Reduction of the external nutrient load

INTRODUCTION

In South Africa the Hartbeespoort Dam (HBPD) is among the water bodies most severely affected by eutrophication. It is positioned downstream of large industrial and densely populated commercial centres (i.e. the Johannesburg and Tshwane Metros) which discharge treated wastewater from sewage treatment works (STW) and urban stormwater.

Runoff from natural and agricultural land, from mining areas, and from townships and squatter camps with no sewerage systems (hot spots), contributes to the HBPD's additional nutrient load, which, combined with local climate characteristics (high summer temperatures, high intensity of photosynthetic active radiation) creates the worst scenario possible in favour of eutrophication and its consequences.

The remediation of the HBPD has to address an excessive nutrient load (dissolved and associated with sediments) either accumulated historically in the dam (i.e. internal nutrient load) or expected to be released from the catchment in the future (i.e. external nutrient load).

In remediating the water quality and the ecosystem of the dam the approach is to decrease the dam's trophic levels by controlling the phosphorous (P) load, phosphorous being a pivotal nutrient in eutrophication abatement. This will be achieved by the reduction of the dam's Internal Phosphorous load, originating from dam sediments (see article "Sediment removal and management") and by the reduction of the External Phosphorous load, originating from the dam's catchment. The latter, which is the main cause of the severe eutrophication in the dam, is the subject of this article.

Table 1 Data on the effluent discharge of STWs in the HBPD catchment

STW	Flow 2007/8 ML/d	Flow 2007/8 ML/yr	Susp. Sol. t/yr	O-Phosphate tP/yr
Randfontein	20	7 300	182.5	14.60
Percy Steward	29	10 585	370.5	39.69
Hartbeesfontein	40	14 600	146.0	7.30
Olifantsfontein	65	23 725	118.6	42.71
Sunderland Ridge	55	20 075	1 806.8	30.11
Driefontein	30	10 950	219.0	5.48
JHB Northern Works	400	146 000	2 920.0	146.00
TOTAL	**639**	**233 235**	**5 763**	**286**

Note: It was estimated that 75–80% of this discharge/load entered the HBPD

EXTERNAL PHOSPHOROUS LOAD TO THE DAM

The External Total Phosphorous load (ETP load) derives from the dam's catchment (point and non-point sources), where the ETP load transferred by the Crocodile River contributes more than 90% of the load. This means that future efforts to reduce this load have to be focused on the Crocodile River catchment.

Following available data on the STWs' effluent discharge, the composition of Phosphorous load and Suspended Solids load from point sources range from 200 – 250 tP/yr (2010 data) and from 5 500 – 6 000 t/yr respectively.

There is no reliable data on non-point sources (agricultural and urban runoff, squatter camps, spillage, etc) contribution in Total P load (TP load), but it most probably ranges between 45 and 55% of total load (ranges from 350 – 650 tP/yr), as roughly estimated from the mass balances performed. The major portion (more than 90%) of non-point sources TP load is associated with eroded soil particles or particles flushed out from urban surfaces and municipal dams.

It should be emphasised that discharge from point sources contains mainly dissolved P species, but TP load from non-point sources contains mainly phosphorous incorporated into fine particles, with a high probability of being released back into the water under a variety of hydrological and bio-chemical conditions in the dam.

The reduction of ETP load to the HBPD will result in dealing with both point and non-point sources, comprising both dissolved and particle phosphorous species.

STRATEGIES FOR THE REDUCTION OF EXTERNAL PHOSPHOROUS LOAD

A comprehensive consideration of the need for reduction of External Total Phosphorous (ETP) load to the HBPD, as well as remedial actions to be considered within the Crocodile River catchment, was done by Prof WA Pretorius (who regrettably passed away in 2009) and his collaborators.

In principle, two approaches have been considered:

The improvement of catchment management, including:

- The upgrade of STWs and the improvement of their operation
- The implementation of stricter phosphorous discharge standards
- Stricter control on point sources of pollution, including industrial effluent
- Improved control of non-point sources of pollution
- Improved management of numerous municipal dams and other retention dams that exist within the Crocodile River catchment
- Chemical removal of part of the phosphorus in the Crocodile River inflow to the dam
- The revival, restructuring, protection and management of natural treatment systems (wetlands, shoreline and in-stream aquatic ecosystems, etc) which retain and absorb nutrients.

ETP load influx control where a barrier between the catchment and the dam is implemented, and where at least 80% of the ETP load to the dam would be retained and removed.

A combination of the above two approaches should be an optimal strategy for the future management of ETP load to the HBPD. A necessary part of this strategy is the formation of a barrier (conditionally termed the "pre-impoundment") which will reduce that part of ETP and sediment load to the dam that cannot be successfully controlled even by the implementation of the planned catchment management improvements, and strict control of their sources within the Crocodile River catchment.

The concept (and conceptual design) of pre-impoundment with flow diversion was developed in 2008. It is based on the assumption that the temperature of water in the Crocodile River permanently exceeds that of surface water layers in the dam, so no mixing (or partial mixing only) of incoming river water and deeper layers of nutrient-rich dam water occurs.

Figure 1: Muddy sediment cloud observed during a flood on 20 Feb 2012 Location: Crocodile River mouth, 200 m downstream of the railway bridge, 150 m from left river bank at Oberon

The opposite assumption was revealed through recent monitoring of water quality in the dam and Crocodile River at the DWAF Hydrological Station AH012 (Kalkheuwel). The temperature of the Crocodile River water appears to be lower than that of water in the dam surface layers, meaning that a plunger point exists in the river mouth, the distance of which (from the mouth) varies depending on the incoming flow energy. This assumption was confirmed during a relatively small flood (peak flow ~150 m^3/s) which occurred on 20/21 February 2012 when the mobilisation of fine bottom sediments was observed (Figure 1).

In extreme flow conditions (peak flow >450 m^3/s) the whole main basin of the dam is partially flushed, so most of the fine top sediments are mobilised and turbid water rich in nutrients can be observed at the dam spillway.

This observation has prompted an update of the previously developed concept of pre-impoundment, and consideration of other possible options for a barrier between the catchment and the dam that would dissipate the river energy and would reduce the ETP load to the dam.

The update of the pre-impoundment (with flow diversion) project has not been done yet, but potential options have already been considered. The preliminary conclusion is that a barrier (conditionally termed the "pre-impoundment") for the reduction of ETP load should be installed between the catchment and the dam. In general, this barrier could comprise a pre-impoundment (or series of impoundments) of an appropriate size close to the dam. Alternatively the settling processes in the river inlet section and the river mouth should be improved, taking the river morphology and possible engineering interventions into consideration. Both options should be considered, and should provide:

- Retention of at least 90% of the suspended solids load associated with phosphorous
- Removal of at least 80% of ETP load from the incoming river flow
- Removal of settled sediments on a regular basis with subsequent processing of sediments at adjacent areas, and
- Retention and removal of floating debris and litter.

Several localities in the Crocodile River zone stretching from the dam to the Hennops River mouth are considered potentially suitable for the formation of a barrier. Each of these localities should be analysed in terms of hydrology, geology, availability of land and required volume, as well as in terms of impact on HBPD operations, residents, the environment, infrastructure, etc. The successful implementation of the barrier will be dependent on innovative engineering practices serving environmental protection requirements through all phases of the project, i.e. in the planning/study phase, the exploration phase and during construction of the barrier.

The construction of a barrier should be synchronised with activities around the reduction of the Internal Phosphorous load (i.e. historical P load within the dam). Dredging of the Crocodile River inlet zone, river mouth and the dam should therefore be completed over the period required to design and to construct the barrier.

CONCLUSION

It should be recognised that there is no quick, easy and cheap solution for the restoration of the HBPD. The problem has been developing over more than 80 years and will take time to resolve.

The restoration of the dam can also not be considered as a once-off action, but should rather be seen as a series of well-planned integrated measures within the Crocodile River catchment and within the dam basin itself, that should be strictly and persistently carried out (now and in the future).

Improved catchment management, the formation of a barrier between the dam and the Crocodile River catchment, as well as interventions within the dam basin should be implemented in parallel and run as long-term interventions.

The formation of a barrier between the HBPD and the Crocodile River catchment is considered a necessary and important step to reduce a part of the ETP load that cannot be controlled successfully even by the implementation of detailed planned improvement of catchment management and stricter control of sources of nutrients within the catchment.

If these actions are well planned, properly implemented and persistently carried out, the HBPD could be successfully remediated and converted from a waste trap to a beautiful body of water. Successful remediation of the HBPD would also earn international recognition of the successful interaction and co-operation between South African water scientists, engineers and decision-makers.

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