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The Berg Water Project supplement scheme

AS THE FIRST LARGE water resources infrastructure development project in South Africa to be designed, constructed and operated within the framework of the National Water Act and in accordance with the guidelines of the World Commission on Dams, a brief overview is given of the Berg Water Project (BWP), with special focus on the Supplement Scheme as part of the broader BWP.

ORIENTATION

The Berg River Dam, Dasbos pump station and pipeline to Dasbos tunnel and adit are situated approximately 6 km northwest of Franschhoek in the Berg River Valley.

The Drakenstein abstraction works and pump station are situated approximately 10 km downstream of the dam site on the right bank of the Berg River on the grounds of Drakenstein Correctional Services, and 1,5 km west of the R301 to Paarl.

The operations offices and control room for the project are situated in the Dasbos pump station, which is on the left bank of the river, approximately 200 m downstream of the dam.

BACKGROUND

In response to the increasing demand for water in the Greater Cape Town region, DWAF initiated the Western Cape System Analysis in April 1989. The BWP, which included inter alia the Berg River Dam (previously known as Skuifraam Dam) and Supplement Scheme, was identified as the preferred new water scheme to augment the water supplies from the Western Cape Water System.

The upper catchment of the Berg River to the south of the dam site is one of the most productive water catchments in the country and the BWP harnesses this resource for the benefit of the water users in the urban and agricultural sectors of the Western Cape. The BWP augments the yield of the Western Cape Water System by 81 Mm^3 (to 523 Mm^3) per year and integrates with the Riviersonderend – Berg River Government Water Scheme.

The project was funded and implemented by Trans Caledon Tunnel Authority (TCTA).

Berg River Consultants, a joint venture between Knight Piésold Consulting, Goba Consulting Engineers and Project Managers, and Ninham Shand Consulting Engineers, were appointed by TCTA in December 2002 as design and construction supervising consultants.

Impounding of the dam started in July 2007 and the pump stations and interconnecting pipework were brought into operation during the middle of 2008.

On completion of construction, the project components will be owned by TCTA, but operated and maintained by DWAF as part of the Western Cape Water System.

GENERAL DESCRIPTION AND MAIN COMPONENTS

In broad terms the components of the BWP are:

- The Berg River Dam on the upper Berg River in the La Motte forest. The dam is a concrete-faced rockfill dam (CFRD) approximately 938 m in length and 62,5 m high. The appurtenant structures include a 65 m high intake tower, a 5,5 m diameter concrete outlet conduit, outlet works and an ungated side channel spillway. The reservoir has a volume of 130 million m^3 and a surface area of 537 ha at FSL. The dam provides an additional 56 Mm^3/a of water to the Greater Cape Town region.
- A pump station (the Dasbos pump station) and a 2,5 km long 1,5 m diameter (Dasbos) pipeline to convey water from the dam to the Dasbos adit of the Riviersonderend Tunnel System and thence into the Western Cape Water System – referred to as the Dasbos System. The system is designed to deliver 3 m^3/s initially, with the option of increasing to 6 m^3/s in future.
- Abstraction works on the Berg River below the Dwars River confluence consisting of a low diversion weir, boulder, gravel and sand sediment traps, a covered diversion canal, a balancing dam and a pump station (the Drakenstein pump station). The water is pumped via a 10 km 1,5 m diameter

(Drakenstein) pipeline to the dam and connected to the pipework at the Dasbos pump station – referred to as the Drakenstein System. The system is designed to extract excess winter water from the Berg River below the confluences of the Franschhoek, Wemmershoek and Dwars rivers and pump it back to the dam for storage, thus supplementing the water stored (25 Mm^3/a) in the dam.

- Wemmershoek Irrigation Release Works on the Wemmershoek River just upstream of the confluence of the Berg River.

OPERATING PARAMETERS AND DESIGN PHILOSPHY

In summarised terms the BWP has been designed to fulfil the following operational requirements:

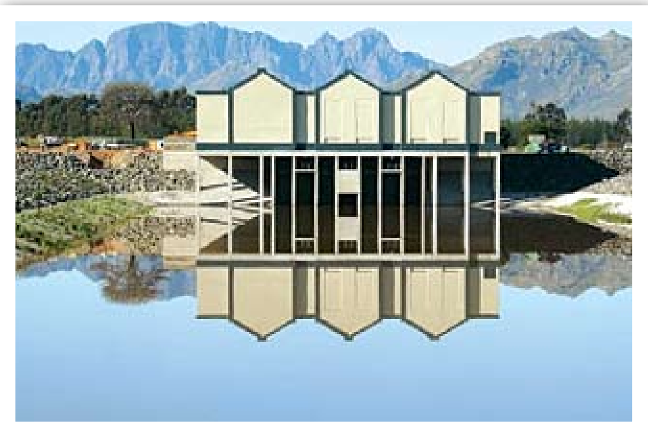
- Flood releases of up to 160 m^3/s through the wet well in the intake tower and the conduit to maintain the ecological status of the Berg River downstream of the dam (the system is capable of releases of up to 200 m^3/s)
- Monthly environmental in-stream flow requirement (IFR) of between 0,36 m^3/s and 8,6 m^3/s released through the sleeve valves at the outlet works
- Draw-off of up to 3 m^3/s (increasing to 6 m^3/s in the future) from the dam through the pipes in the dry well in the intake tower and pumped through the Dasbos System into the Riviersonderend Tunnel System and Theewaterskloof Dam
- Future requirement to feed directly to the proposed Muldersvlei Water Treatment Plant by means of gravity or the Dasbos pump station
- Abstraction of up to 4 m^3/s from the Berg River at Drakenstein Correctional Services in winter and pumped through the Drakenstein System and the dry well piping in the intake tower to discharge into the dam to supplement storage in the dam
- Releases of up to 6,7 m^3/s from the Berg River Dam, or preferably Theewaterskloof Dam, via the Riviersonderend Tunnel System into the Berg River at the confluence of the Wemmershoek River for irrigation purposes in summer

These operational requirements have set a challenge for the designers to economically integrate the requirements with the infrastructure designed and constructed as part of the project.

SUPPLEMENT SCHEME

The Dasbos System is required to transfer water from the Berg River Dam to the Riviersonderend Tunnel System. Furthermore,

Drakenstein Pump Station



it was recognised that by constructing a diversion weir downstream of the dam at Drakenstein, surplus water from the Franschhoek, Dwars and Wemmershoek rivers could be pumped to the dam to supplement yield of the scheme.

1 Dasbos Pump Station
2 Berg River Dam outlet works and Dasbos Pump Station
3 Dasbos Pump Station installations
4 Dasbos tunnel and adit strake D delivery to site

Dasbos System

Dasbos pump station

The pump station has a reinforced concrete substructure (pump well) and a superstructure of reinforced concrete columns and beams, with plastered and painted brick infill wall panels. The pump units are positioned in the pump well on concrete plinths. Provision has been made for five pump sets, but only four sets have been installed. The fifth set can be installed when and if water demand increases beyond present capacity.

Operating staff offices and facilities as well as the project control room overlooking the outlet works of the Berg River Dam are housed in the pump station building.

Four Sulzer SM 501-640/Imp 635 mm single-stage horizontal centrifugal split casing pumps with 3,01 MW ALSTOM motors and controlled by ABB variable speed drives capable of delivering 3 m^3/s now and 6 m^3/s in future, with the installation of a fifth set at 135 m head, are installed. Transformers and switchgear were manufactured by ABB and ALSTOM respectively. The suction and delivery manifolds are situated underground outside the building.

The suction manifold draws water from one of five bell mouth intakes from five levels and either one of two pipe stacks in the dam intake tower and by way of cross-connected pipework south of the pump station. The Drakenstein pipeline is situated to the east of the pump station and is connected directly to one of the pipelines and pipe stacks or via the cross connection to the alternative pipeline and pipe stack in the intake tower. The delivery manifold is connected to the Dasbos pipeline.

The Dasbos – Drakenstein cross connection connects the Dasbos pipeline and the Drakenstein pipeline to the north of the Dasbos pump station.

The Dasbos pump station bypass pipeline is provided to feed water directly by gravity to the future Muldersvlei Water Treatment Works (WTW) bypassing the pump station when the water level in the dam is sufficiently high to allow this.

Dasbos pipeline

This pipeline serves three functions:

- To transfer water from the Berg River Dam to the Riviersonderend Tunnel System
- To transfer irrigation water from Theewaterskloof Dam to the Wemmershoek Irrigation Release Works (via the Drakenstein pipeline)
- To transfer water from the Berg River Dam to the future Muldersvlei WTW

The pipeline to the west of and from Dasbos pump station to the Dasbos adit and tunnel follows a gradually rising route around the toe of a mountain above the left bank of the Berg River. The pipeline connects the Dasbos pump station with the Dasbos tunnel and adit, which links up with the Riviersonderend Tunnel System. The latter conveys raw water from Theewaterskloof Dam via Kleinplaas Dam, situated in the Jonkershoek valley above Stellenbosch, to the Faure and Blackheath Water Treatment plants. This tunnel system was constructed at the same time as the Theewaterskloof Dam, in the mid 1970s.

Just before entering the Dasbos tunnel the pipeline passes through a chamber, in which an isolating valve is installed. At the chamber exit a sweep tee turns the pipeline into the tunnel. In view of a possible future connection to the Muldersvlei WTW a Y-branch has been installed just beyond the sweep tee, with a second sweep tee back towards the chamber, all with isolation valve and blank flange for later connection to the proposed Muldersvlei pipeline.

The Dasbos pipeline has a cross connection to the Drakenstein pipeline just north of Dasbos pump station to:

- divert water from the Theewaterskloof Dam via the Dasbos tunnel and Drakenstein pipeline to the Wemmershoek Irrigation Release Works during the summer months
- gravitate water from the Berg River Dam past the Dasbos pump station to the future Muldersvlei Water Treatment Works

Dasbos tunnel and adit

The pipeline connects to the Riviersonderend Tunnel System (RTS) about 200 m into the adit.

Inside the Dasbos adit and up to a domed bulkhead the pipeline is mounted on concrete pedestals, offset to the right with a sufficient clearance between the pipe pedestals and the left tunnel wall to allow vehicular access down the adit and through the dome (when opened) into the tunnel.

The connection to the concrete lined tunnel is by means of DN2500 3CR12 strake fully concrete and grouted into the tunnel with a hinged dome on the end to allow vehicular access to the tunnel. From this strake a bifurcation and DN1500 valve connects to the Dasbos pipeline. For safety reasons a further isolating valve has been installed inside the tunnel in close proximity of the access dome. The design of the connection to the RTS took into account minimal downtime and disruption of water supply from Cape Town's main water source, the Theewaterskloof Dam. The dewatering of the Riviersonderend Tunnel System and connection to the existing bulkhead was achieved in nine days – the physical connection / tie-in taking just two days.

Drakenstein System

The Drakenstein System's primary function is to abstract surplus water from the Berg River during the winter months and pump it to the Berg River Dam to supplement the yield of the dam.

During the summer months the Drakenstein pipeline will be utilised in reverse mode to convey irrigation water from Theewaterskloof Dam (via the Dasbos pipeline) or Berg River Dam to the Wemmershoek Irrigation Release Works, situated on the Wemmershoek River, immediately upstream of the confluence with the Berg River.

The Drakenstein System of the Supplement Scheme consists of the following elements:

- Drakenstein abstraction works on the Berg River consisting of:
  - Diversion weir with canoe chute and fish ladder
  - Diversion works including boulder, gravel and sand traps and associated stop logs, gates and sluices
  - Diversion canal to the balancing dam with inlet control gate
  - Balancing dam
- Drakenstein pump station
- Drakenstein pipeline from Drakenstein pump station to the Berg River Dam

Drakenstein abstraction works

The diversion weir has an ogee crest and roller bucket energy dissipater to prevent downstream erosion. This type of weir has the advantage that it effectively reduces erosion downstream by creating an opposite flow direction at bottom level. The structure is positioned perpendicular to the anticipated flow direction during high floods and has an overflow length of 65,25 m. The total width of the weir, in the direction of flow, inclusive of the roller bucket, is 12,53 m. The weir has a flat bottom, and is supported in the cobble/boulder strata, about 4 m below natural river bed level. Its underside is linked to an engineered cut-off through the cobble/boulder strata down to a low-strength base rock. The cut-off consists of a pressure-grouted 1,5 m wide strip and is intended to prevent piping and essentially reduce seepage below the weir to a minimum. The river bed downstream of the weir is protected against erosion by means of rip-rap, with a D50 size of 1,1 m sourced some 60 km from site and almost delivered one by one to site! The rip-rap was placed on a filter layer of smaller size rip-rap.

The left-hand non-overflow section of the weir has a flank wall rising to level above the calculated level of a 1:100 year flood at this point.

On the right-hand side of the weir a canoe chute and fish ladder have been incorporated in the weir/ diversion structure. Water flows uncontrolled firstly through the fish ladder and then through the canoe chute fulfilling the river instream flow requirements (IFR) of up to 1,5 m^3/s during the drier summer months. The adopted average minimum and maximum monthly IFRs in winter vary between 1,5 m^3/s and 2,86 m^3/s.

At full supply level (FSL) the combined flow through canoe chute and fish ladder would be about 1,5 m^3/s. At higher IFRs the boulder trap gate will be opened to provide additional capacity.

Of the various fish ladder designs available the one chosen is considered the most suitable for fish found in the Berg River. It is provided with vertical slots in the baffle walls, placed in one line near one side, thereby creating sheltered small pools at each step for the migrating fish.

Downstream of the canoe chute a pool has been created, which basically consists of a deepening of the rip-rap protection. In addition, the rip-rap has been grouted in this location for the protection of canoeists and canoes.

Embankments protected by rip-rap have been constructed on the left and right banks to contain the river during floods of up to a 1:50 year event and to prevent the river scouring a new channel and thus bypassing the diversion works during 1:100 year flood conditions. The left hand embankment extends upstream to the confluence of the Dwars River. It is provided with a drainage system alongside the toe of the embankment on the landward side in order to control the ground water level in an adjacent vineyard and for releasing storm water to a point downstream of the diversion weir. It also functions as a draining devise after flooding. The embankment connects onto the non-overflow section of the weir on the left bank.

The right-hand embankment extends for a similar distance upstream of the diversion works, but excludes a draining system along the landward side. The right-hand embankment butts up against the extended wall of the gravel/boulder traps and has been built to generally the same levels as the left-hand embankment.

The diversion works are situated on the right bank and bend of the Berg River following investigations into the course of the

5 Drakenstein abstraction works
6 Drakenstein diversion works – sediment removal structures
7 Fish ladder; canoe chute; boulder, gravel and sand traps
8 Pipe installations at Dasbos Pump Station

river over 60 years. The works are designed to divert water from the river into the works, remove sediment down to a particle size of 0,4 mm and divert the water to the balancing dam via an underground diversion canal. The diversion works, diversion canal, balancing dam and pump station are all located in the 1:200 year flood plain of the Berg River, which is 300 mm higher than the 1:50 year flood level, and was the subject of a model study at the University of Stellenbosch to ensure minimal river flow obstruction in the floodplain.

The sediment removal structures consist of boulder, gravel and sand traps and have been configured on the basis of model studies of the whole diversion works complex. These structures are designed to divert a maximum of 6 m^3/s of river water. The boulder, gravel and sand traps remove sediment down to 40 mm, 2 mm and 0,4 mm in size respectively. A key emphasis in the design was to make the structure self-cleaning, using gravity flow washing sediment back into the river. This maintains the sediment load and river ecology and negates the necessity for costly removal of sediment from sediment traps.

Boulder scour (radial) and gravel scour (radial) gates, situated in the flushing channels downstream of the boulder and gravel traps, are used in the periodic controlled discharge of river water to flush out the boulder and gravel accumulations. The sand traps, of which four have been provided, can be flushed individually by means of sliding (sluice) gates. Trash racks are installed on the trailing wall upstream of the sand traps.

A sand scour (radial) gate positioned downstream of the sand traps is opened during flushing of one of the sand traps, allowing the flow plus sediment to be diverted back to the river downstream of the weir.

A 4,0 m wide by 2,5 m high roofed concrete diversion canal discharges the cleared water from the diversion works into the balancing dam. The flow through the diversion canal is regulated by means of an automated diversion (sluice) gate, which is controlled via a combination of signals from instruments placed in three locations. A level monitor in the river, upstream of the weir, triggers the opening or closing of the diversion (sluice) and boulder and gravel (radial) gate by comparing actual river level with the level at IFR and diverted flow. An ultrasonic flow meter, working in conjunction with a parshall flume inside the diversion canal, as well as a level monitor in the balancing dam, provides further control signals.

Abstraction starts when the IFR is exceeded, by opening the diversion (sluice) gate, which will allow water to enter the diversion canal up to a maximum of 6 m^3/s. Above IFR + 6 m^3/s the boulder scour gate opens further, followed by the opening of the gravel scour gate. These two gates will close in reverse sequence when the flow subsides again. The purpose of these operations is to maintain the FSL upstream of the weir as long as possible to maximise river abstraction. Overflow of the weir will thus only occur when river flow exceeds IFR + 6 m^3/s + capacity of boulder and gravel trap (radial) gates.

The diversion canal discharges the flow through six 1,0 m wide by 0,6 m high openings, placed at the invert of the canal, into the balancing dam. These six openings are strategically spaced to obtain even flow into the balancing dam.

The balancing dam optimises water storage for pumping purposes and to allow settlement of fine sediment up to 0,2 mm in size. Its crest level dimensions are approximately 360 m x 123 m. Embankments with rip-rap protect the balancing dam from floods up to a 1:200 year event. Generally the sides below FSL and

10 m rim of the bottom of the dam are lined with Armourflex to keep the shape of the dam. As the FSL of the dam is below the natural groundwater level, loss of water is not a concern.

Plant access into the diversion canal and the balancing dam itself for clean-out purposes is obtained by means of a ramp at the northeast side of the balancing dam. Clean-out operations could take place during the summer months once the sediment reaches a predetermined level immediately upstream of the pump station pump intakes.

Drakenstein pump station

This pump station pumps water from the balancing dam through the Drakenstein pipeline to the Berg River Dam.
The pump station structure consists of a substructure of four separate concrete sumps and a superstructure of reinforced concrete columns and beams, with plastered and painted brick infill panels. The electrical motors, screens loading bay, storage area, operators' facilities, switch room and transformer bays are situated at ground floor level above the 1:200 year flood level.

Flow into the sumps passes through trash racks. These are cleaned by manual intervention. The sumps of the pump station, inclusive of the secondary concrete, guide vanes and inlet configuration below the pump intakes were analysed with CFD (Computerised Fluid Dynamics) software to ensure proper operation in order to prevent vortex formation, pre-rotation and swirling.

Four Sulzer BK 850 3-stage vertical spindle turbine pumps driven by 2,67 MW ALSTOM motors and capable of delivering 4 m^3/s at 145 m head are installed (three in operation, one standby). Soft starters, transformers and switchgear were manufactured by Allan Bradley, ABB and ALSTOM respectively.

An external delivery manifold with isolating valve joins onto the Drakenstein pipeline.

Drakenstein pipeline

The pipeline from the Drakenstein pump station to the Berg River Dam (the Drakenstein pipeline) follows a route generally parallel to the Berg River but outside the 1:100 year flood line at varying distances of up to 600 m from it. The pipeline crosses several services, such as the Wemmershoek potable water pipeline to Cape Town, irrigation pipes in the agricultural areas, and the R45. It also crosses the Wemmershoek and Berg rivers. This presented various construction challenges to the contractors as the Berg River pipeline crossing immediately upstream of the R45 bridge crossing is 6 m below natural riverbed level.

The selection of the route was a lengthy procedure and determined on the basis of topographical surveys, the 1:100 year flood lines, and land owner input. Geological investigations were undertaken and the results used in the final stages of the selection process.

The vertical alignment of the pipeline has a minimum slope of 0,35% for drainage purposes. A maximum negative slope of 21% has been adopted for the effective removal/transportation of air (that is, pressure increasing in the direction of flow with pumping).

The R45 is crossed inside a 1 800 mm diameter concrete jacked sleeve pipe. The annulus between sleeve and pipe is grouted up. Small diameter sleeves for cathodic protection cabling and possible future use were installed in the annulus before grouting.

PIPE DESIGN

Whilst the consultants' original preference was a 10,3 mm wall thickness DN1500 mild steel, epoxy lined pipe, a 30 mm thickness cement lining (the preferred lining by the City of Cape Town) and maximum allowable velocity in the pipeline of 4 m^3/s were adopted. The thickness of the cement mortar lining was derived after extensive laboratory investigations and is the result of the aggressive and low pH levels (down to 2,9) of the water to be conveyed and high flow velocity adopted over the design life of the pipeline.

Pipes encased in concrete, generally below the river crossings, specials and valve chambers, and in Dasbos tunnel and adit are manufactured from 3CR12. The section of pipe inside the sleeve at the R45 crossing is of mild steel with a wall thickness of 20 mm to provide for additional safety in a position difficult to access. The individual pipes have been factory hydraulic tested. After installation and completion of the pipeline a further in-situ hydraulic test has been carried out. All pipes are continuously welded and joined by means of welding.

The selected corrosion protection system for the standard pipes consists of a factory applied 3,4 mm Sintakote (polyethylene) coating and a 30 mm cement mortar lining (CML) applied in two layers followed by a bituminous (Ravenol) coat which were applied in situ.

At the welds the pipe is wrapped with a shrink-on band. This is a double-layered bitumen/polyethylene band which is heat-applied on the prepared steel surface while overlapping the Sintakote coating on both sides. Pipes encased in concrete are coated with an epoxy paint.

The minimum cover on all pipes is 1,3 m. A cathodic protection system is also in place.

WEMMERSHOEK RIVER IRRIGATION RELEASE WORKS

The Wemmershoek Irrigation Release Works are positioned on the Wemmershoek River immediately upstream of the confluence with the Berg River and can release flows of up to 6,7 m^3/s through two DN600 sleeve valves. This facility enables irrigation releases to be made from either the Theewaterskloof or Berg River dams via the Dasbos and Drakenstein pipeline system into the Berg River. It consists of two DN600 sleeve valves housed in a concrete substructure discharging water with a head of up to 110 m into two chutes and stilling well. A building housing electrical and control equipment is erected on top of the chamber and above the 1:100 year flood level. For aesthetic purposes, and in order to blend into a future high-cost housing development, the outside of the building is clad with gabion baskets filled with small diameter river boulders.

GENERAL

The Supplement Scheme was constructed under three separate contracts. All pump stations, civil, tunnel and hydro mechanical installation works were undertaken by the Department of Water Affairs and Forestry Construction Division. All mechanical and electrical installations were undertaken by SULZER Pumps (SA). The construction of the Dasbos and Drakenstein pipelines was undertaken by Cycad Pipelines. Costs for the construction of the whole of the Supplement Scheme are approximately R450 million.

We wish to express our gratitude and thanks
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