remove or transform water pollutants. The institution of litter traps and a sand filter upstream of the wetland ensured that the functioning of the system was not compromised. The design also ensured that very limited ongoing maintenance would be required.

A marked reduction in the concentration of *Escherichia coli*, faecal coliforms and total coliforms was achieved during the water quality monitoring period. However, the effectiveness of the system was

moderately reduced upon substantial increase in the intake water beyond optimum levels. The ability of the system to assimilate pollution was also reduced upon substantial reduction in intake water quality when coupled with a high intake water rate.

The artificial wetland system proved highly effective in removing and transforming bacteriological water pollutants, but operation of the system within its intended capacity is vital to achieving optimal effectiveness. Periodic assessment of the performance of the system is recommended to enable optimisation and ongoing efficacy.

## **REFERENCES**

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