Sludge and washwater management strategies for the Vaalkop water treatment plant

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Abstract The Vaalkop plant, owned and operated by Magalies Water, provides a valuable South African case study of sludge and washwater management at a large water treatment plant. Starting out as a small plant of 18 Ml/day about thirty years ago, it has steadily grown to a plant with treatment capacity of 210 Ml/day; fairly large by South African standards. During the preceding years, it has not only been subject to a vastly larger scale of operation, but it also had to adapt to a tremendous increase in the cost of raw water, an increased environmental awareness amongst water treatment professionals and general public alike, and a much more sophisticated and complicated legislative framework. It is the objective of this paper to track the sludge and washwater management practices adopted over the years at Vaalkop, and to present the current strategies adopted for the medium to long term.

The paper will summarize the previous methods of sludge and washwater disposal, with reasons why they were adopted. The multitude of technical analyses and alternatives that were performed over the years will be summarized, and may provide valuable pointers for other applications in South Africa. The current system, which has just been commissioned, will be presented; its technical design parameters, the anticipated mode of operation, its costs and how the current environmental and legislative requirements are being met.

Keywords Magalies Water; sludge dams; sludge disposal; sludge production; washwater recovery; Vaalkop water treatment plant

Introduction

The Vaalkop water treatment plant is situated immediately downstream of the Vaalkop Dam, which was built at the confluence of the Hex and Elands Rivers in the North-West Province. It started out with a capacity of 18 Ml/day in 1970, extended to 30 Ml/day in 1979, extended to 60 Ml/day in 1983, and yet again to 120 Ml/day in 1990. At the present moment (2000), extensions have just been completed to bring the total capacity to 210 Ml/day. The plant is owned and operated by Magalies Water. Figure 1 shows a site layout of the dam and the treatment plant, as well as how the plant was progressively enlarged over the past thirty years.

It is the objective of this paper to track the sludge and washwater disposal practices at Vaalkop since its beginning. During the past thirty years, the following factors forced Magalies Water to continuously assess alternative disposal practices and to make adjustments when necessary:

- the plant increased its capacity from 18 Ml/day to 210 Ml/day;
- the cost of raw water (and thus the benefits of water recovery) increased dramatically as more expensive sources for the Gauteng area had to be developed;
- a greater awareness on the potential environmental impacts developed amongst water treatment professionals and the general public; and
- a much more stringent legislative framework for sludge disposal was put in place.

The situation before 1989

The Vaalkop Dam wall cuts across both the Elands and Hex Rivers, about 600 metres upstream of their confluence. The spillway of the dam discharges into the course of the Elands River, while the last section of the Hex River was left dry upon construction of the...
dam wall. This section of the old Hex River was utilized as a sludge lagoon for the treatment plant since 1972 by building two simple, cheap embankments across the Hex River course, immediately ahead of the confluence. The supernatant from the lagoon discharged into the river, without any water recovery.

This arrangement worked without problems and intervention for more than fifteen years, during which time the sludge lagoon was gradually filled with solids. During 1987/88, unusual inflow patterns into Vaalkop Dam caused prolonged periods during which exceptionally high turbidity was sustained. The four highest monthly average turbidities were 884, 369, 175 and 99 NTU, with the other eight months between 40 and 60 NTU. Increased backwash and desludging frequencies at the treatment plant led to a complete overloading of the sludge lagoon, to the extent that it overflowed its banks and ponded on a large area adjacent to the lagoon. This situation was clearly unacceptable and Magalies Water commissioned GFJ Consulting Engineers to formulate a sludge management strategy for the Vaalkop treatment plant.

**The 1988 sludge management study**

The 1988 study (GFJ, 1988) firstly provided an estimate of the expected solids mass generated by the purification process. Having measured a turbidity:mass ratio of 1.2 mg SS.l⁻¹.NTU⁻¹, the daily sludge production (as dry solids) for the 1987/88 year could be calculated. This analysis showed that:

- the daily dry solids production fluctuated wildly between 0.1 and 1.3 t.Ml⁻¹;
- the 95th percentile (adopted as a design guideline for sizing the maximum capacity of sludge handling equipment) was 1.0 t.Ml⁻¹; and
- the 50th percentile (adopted as the average production rate) was slightly less than 0.1 t.Ml⁻¹.

Secondly, it demonstrated the varying nature of the solids produced and suggested ways of minimizing the volumes of sludge to be treated:

- the maximum solids concentration of sludge withdrawn from the hoppers of the settling tanks was 3.9%;
- the maximum solids concentration of the filter backwash water was 0.2% or twenty times less than that of settling tank sludge;
- filter backwash water can be more effectively utilized by having two short wash periods rather than one long wash period;
- the option to recover relatively clear supernatant for re-treatment had great potential for cost savings; and
- small-scale laboratory tests indicated that a solids content of 13.9% could be attained after 100 days consolidation by gravity.
The third part of the investigation demonstrated the effect of conditioning polymers on the thickening behaviour of sludge:
- anionic polymer performed significantly better than nonionic polymer;
- sludge thickening under gravity was greatly accelerated by anionic polymer (a concentration of 8% could be achieved within 3 minutes, while a control sample without any polymer added took about 20 hours to attain the same concentration); and
- the ultimate sludge concentration (after tens of days), however, was approximately the same, whether polymer was added or not.

The fourth part of the investigation considered mechanical means of sludge thickening, including drying beds, centrifuges, vacuum systems, synthetic screens and tubular pressure filters. It was clearly demonstrated that the costs of these systems were excessive, mainly due to the fluctuating nature of the solids loads. These systems have to be sized for the maximum sludge load, which are more than ten times higher than the average sludge load. Coagulant recovery (acid extraction of Fe or Al from the sludge) was also not cost-effective due to the relatively low percentages of iron hydroxides in the sludge. The study concluded that sludge lagoons were the most appropriate long-term solution at Vaalkop, as they:
- are large enough to buffer the varying solids loads;
- allow enough time for adequate thickening without the need of conditioning polymers; and
- allow easy and cost-effective recovery of the supernatant with a simple overflow structure.

The 1990 sludge lagoon system
Based on the 1989 study, a first lagoon (useable volume 10,700 m³) was constructed during 1990 and a second, similar lagoon (useable volume 11,500 m³) was constructed during 1992. The combined sludge and washwater pipeline transfers the sludge from the treatment plant to the lagoons at an average slope of 1.2%. The supernatant is collected in a sump of 200 m³ and intermittently pumped to the inlet of the plant at 100 m³.h⁻¹.

The performance of these lagoons was closely monitored during the 1990s. After a few years of operation, one of the dams was taken out of service in order to excavate the thickened sludge from the bottom. It turned out that it took several months before the sludge was adequately dried out to allow movement of equipment in the sludge lagoon. Upon mechanical excavation, which proved to be time-consuming and tedious, the sludge was piled into heaps next to the sludge lagoons. After the sludge had been removed from the sludge dams, it took another few months to completely dry out. The dried sludge initially formed crystalline-like particles, but later degenerated to small cubic shaped granules. Natural vegetation started to cover the sludge heaps soon after it was spoiled. Initial concern was that the dried sludge would be rendered sterile by the treatment chemicals added, but the rapid and luscious growth demonstrated that the small quantities of iron hydroxide added had no noticeable effect on the fertility of the natural sediments washed into the Vaalkop Dam. Figure 2 shows an aerial photograph of the area where the sludge was left to dry. The spoiled sludge had a negligible effect on the adjacent environment.

The savings realised by the recovered supernatant were significant and fully justified the operational burden of operating and cleaning the sludge lagoons. At the time of cleaning, the lagoons recovered an approximate average of 2,400 kl.d⁻¹ of supernatant, which translated into an annual saving of R175 000.

The 1998 sludge management study
During 1998, a further doubling of the Vaalkop treatment plant was again being planned. The greater need for sludge disposal, coupled to the difficulties encountered during the mechanical excavation of the existing lagoons, prompted Magalies Water to commission
GFJ Consulting Engineers to update and possibly revise their 1989 study, before additional land was purchased for further sludge lagoons (GFJ, 1998).

The maximum and average sludge production rates were firstly revised. The data of the 1987/88 (the only data available at the time of the 1989 study) was supplemented by data from the years 1991/92/93 and 1995/96/97, which showed that the average sludge production in later years was about 0.05 t.Ml⁻¹, significantly less than the 0.10 t.Ml⁻¹ assumed in 1989. The maximum recorded monthly average was 0.4 t.Ml⁻¹ compared to the 1.3 t.Ml⁻¹ measured in 1987/88. The probable reason for this marked drop in sludge production rate is the change in river flow due to increased return flow from the Johannesburg/Pretoria complex. Part of this flow is partially transferred from the Crocodile River to the Vaalkop Dam by a canal, which has allowed an increase in yield of the Vaalkop Dam from its natural 32 Ml.d⁻¹ to the present installed capacity of 210 Ml.d⁻¹.

The density of sludge at the bottom of the sludge lagoons was secondly estimated from surveys done in the existing lagoons. Whereas the laboratory results during 1989 indicated a density of 13.9% after 100 days of settling, higher values are expected in practice due to the weight of the newly deposited sludge bearing down on the older sludge below. By estimating the total volume of sludge occupied after seven years of operation (which can obviously not be done with great precision), and knowing what the average sludge production was during this time, an average sludge density 40% was estimated, which seems to be unrealistically high. A conservative figure of 20% was assumed for future projections, subject to revision upon closer monitoring of the sludge lagoons in future.

Alternative operational strategies for the sludge lagoons were investigated next. Three options were considered in detail from a technical perspective.

- The first option was to keep to the existing type of sludge lagoon, which could be taken out of operation when filled, allowed to partially dry out and then mechanically excavated with the material landfilled close by. This option has the significant advantage that sludge and backwash water will always gravitate to the sludge dams, thus obviating the need to pump sludge at constantly changing rates and consistency.
- The second option was to use a continuously operated sludge lagoon, from which settled sludge could be continuously sucked up from a travelling bridge and pumped elsewhere. The capital cost of the relatively sophisticated mechanical equipment made this option uneconomical.
- The third option was to deposit the sludge in a tailings dam, i.e. to construct a solid...
sludge dump by controlled deposition of the sludge; a method used extensively in the mining industry. The water treatment sludge would need gravity thickening before deposition. This option, which would have been a first for a water treatment plant in South Africa, required fairly detailed information on the properties of the water treatment sludge, information not available at the time (Wates, Meiring and Barnard, 1998). The main drawbacks of this option, however, were the continuous supervision required and most importantly, the eventual abandonment of the only available site to which the sludge and washwater could be drained under gravity.

The final part of the investigation dealt with environmental and legal concerns. Magalies Water was at the time in the process of constructing a major new expansion at its Vaalkop treatment plant, and had to compile an Environmental Impact Assessment (EIA) of the new development in terms of the Environment Protection Act, including the sludge disposal system. The EIA pointed out that the disposal of sludge required special attention in terms of the new Environment Protection Act as well as the Minimum Requirement for Handling, Classification and Disposal of Hazardous Waste (DWAF, 1998).

The proposal to eventually landfill the sludge initially raised the eyebrows of government officials and environmentalists, until it was demonstrated that the water treatment sludge resembles neither the sludge typical from a mining operation nor the typical sludge from a sewage treatment sludge; the two sludge types which were routinely dealt with in terms of the above laws. The sludge from the treatment plant is, with the exception of minute additional quantities of inert ferric hydroxide, exactly the same material deposited in vast volumes within the Vaalkop Dam from which the water for the treatment plant is extracted!

The claim for exempting the sludge lagoons from the usual restrictions was based on two main arguments, namely that: a) the sludge lagoons are an integral post-settling part of the treatment process to allow water recovery and not a final means of sludge deposit; and b) that the sludge is inert and will not contaminate the adjacent area. The officials were satisfied with the first argument, but had reservations about the latter and requested further testing. A series of tests were therefore conducted to determine the presence of potential harmful substances by performing inorganic and organic analysis of the sludge as well as the potential leachate. The results showed that most compounds were not detectable in the leachate and that those which could be detected were well below the allowed limits (Wates, Meiring and Barnard, 1999). The sludge was therefore classified as inert, paving the way to apply for exemption from section 20 of the Environment Conservation Act.

The 1999 sludge lagoon system
The new lagoon system was designed to accommodate sludge and backwash water from those parts of the treatment plant which had a total capacity of 180 MI.d⁻¹ i.e. from the 1983, 1990 and 1999 extensions. The existing two lagoons constructed during 1990 and 1992, were retained to treat sludge from the 1970 and 1979 treatment plant extensions. A layout of the system is shown in Figure 3.

The new sludge lagoon system consists of the following main components.
• A channel to transfer the combined washwater and sludge flows from the treatment plant to the sludge lagoons under gravity.
• Two sludge lagoons to provide retention for sludge settling and to retain settled sludge.
• A pumping system to return supernatant from the lagoons to the treatment plant.

The hydraulic design of the transfer channel makes provision for an instantaneous peak washwater and sludge flow rate of 6,660 m³.h⁻¹. To determine this peak flow rate, a conservative assumption was made that washwater / sludge could be discharged from both the 1983/1990 and the 1999 plant extensions simultaneously. A trapezoidal channel with effective cross-sectional area of 1 m² and longitudinal gradient of 0.1% was required and constructed.
Sludge is discharged into one of two sludge lagoons, constructed on land that is conveniently located and downhill from the treatment plant. The anticipated operation philosophy is to fill one dam with sludge over an estimated period of 18 months. During the following 18 month period this lagoon is then isolated, the sludge left to dry and the sludge removed mechanically while the second dam is filled with sludge, etc. The in-situ soil allowed for the construction of the lagoon earth walls by a simple cut-to-fill earthworks operation. Each lagoon has a storage volume of approximately 32,100 m³ and an effective depth of 1.6 m. The storage volume allows for the following.

- At an average water treatment capacity of 150 Ml.d⁻¹, average sludge production of 0.05 t.Ml⁻¹ and a sludge concentration of 20% being achieved in the lagoons, the annual sludge production amounts to 13,700 m³ as dry solids. Over a period of 18 months a lagoon will thus be 65% filled with sludge – the maximum sludge level anticipated at this stage before the sludge is left to dry and removed from a lagoon. If any of the sludge production parameters varies from the above, the filling period might be longer or shorter.
- With the above maximum sludge level in a lagoon, a volume of 11,500 m³ is still available above the sludge layer, to provide retention for sludge/wash water settling. The anticipated daily peak sludge/wash water production is 7,200 m³.d⁻¹ (4% of 180 Ml.d⁻¹). The minimum available retention period will thus be 38 hours at peak flows through a lagoon filled with sludge to the maximum anticipated level. At an average sludge/wash water production of 4500 m³ (3% of 150 Ml.d⁻¹) the available retention period will be 60 hours.

To achieve some extent of plug flow through the lagoons, a baffle earth wall was provided in each lagoon. This feature can be seen in Figure 4, which shows the dams being constructed. Supernatant is withdrawn from the lagoon over a weir at the farthest end from the inlet. The level of the weir is adjustable to accommodate varying sludge levels in the lagoon. The weir is sized to limit the rate of supernatant discharge, the lagoon thus also act as balancing reservoir.

The earlier excavation of the older sludge lagoons, described earlier, was hindered by difficult access to the sludge lagoons. The in-situ sludge on the lagoon floor is saturated and mechanical plant tended to get stuck. To improve accessibility in the new lagoons, a concrete access ramp and rock fill platform were provided in each new lagoon.
Supernatant from the lagoons is collected in a balancing sump with effective volume of 430 m$^3$. From here the supernatant is pumped back to the treatment plant with dry well pumps (two units, one or both on duty) via the raw water pumping mains. The pumping rate can vary between $330 \text{m}^3\text{h}^{-1}$ and $480 \text{m}^3\text{h}^{-1}$ depending on the pressure in the raw water pumping mains and whether one or two pumps are operational. These rates were selected to be as low as possible to minimize the impact of returned supernatant on the chemical dosing system at the treatment plant.

Once a sludge pond is filled with sludge it will be taken out of commission, allowed to dry out for a few months and then the semi-dried sludge will be spoiled on a special landfill site where the sludge will be allowed to dry completely. This site will only be required in about five years time. A site has already been identified and negotiations with land owners will start soon.

**Conclusions**

The historical development of the sludge management system at the Vaalkop water treatment plant is a valuable case study, as it shares many of the typical problems encountered at other water treatment plants in South Africa. After thirty years of operation, the following general conclusions are drawn.

- The solids production rate for treatment plants treating inland surface waters, even after being impounded in a relatively large dam such as Vaalkop Dam, is highly variable and occasionally reaches extremely high peaks. The monitoring at Vaalkop, for example, indicates a long-term average of between $0.05$ and $0.10$ t.ML$^{-1}$ of raw water treated, while the maximum recorded monthly average value was $1.3$ t.ML$^{-1}$.
- There are indications that the solids production rate at Vaalkop is gradually dropping as inflow into the dam is augmented and partially stabilized by increasing transfers from the Crocodile River (conveying eutrophic return flow from the Johannesburg/Pretoria metropolitan area). This trend can only be properly quantified after further long-term monitoring.
- The highly variable nature of the solids load puts mechanical thickening options such as centrifuges, belt and vacuum presses, mechanical screens, etc beyond economic reach. These systems, which are expensive and require constant supervision, have to be sized for maximum loading, but on average will only be loaded at about one-tenth of their capacity.

**Figure 4** The new sludge lagoons under construction, with the Vaalkop Dam on the far left.
• The use of conditioning polymers dramatically speeds up the thickening process during the first few hours, and are thus indispensable when dealing with thickening systems where the throughput time in measured in minutes or hours. Tests on Vaalkop sludge with long-term gravity thickening (tens of days or longer) have however shown that these polymers have little or no effect on the eventual sludge concentration.

• These technical and cost considerations strongly suggest that sludge lagoons remain the most appropriate sludge disposal system. With adequate volume, they effectively even out the variable solids load, allow enough time for sludge consolidation at the bottom of the tank, and allow water recovery by simple decantation. The turbidity of the supernatant is most of the time less than the raw water from the Vaalkop Dam.

• An important design parameter for sludge lagoons is the bottom sludge concentration attained after a few months of retention. Small-scale laboratory tests (without the benefit of a thick layer of overlying sludge bearing down on the bottom layer) indicate a sludge concentration of 14% after 100 days. An attempt to estimate this number from the sludge buildup in the existing lagoons (a notoriously difficult procedure) indicated that it could be as high as 40%. A conservative design figure of 20% was adopted at Vaalkop.

• The interesting option of a tailings dam (where the sludge is deposited in a controlled manner to eventually form a large dump) was eventually abandoned as it would require a thickener prior to the tailings dam, and would require continuous pumping of sludge and washwater from the treatment plant to the disposal site. Sludge and washwater disposal is critical for continuous plant production. The lower reliability of a sludge pumping system (as opposed to drainage by gravity) thus weighed heavily against this option.

• The final solution being implemented at Vaalkop consists of two additional dams which will provide a water retention time of about three days under average conditions. It is anticipated that one dam will be taken out of service every 18 months, allowed to dry out and then mechanically excavated before being put back into service. The excavated material will be landfilled.

• The proposed system complies in all respects with current environmental legislation and has been approved by the Department of Environmental Affairs and Tourism as well as the Department of Water Affairs and Forestry. It was the first water treatment plant in South Africa that had to classify its sludge under the new legislation.

• An integral part of the system is a water recovery system which proved to be highly cost-effective in the past, and will continue to do so as raw water costs escalate. A 150 Ml.d−1 production rate will approximately produce 6 Ml.d−1 recoverable supernatant. Using a conservative raw water cost of R0.50/kl a saving of more than R1m per annum can be realised. The total cost of the land purchased, the construction of the sludge dams and the supernatant recovery system was R3.8m, indicating a payback period of less than four years, or even shorter if the raw water tariff escalates above R0.50/kl.

• Apart from the issues relating to the economics and legislation, a final benefit of another kind arises from this particular type of sludge lagoon. The lagoons offer a habitat for many bird species and the species diversity frequenting the sludge dams have been monitored since it construction.

References