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Umgeni Water's Durban Heights Booster Pump Station

INTRODUCTION

The Durban Heights Booster Pump Station (BPS) has been built at the head of the Northern Aqueduct, a water main (initially 1,6 m NB concrete 'Soccoman' pipe, thereafter more than 100 km of 1 050 mm NB and 750 mm NB steel pipes) installed in the 1960s and fed by the 361 Mℓ reservoir (Reservoir 3) located within Umgeni Water's Durban Heights Water Treatment Plant (WTP).

The Northern Aqueduct serves Durban North consumers via a network of 26 local distribution storage reservoirs operated by eThekwini Water and Sanitation (EWS), but the elevation of some of these reservoirs (particularly the one serving Ntuzuma Township) is such that during times of peak demand (up to 400-450 Mℓ/d) coupled with low Reservoir 3 operating levels, they were not being fed at a sufficient rate to satisfy local demand. Hence EWS required Umgeni Water (UW) to maintain Reservoir 3 at the top water level (TWL) of 272 masl in order for their demands to be satisfied.

Accordingly UW agreed to provide a booster pump station that would ensure that the pressure at the head of the Northern Aqueduct was always equivalent to Reservoir 3 being nearly full whatever the demand level, but never to be greater than the reservoir TWL, so as to avoid the hazard of over-pressurising the aqueduct, due to its age and vulnerability to fracture.

The design of such a closed system BPS is potentially much more complex than the more frequently used alternative of an open system BPS, i.e. one that pumps into a secondary reservoir open to the atmosphere, which is kept at the required pressure head. Specifically this is because of the necessity to precisely match supply with demand – determined by the rate at which the pump speeds can be changed via variable speed drives (VSDs) coupled with electronic safety interlocks to protect the downstream pipe system from operational damage due to over-pressurisation and/or demand-supply mismatch.

Because of the very low boost pressure for the BPS (10 m max), the incorporation of a pressure relief valve (PRV) into the pipework system was found to be impractical. Instead, a small surge tank was used, bestowing the additional advantage of compensating for any short-duration mismatch between supply and demand. Further details of the surge tank design are given below.

1 Figure 1: Durban Heights Booster Pump Station: physical and hydraulic schematic

The elements of the BPS design/construction are shown schematically in Figure 1. Figure 2 shows the location of the BPS within the Durban Heights Water Treatment Plant, sited between the pair of existing Reservoir 3 service shafts. These now house the Primary Reservoir 3 isolating valve, suction line tie-in point (upstream shaft) and the delivery line tie-in point (downstream shaft).

The BPS has been constructed at the base of an existing 'cone-shaped' valley on the southern boundary of the WTP site that appears to have been created at the time of inception of the Reservoir 3 / Northern Aqueduct supply scheme around 1968.

To avoid erecting a new structure vertically above the existing Northern Aqueduct it was necessary to offset the station and excavate to a depth of about four metres at the foot of the western slope of the valley so as to ensure sufficient net positive suction head (NPSH) to allow for the BPS operating with the reservoir at its minimum operating level of 262 masl.

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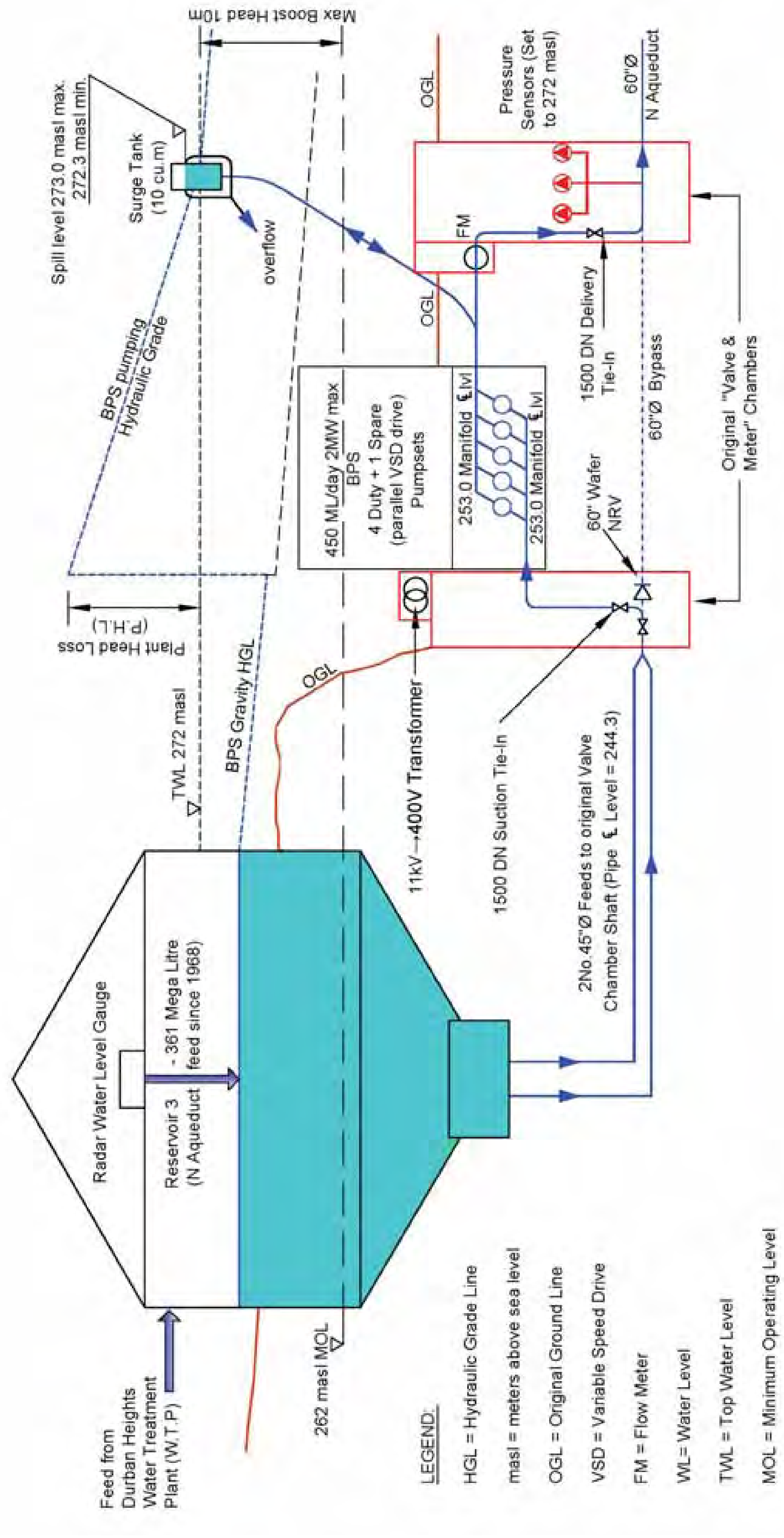

Feed from Durban Heights Water Treatment Plant (W.T.P)
Radar Water Level Gauge
Reservoir 3 (N Aqueduct
- 361 Mega Litre feed since 1968)
262 masl MOL
TWL 272 masl
BPS Gravity HGL
Plant Head Loss (P.H.L)
BPS pumping Hydraulic Grade
Spill level 273.0 masl max. 272.3 masl min.
Surge Tank (10 cu.m)
overflow
Max Boost Head 10m
OGL
OGL
OGL
11kV→400V Transformer
450 ML/day 2MW max BPS
4 Duty + 1 Spare (parallel VSD drive) Pumpsets
253.0 Manifold ℄ lvl
253.0 Manifold ℄ lvl
FM
Pressure Sensors (Set to 272 masl)
60"Ø N Aqueduct
1500 DN Delivery Tie-In
60"Ø Bypass
60" Wafer NRV
1500 DN Suction Tie-In
2No.45"Ø Feeds to original Valve Chamber Shaft (Pipe ℄ Level = 244.3)
Original "Valve & Meter" Chambers
LEGEND:
HGL = Hydraulic Grade Line
masl = meters above sea level
OGL = Original Ground Line
VSD = Variable Speed Drive
FM = Flow Meter
WL= Water Level
TWL = Top Water Level
MOL = Minimum Operating Level

DESIGN OF PUMP SETS

Figure 3 shows the degree of variability of demand from the EWS Durban North consumers, underlining the necessity for the BPS pump sets to operate at highly variable speeds.

Following the finalisation of the BPS operating criteria, the award of the pump set supply and install contract to Sulzer Pumps was based, inter alia, upon their submitted combination of competitive pricing and peak (variable speed) pump efficiencies – for operational parameters ranging from a peak demand of 450 Mℓ/d (5,2 cumecs via 4 No pumpsets) to a low demand of 150 Mℓ/d (1,7 cumecs) at a range of operating heads between 10 m and 19 m, reflecting a maximum boost head of 10 m combined with an allowance of up to 9 m for plant head losses.

Figure 2: UW BPS locality, Reservoir Hills, Durban

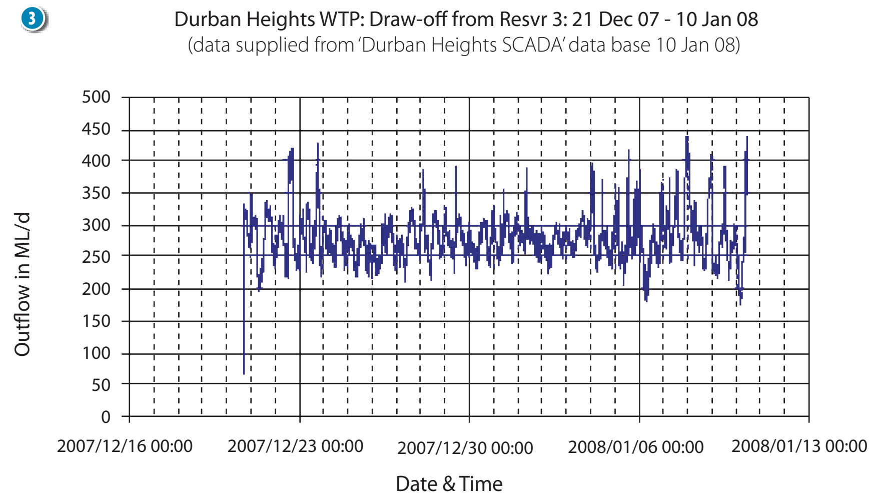

Figure 3: UW Durban Heights WTP: Reservoir 3 draw-off rates

CREATION OF AUTOMATIC OPERATIONAL AND CONTROL PHILOSOPHY, AND HYDRAULIC PARAMETER INPUTS

The programming of the BPS programmable logic controller (PLC) to deal automatically with constantly changing Northern Aqueduct demand (via pump set speed control), whilst maintaining constant pressure, was addressed by the electrical and instrumentational contractor's programming subcontractor (Abacus Automation), following the approval of a complex functional design specification, drafted by the electrical subconsultant, Rob Anderson Associates, after numerous workshops with Umgeni Water. The main consulting engineers (Goba) developed algorithms relating the four pumpset operating speed "n rpm" parameters – BPS Flow: Q_{DEMAND} m^3/hr, i.e. (N x q) where 'q' is the flow rate for each online pump; BPS Total Operating Head: metres, i.e. $H_{TMH} = (H_{BOOST} + H_{PLANT\ HEAD\ LOSS})$; Pump and Motor Efficiency: η_{P+M} (%) and N = number of on-line pumps.

However, referring to the detailing of principal commissioning findings at the end of this article, with hindsight it would have been advantageous to incorporate a 'sensitivity factor' into this pump start-up speed algorithm. By doing so when first going online, the pump start-up speed would have been reduced by (say) 10 to 20% – so as to avoid the possibility of generating an excess in boost head due to an over-estimation of head losses within the BPS or under-estimation of the pump operating efficiency.

Following an extensive HAZOP study, which stakeholders from Umgeni Water and eThekwini Water participated in together with the design team, several electronic safety interlocks were built into the system, over and above those called for in respect of normal operating conditions. One of the consequences of the HAZOP debates was the incorporation of a surge tank into the booster pump station delivery system so that any excess head generation (caused for instance by the control system malfunctioning, or unpredictably sudden reduction in demand) would be dissipated into the storm water system via the surge tank's built-in overflow spillway.

As previously noted, this surge protection device was used instead of the more conventional pressure relief valve

(PRV) because the manufacturers could not guarantee performance at the very low operating pressures and also because of the parallel ability of the surge tank to act as a buffer if the demand almost instantaneously falls or rises – preventing induction of air into the aqueduct in the event of a sudden high rise in Q_{DEMAND}. The surge tank will of course also deal with water-hammer surge (calculated to be of the order of only about 3 m) caused by power-cut induced pump trip.

The surge tank (2,2 m dia x 3 m high, 10 m^3 active vol) is sited on the top of the valley slope above the BPS, being designed using the existing topography to maximise operational efficiency. It is served by an 80 m long DN 450 HDPE pipeline fed from the delivery end of the BPS manifold and equipped with an internal drop inlet overflow spillway set at Z_{SPILL} = 273,0 masl – i.e. 1 m above Res 3 TWL – but able to be adjusted down to Z_{SPILL} = 272,3 masl by removal of flanged pipe-spools. The 0,5 cumec rated GRP 450 mm ID overflow pipes are connected at the tank base to a DN 300 PVC overflow discharge pipe (see Photo 3), which at a grade of about 30% flows back down the hill to discharge into the 1 200 mm NB concrete storm water pipe running parallel to the Northern Aqueduct.

'PIPE SPECIALS' DESIGN

Traditionally, the design of reinforcement of pipe tees and branches (to compensate for loss of hoop stresses at the main-pipe aperture) is carried out according to guidelines appearing in AWWA Pipe Manual M11.

However, notwithstanding the logic of the Chapter 13 design criteria (reportedly based on a Swanson et al study published by AWWA in the US in 1955) it was deemed desirable to check the AWWA M11 design conclusions (i.e. "No reinforcement necessary since main and branch pipe wall thicknesses (T_Y; t_Y) are 4.4 times what is required (T_R; t_R) to ensure '$P_{INTERNAL-MAX}$ = 0.45 MPa' does not induce hoop stresses > 50% f_{YIELD}") by conducting finite element analyses (FEAs) centered around potential high-stress zones. This precaution proved to be justified, since the FEA revealed alarmingly high local stress levels at the apex of the 45° crotch-welds.

Accordingly, to reduce local stress peaks to < 75% of yield stress, 45° lateral branch wall thicknesses were increased (employing ± 1 m mean length stub branches) from 8 mm to 20 mm (for DN 1 000 branches from DN 1 500 x 10 mm or from DN 1 200 x 8 mm manifold sections) and from 6 mm to 16 mm (for DN 800 branches from DN 1 500 or DN 1 200 manifold sections).

This solution was deemed preferable – i.e. more cost and space efficient – than the alternatives of welding on either bulky crotch plates or manifold branch-collars (see Photo 1, left-hand side).

Specials fabrication was subcontracted by the main contractor (ICON Construction) to Bambanani Pipes & Fittings in Krugersdorp.

CIVIL WORKS

The BPS required a relatively large structure – 47 m long, 16 m wide and 10 m high (see Photo 2). Whilst the 168 m diameter Reservoir 3 occupies a large site, its hilltop location meant that a substantial portion of the site would have steep topography. The size of the BPS building and the position of the existing pipe network resulted in large quantities of excavation being required, to depths in some locations of over 10 m.

The geology of the site comprises a silty-clayey alluvium overlying highly-weathered Natal group sandstone with the water table at the valley line typically located only 1 m below the surface. Whilst the foundation loads were relatively low it was necessary to provide sufficient mass to counteract buoyancy forces due to a high water table. As a result a 750 mm thick concrete base had to be provided under the building.

The lower portion of the pump station walls (up to 5 m high) were designed as cantilever retaining walls with the upper portions made up of concrete framing columns and brick infill.

The pump station is located within a residential area, and to limit the transmission of noise, the roof of the building was initially designed with concrete slabs spanning between prestressed concrete beams installed transversely across the building. After procurement of the pump sets it was found that the acoustic load would be substantially lower than anticipated. It was therefore possible to switch to timber trusses supporting aluminium sheeting, which provided appreciable savings in cost and the construction programme duration. The building also has a large structural steel component with walkways, stairs and cat ladders facilitating access to all equipment and instrumentation, as well as a 10 t gantry crane which can be used to remove any equipment for off-site repair.

1 Photo 1: Internal hydro-mechanical and electrical components and features in the Durban Heights Booster Pump Station (BPS). From left to right: 1,5 m max ID intake manifold, Sulzer/WEG pump sets, walkway to electrical plant (isolators, VSDs, MCCs etc) and control room (in the background)

2 Photo 2: Main structure of the BPS, with 11 kV – 400 V substation (control room Aircon unit on its roof) at its northern end (l.h.s. foreground) and original Northern Aqueduct access shafts (BPS intake tie-in and outlet tie-in) in the foreground and background respectively

3 Photo 3: The BPS Famsys HDPE surge tank (before excavation backfill) c/w 450 NB HDPE inflow/outflow (surge) pipe and 400 NB GRP overflow / pressure relief pipework – normally dry (no signal from flow detector), but able to carry up to 0,5 cumec feed from internal 600 mm ND (variable elevation setting) drop-inlet spillway

ELECTRICAL AND INSTRUMENTATION (E & I) WORKS

The 5 x 330 kW 8-pole VSD pump sets required a specific 11 kV / 400 V AC BPS substation. The substation is located in a separate building adjacent to the northern end of the BPS (Photo 2 foreground).

The substation comprises:

- an MV ring main unit (RMU) for isolating the MV supply, complete with a protection relay
- a 2 500 kVA step-down transformer (11 kV – 400 V.AC)
- encapsulated busbars from the transformer LV terminals, feeding the motor control centre (MCC) that is located within the pump station control room (see Photo 1, background).

The pumpset MCC comprises:

- main incoming 3 200 A LV circuit breaker for isolation and protection of the MCC
- Siemens variable speed drives (VSDs), one for each of the 5 No pump sets, and each with its own isolating switchgear
- panel-mounted human machine interface (HMI).

The BPS LV distribution board feeds the sub-distribution boards located within the plant, which supply the uninterruptible power supplies (UPSs) that feed the valve actuators, lighting, small power and airconditioning unit.

The BPS programmable logic controller (PLC) is programmed to provide the required degree of plant automatic operation. The PLC constantly compares process feedback signals with programmed process set points and automatically provides the appropriate response to any variations between the two. These BPS operating parameters are displayed on the operator control desk located in the control room – provided also to allow local control of the BPS and incorporating a supervisory control and data acquisition system (SCADA). The SCADA provides control, indication and visualisation (current and historical) of the BPS. The BPS PLC and SCADA are connected via a fibre-optic cable to the Water Treatment Plant's ethernet network, thus providing remote monitoring and control of the BPS from the Water Treatment Plant main control room SCADA.

The field instrumentation provided to monitor the process conditions and feed these back to the PLC comprises, inter alia:

- a radar gauge transmitter, installed within the roof of Reservoir 3, to indicate the reservoir water level
- an ultrasonic level transmitter and overflow monitor installed in the surge tank to provide the water level in the tank and indicate when an overflow occurs
- an ultrasonic flow meter, incorporated into the BPS delivery piping, to provide the instantaneous output flow of the BPS (this flow is compared to the existing sales flow meter downstream of the BPS to allow the accuracy of the metering devices to be compared)
- various pressure gauges and pressure transmitters installed in the process pipe work to monitor pump suction pressures and delivery heads
- temperature and vibration monitors installed on the pumps and motors to ensure operation within pre-set limits.

END-OF-JOB (PRE-WET-COMMISSIONING) BPS TIE-INS

Towards the end of the BPS construction period, Umgeni Water and EWS were in discussions to allow the Northern Aqueduct's prime supply from Reservoir 3 to be cut off so that contractor ICON could (under severe time constraints) install the BPS 1 500 NB outlet and intake tie-ins. The onerous time constraint associated with ICON's intricate base-of-valve chamber pipe-special / valve installation work was exacerbated by the extra time taken to drain Reservoir 3 to allow renewal of UW's 60 inch aqueduct isolating valve (and in parallel install the new 60 inch BPS by-pass NRV immediately downstream of the BPS intake lateral branch). In the midst of this exceptional operational state of affairs, UW organised internal inspection and maintenance of the huge reservoir (and associated outlet pipes).

COMMISSIONING OF THE BPS

The site testing of the individual pumps was to try to replicate the factory acceptance testing (FAT), but with operation at variable speeds, which had not been possible during the original FATs due to lack of equipment at the contractor's factory. The main problem facing the site commissioning was that testing could be done only under live flow conditions or by pumping into the storm water system, which limited the testing at higher flows due to possible flooding within the residential area surrounding the site. Testing at lower flows for short periods enabled individual pump curves to be confirmed and to progress to an online live commissioning process.

The online testing presented the project with certain risks in that the only way to test the system was to run it live. There was no way of testing the full system off-line. A major safeguard that mitigated the interruption in Northern Aqueduct supply risk was that the original gravity line was always still operational and the new system had been designed such that in the event of any problem being detected, related to the operation of the BPS, it could instantaneously be shut down without any supply disruptions, since the system would immediately revert to a gravity supply. As shown in Figure 1 (and Photo 4), a 1 500 ND wafer-type double disc non-return valve (NRV) was installed immediately downstream of the DN 1 500 intake pipe on the gravity line. This NRV closes when the BPS is running, due to higher delivery pipe pressures. As soon as the BPS stops, it opens and flow reverts to gravity instantaneously.

During this process it was discovered that internal plant head losses were apparently considerably less than originally calculated, resulting in a degree of BPS over-pressurisation during start-up prior to the PID-loop coding initiating an automatic reduction in pump speed. This event, as discussed previously, necessitated accessing the PLC programming again so as to bring about a 15% reduction in the PLC-derivation of pump-speed presetting immediately before BPS start-up.

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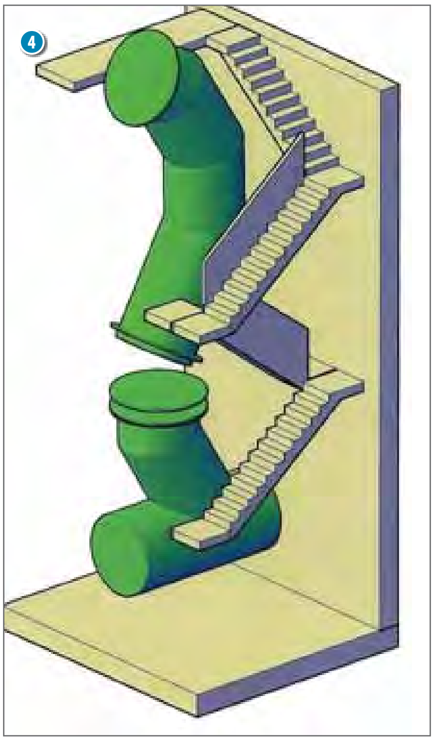

This start-up system over-pressurisation logically resulted in the safety interlocks thus being activated automatically and instantaneously closing down the BPS. However, once this PLC programme initial pump-speed coding had been suitably adjusted, the BPS ran relatively smoothly and was stable for sustained periods as the commissioning progressed to the fine-tuning process following handover to Umgeni Water in December 2009. The fine-tuning process ran throughout the defects notification period of one year during which time the BPS was continually monitored and adjusted according to 'bugs and snags' discovered.

CONCLUSIONS

The Durban Heights Booster Pump Station was delivered on time and within the budget of R60 million. The boosted heads were delivered to eThekwini Water prior to the December 2009 deadline when demands were at their highest.

Reports from eThekwini Water are that operations within the Durban North area have improved vastly since the commissioning of the pump station.

Any BPS closed-system project undertaken in the future will clearly benefit from the hydraulic / algorithmic / electromechanical design experience gained prior to commissioning the Durban Heights BPS, but of course particularly the operational insights gained during commissioning.

The relative costs of the prime Booster Pump Station components were roughly as follows:

- Pump sets: Sulzer pumps 15%
- E & I & Control System: Cato Ridge Electrical 15%
- Civil / Structural / Mechanical Works: Main Contractor ICON 55%
- Design and Contract administration 15%

ACKNOWLEDGEMENTS

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4 Figure 4: Illustration of installation of BPS tie-in pipe specials (within existing Northern Aqueduct access shafts)

4 Photo 4: DN 1 500 BPS Bypass Non-Rtn Valve (60 inch Wafer Check Valve, ex-APCO, Illinois, USA)

Source: http://www.saice.org.za/downloads/monthly_publications/2011/2011-Civil-Engineering-Jan_Feb/#/0