Appraising the lifecycle costs of SA's INTERBASIN WATER TRANSFER PROJECTS

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South Africa has one of the most sophisticated bulk water infrastructure networks in the world where water is often pumped hundreds of kilometres from areas of surplus to areas of need through inter-basin transfer schemes (IBTs). Research undertaken by Dr Peter van Niekerk, formerly of the Department of Water Affairs (DWA), has shown that the way in which lifecycle costs have been historically evaluated, especially in South Africa, has not been done optimally, which could have severe repercussions for operational cost estimation.

From the 1960s South Africa has seen an increasing number of IBTs being constructed to meet its growing water demands. One of the most sophisticated of these is the complex interconnected Vaal River system, which includes a number of IBTs constructed to serve the economic heartland of the country. The most well-known of these IBTs is the Lesotho Highlands Water Project (LHWP) of which planning of Phase 2 is currently underway.

IBTs often involve pumping water to overcome differences in elevation. The associated energy costs typically form a significant part of the lifecycle costs of IBTs, and it is expected that such energy costs will proportionally increase in future as water has to be sourced from more distant basins. It is therefore important that a robust appraisal methodology be followed when assessing the costs of water transfers of future IBT projects.

A conceptual inaccuracy has, for decades, been part of the water engineering standards of practice so that certain calculations are generally calculated incorrectly. Over time this error has worked its way into the accepted methodology of evaluation of the lifecycle costs of IBTs. This has caused a bias in the estimations of variable costs, such as pumping costs, and made capital intensive gravity schemes seem, in comparison, more attractive than they really are.

INCREMENTAL APPROACH

Case study research and secondary data analysis was employed to examine the accuracy of the appraisal approach, called the Incremental Approach, originally followed during the planning of the Usutu-Vaal Government Scheme (GWS) (Second Phase) as a case study. This IBT scheme was originally planned and built in the early 1980s to supplement the water resources of the Vaal River system. The scheme shown in Figure 4 (along with other IBTs similarly connected) consists of the Heyshope Dam on the Assegai River, a tributary of the Usutu River, and transfer infrastructure to convey water against an elevation difference of 183 m over the continental divide into the Vaal River catchment, upstream of the Grootdraai Dam in the Vaal River.

The Incremental Approach, depicted in general terms in Figure 1, is a deterministic planning approach where the growth in demand is such that a new scheme, an IBT in this case, is required to meet requirements beyond time T1. The Incremental Approach assumes that all requirements beyond the capability of the existing system, i.e. the shaded area in Figure 1, must be met from the new resource. The annual water transfers therefore will exhibit gradual growth, from time T1 until time T2 and then be capped by the yield capability of the new scheme. As pumping costs are directly related to quantities transferred, these annual costs exhibit the same pattern.

ACTUAL TRANSFERS OF THE USUTU-VAAL GWS

The actual annual volumes of water historically transferred from Heyshope Dam are shown in Figure 2, and compared to the original projection, undertaken in 1981. Whereas the original projection was for a smoothly growing transfer, capped by the capacity of the transfer scheme, the actual transfers exhibited an erratic pattern. It was also found that the average transfer was 26.5 million m^3/a over the period – only 35% of what had been envisaged at the planning stage.

Plausible explanations for the differences between predicted and actual transfers were sought by examining possible impacts from other resource developments in the basin, changes in demand and source constraints.

A resource development that did have an effect was another IBT completed in 1988, namely the Slang River GWS. This scheme (also shown in Figure 4) was built primarily to supply water from the Zaaihoek Dam on the Slang River to a new power station, but the facility to transfer water to the upper reaches of the Vaal River was included in its design. Actual water transfers from the Zaaihoek Dam to Grootdraai Dam over the period 1990 to 2010 were combined with the transfers from Heyshope Dam to obtain a more complete perspective as depicted in Figure 3.

The erratic nature observed is, if anything, reinforced by the transfers from the Slang River. The combined average transfer of 42,5 million m^3/a reduced the discrepancy somewhat, but it remains significantly less than the average of 73,5-million m^3/a water transfer originally envisaged for the period.

Another scheme, the Vaal River Eastern Subsystem Augmentation Project (VRESAP), links the Grootdraai Dam subsystem to the Vaal Dam. The VRESAP was completed in 2009 and made no significant contribution during the period under observation.

An examination of changes in demand revealed that growth had been slower than predicted. This would explain the lower volume in water actually transferred. However, the historic firm yield of Grootdraai Dam had been reassessed in 2001 and found to be only 77% of the earlier estimate. The incremental water requirement, following the approach as depicted in Figure 1, would in retrospect have averaged 61,4-million m^3/a for the equivalent period, which still meant that the actual transfers fell significantly short – by some 30%.

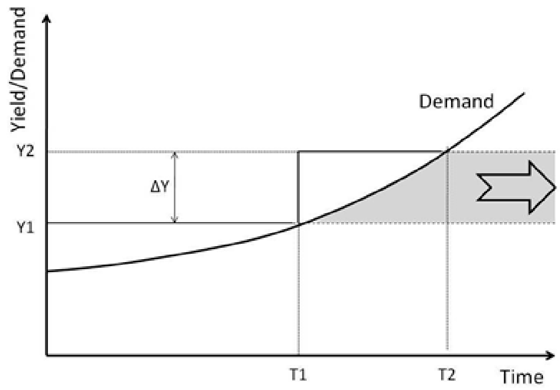
As regards the possibility of supply constraints causing lower transfers, records showed that both the Heyshope and Zaaihoek Dam had been relatively full over the period, indicating that there had been no impediment, from a source perspective, in transferring water to the Vaal River basin.

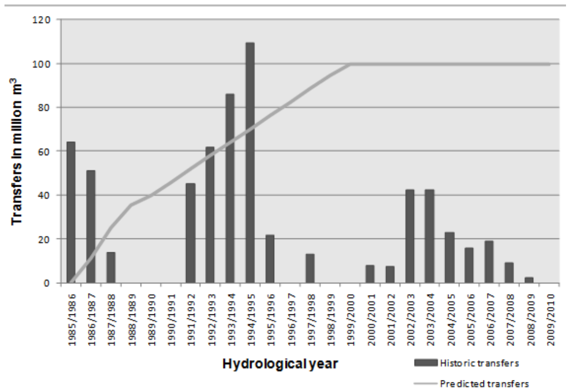
A detailed tracing of the annual operation of the Vaal River supply system, with the inclusion of the Grootdraai Dam subsystem, was required to shed further light on the reasons for the observations depicted in Figures 2 and 3.

ANNUAL OPERATIONAL SYSTEMS ANALYSES

Annually, at the end of the rainy season, the DWA undertakes an analysis of the Vaal River system in order to set the operational regime for the following year. This so-called Annual Operating Analysis (AOA) takes into account the state of the system (i.e. storage of each dam) as at 1 May of each year. The analysis is conducted soon afterwards.

The AOA entails running DWA's Water Resources Planning Model (WRPM) to simulate the behaviour of the Integrated Vaal River System (IVRS), usually for 1 000 stochastic time-series of flows of 20-year duration. This is repeated for various scenarios to test the impact of variations in operational rules, different growth





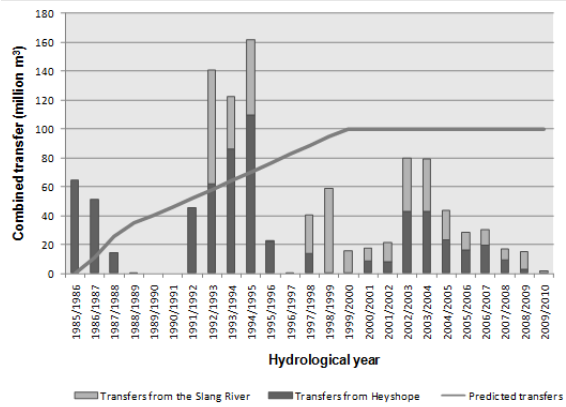


Figure 1, top: *Determining pumping costs with the Incremental Approach of IBT project appraisal.*

Figure 2, middle: *Usutu-Vaal GWS (Second Phase): Historic water transfers from Heyshope Dam against transfers predicted.*

Figure 3, bottom: *Combined historic water transfers from the Heyshope Dam and the Zaaihoek Dam on the Slang River.*

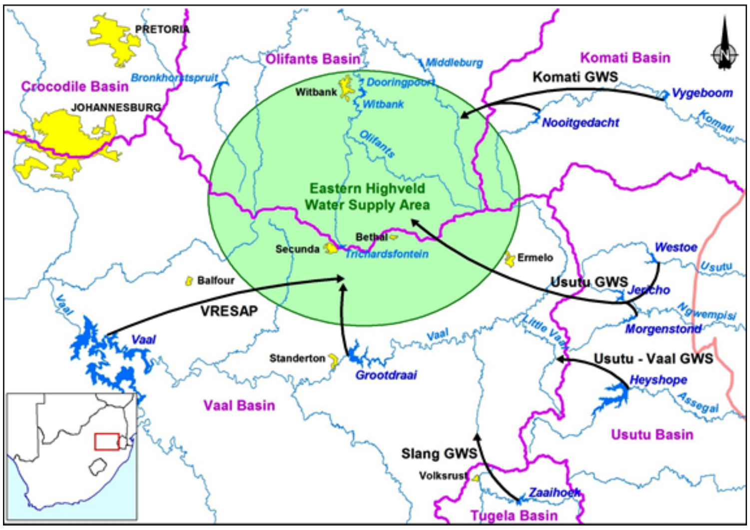


Figure 4: *Locality of Usutu-Vaal GWS (Heyshope Dam) within the upper Vaal River system.*

projections, and possible changes to the configuration of the system.

The WRPM is a South African developed system analysis simulation tool to determine the probabilistic yield characteristics of complex water resource systems. It can accommodate multiple demand centres (i.e. yield channels), take into account growth in demand and changes in land use, allow expansion of the system at future dates, deal with quality constraints, and impose curtailments. Its great advantage is that it explicitly provides information on future risks associated with postulated management and intervention scenarios. It is used for operational as well as planning purposes.

Dr Van Niekerk studied annual reports, covering a period of 22 years, starting in 1990/91 and ending in 2011/12, to see how the IBTs from Heyshope Dam and Zaaihoek Dam were operated in the light of the conditions in the rest of the IVRS during that period, and in particular that of the Vaal River Eastern Sub-System (VRESS) to which these IBTs are linked. A timeline perspective could be obtained of the four variables that influenced the decisions related to the transfers from these IBTs; the state of the system at decision date, the changes in system configuration and capacity, the projections in demand on the system for the short and medium term and the levels of assurance of water supply.

It was found that the state of the system, in particular the level of water in storage in Grootdraai Dam, had been the dominant determinant in the decisions related to the transfers from Heyshope and Zaaihoek dams. The state of the system at the decision date is influenced by the inflows the dams received in the preceding period and the abstractions that were made. Of these, the inflows are by far the dominant factor; abstractions were more stable and predictable.

During the 22-year period the system storage generally remained fairly high, except for a period between 1992/93 and 1995/96 when a drought occurred. This drought was of such a severity that restrictions had to be imposed on all water users on 1 April, 1995. Irrigation water users were restricted by 40%, municipal users by 20%, mines and the SASOL oil-from-coal facility by 10% and Eskom power stations by 5%. Following exceptionally good rains in November, 1995 the drought was broken. Restrictions were lifted in January 1996.

For the four years of the drought, large quantities of water were transferred from the Heyshope and the Zaaihoek dams. Problems with the pumps at the Geelhoutboom pumping station at Heyshope prevented continuous transfer at maximum capacity during these years. The policy at first was to keep all the water transferred in Grootdraai Dam, i.e. not to support the rest of the system. When Grootdraai Dam filled completely (largely as a result of the transfers) it was decided to continue pumping as there were delays in bringing the LHWP on stream, keeping Grootdraai Dam full and the spills to augment Vaal Dam. All transfers were stopped in December 1995 due to the system having recovered from the drought.

After the drought years of 1992/93 to 1994/95 the operating rule for transfers to Grootdraai Dam followed a fairly consistent pattern. The two transfer projects were treated in tandem, and similar recommendations made for transfers from the Heyshope Dam and the Zaaihoek Dam for the year that lay ahead. These recommendations were based on the likelihood that water shortages may develop in the short to medium term. Basically, interbasin transfers were made from Zaaihoek Dam and Heyshope Dam to Grootdraai Dam every time the latter reached a certain percentage of its full supply storage.

For 11 out of the 16 years since the drought, this level was set at 75%. During these years the starting storages of Grootdraai Dam averaged 96.1%. For four of the years a 90% rule was adopted. The average starting storage in these cases was 95.2%, which was not significantly different to the average for the 75% rule. It is noticed that three of these years occurred in the five years before the VRESAP pipeline started at the end of 2008 to augment the system from the Vaal Dam. This is consistent with the behaviour that can be expected of a system that is moving closer to its maximum safe yield capacity, with a growing demand and just prior to the system being augmented.

In the case study of the Usutu-Vaal GWS IBT the lower quantity of water actually transferred, as compared to what had originally been predicted, as well as the erratic nature of actual transfers as compared to the smooth growth originally assumed, could be explained by tracing the annual operations of the project over 24 years. It was shown that the Heyshope and Zaaihoek transfers were primarily determined by the state of storage in the Grootdraai Dam, and that the latter storage was dependent on the inflow into the dam, i.e. the run-off arising naturally in its catchment. By extension therefore, the Heyshope and Zaaihoek transfers were dependent on the runoffs that occurred in the catchment of the Grootdraai Dam, i.e. the receiving catchment. As these runoffs are inherently uncertain, hydrological uncertainty similarly characterises water transfers.

In the original planning of the Usutu-Vaal IBT, the investigation into the annual operating analysis showed that the assumption that all incremental water requirements, beyond the yield capability of Grootdraai Dam, would be required to be met from transfers had been incorrect.

The Incremental Approach led to an overestimation of the quantities of water to be transferred and, by the same token, operational costs. The correct appraisal approach would be to treat water transfer as a stochastic variable. The Incremental Approach, being a deterministic approach to IBT scheme appraisals, does not capture the essential characteristic of future water transfers – these being of an erratic and uncertain nature.

A further four South African case studies and two international case studies (in Australia and China respectively) showed that the Incremental Approach is still in general use today.

THE PROPOSED COMPREHENSIVE APPROACH

An improved approach, called the Comprehensive Approach, is proposed to explicitly address the probabilistic characteristics of water transfers and, following this, to upgrade the estimation of the costs associated with such transfers.

The Comprehensive Approach firstly requires the integrated analysis of the source basin and the receiving system, in combination. A simulation model, such as the WRPM, must be set to record water transfers, at suitable (typically monthly) intervals. The model is then employed to obtain simulated sequences of future water transfers of IBT schemes under consideration. With stochastic hydrological data input the transfer data sequences thus generated will exhibit characteristics similar to the actually observed water transfers of existing IBT projects.

With the synthetically generated water transfer data as input into the lifecycle cost model, the analyst is able to obtain a representation of the probabilistic characteristics of the lifecycle costs of an IBT scheme under consideration. Such output would form an important input into further economic investigations, such as cost-benefit analysis, to ascertain the feasibility of a proposed IBT scheme.

The application of the Comprehensive Approach was consequently demonstrated by means of an example using the Thukela Water Project, a proposed IBT to further augment the Vaal River system. It was shown that the Incremental Approach is severely biased with respect to variable costs and that this bias leads to significantly different estimations of likely lifecycle project costs. Such differences conceivably lead to suboptimal decision-making.

These findings have relevance not only to water scheme comparisons, but also to the institutional and financial design of water augmentation projects, such as seawater desalination works as well as the calculation of international water royalties, such as exist currently between South Africa and Lesotho.

In addition, the generally used unit reference value (URV) measure for appraising and ranking water resource projects in South Africa also required improvement. Dr Van Niekerk has shown that the current approach is conceptually flawed as it fails to distinguish between water transfers and effectiveness outputs. He proposed an expanded and improved determination of the URV measure.

- This article is based on two papers originally published in *Water SA* Vol 39 No 4 titled 'Hydrologic-economic appraisal of lifecycle costs of inter-basin water transfer projects' and 'Unit Reference Value: Application in appraising inter-basin water transfer projects'. Visit: www.wrc.org.za ❑

The Vaal River system combines a number of inter-basin transfer schemes to water South Africa's economic heartland.