Lessons learned from three decades of water resource planning of the Integrated Vaal River System

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Abstract

While the central objective of water resource planning in the Vaal River System was to maintain a positive water balance between the available water and water requirements, changes in the environment at large necessitated adaptations in thinking and approach. At the onset of the past three decades, the severe drought of the early nineteen eighties (with the accompanied heightened awareness and concomitant funding allocations) led to the development of risk based systems analysis techniques which later became standard practice in South Africa. The initial derived analytical methods and associated drought management approaches were applied in the 1994/1995 drought and more recently during the 2017/2018 dry period. The lessons learned during these events and the history of planning activities provide valuable insight in water resource planning where the interfaces between institutional arrangements, analytical methods and complex hydrological systems poses challenging management endeavours.

An example of change that led to a new era in planning commenced with the adoption of the Constitution in 1996 followed by the promulgation of the National Water Act of 1998. Among other aspects, the Act introduced the Reserve (basic human needs and the ecology), the requirement for water resource Classification (Part 2 of the Act) and water use regulation though licensing - all of which required "business unusual" thinking.

One activity that continued unabated throughout the period was the application of Annual Operating Analyses aimed at, among other things, identifying possible drought events early in the drought cycle. The approach made it possible to take action in the form of low level restrictions and inter-basin transfers at an early stage in the drought which prevented the need for more serious and potentially damaging restrictions later in the drought sequence. Parallel to this, long term planning were carried out through several investigations namely the Vaal Augmentation Planning Study (completed in 1996), Thukela Water Project Feasibility Study (2001), Lesotho Highlands Water Project Phase 2 Feasibility Study (2007) as well as the development of the Integrated Water Quality Management Plan (2009) to deal with, among other issues, the management of Acid Mine Drainage. During the latter half of the period the Integrated Vaal River System Reconciliation Strategy was development in 2009 and subsequently implemented to serve as the focus activity to safeguard against water availability problems in the system.

The paper presents how water resource planning has evolved by discussing key themes such as cooperative institutional arrangements, communication, hydrological observations and analyses, introduction of new research products as well as the application of decision support systems (software) - all essential elements needed to implement integrated water resource management in a consistent manner. With this as background, forward looking recommendations are provided to guide water resource management and planning in the years to come.

Keywords: *Hydrological analysis, Drought risk assessment, Water supply reconciliation strategy, Water resource planning, Integrated Water Resource Management.*

1. Introduction

Given the extent of the footprint of the Integrated Vaal River System (IVRS) as depicted in **Figure 1,** the necessity of making sufficient water available for current and future socio-economic activities while sustaining a healthy ecological environment, not only in the Vaal River catchment (yellow shaded area) but also the numerous linked receiving and source catchments (various colours), is evident. Each arrow in the figure represents a major water transfer scheme which represents many billions of rand of infrastructure investment.

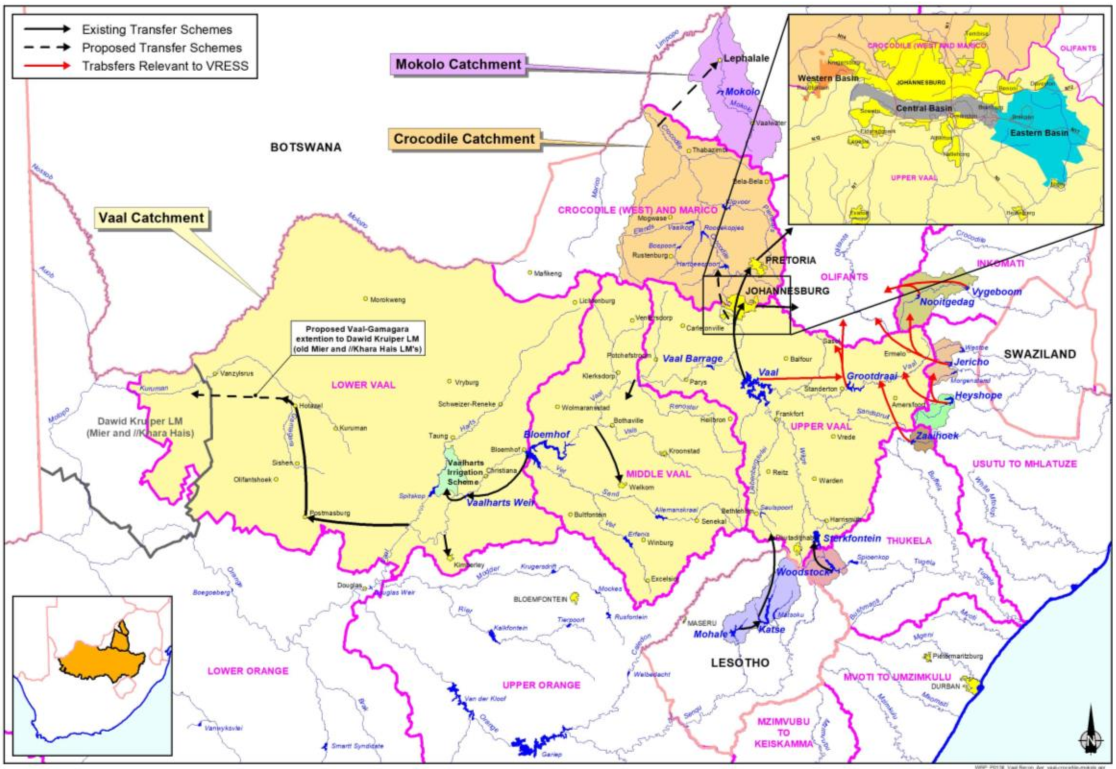


Figure 1: Map with inter-basin transfer links of the Integrated Vaal River System (DWS, 2018)

The water resource infrastructure (dams and conveyance system) that are present today were incrementally developed over many decades, see (**Rademeyer, 2005**) for an historic overview and **Appendix B** of the Overarching Internal Strategic Perspective (**DWA , 2004**) for a detailed schematic of the system components. A concise descriptions of the hydrological information and the current water resource infrastructure are provided in (**ORASECOM, 2007 a & b**).

In comparison to the other water resource systems in South Africa, the water balance information provided in the First Addition of the National Water Resource Strategy (**DWA, 2004**) indicates that from a quantitative viewpoint the water available (reliable yield) from the Integrated Vaal River System ranks second to the Orange River System.

If the economic value of the water is considered, however, the Integrated Vaal River System ranks well above the Orange River System since it supports more than 46% of the country's Gross Domestic Product (GDP) and a growing urban population due to the migratory patterns of people seeking socio-economic opportunities offered in the Gauteng Province, the economic hub of South Africa.

Due to the importance of the Integrated Vaal River System, the Department of Water and Sanitation (DWS), previously the Department of Water Affairs (DWA), embarked on various innovative initiatives that were first introduced and evaluated in the Integrated Vaal River System and thereafter rolled out to other systems in the country. As an example, the Vaal River System Analysis carried out in the late 1980's, summarised in Study Overview report (**DWAF, 1991**), spearheaded the development of risk based system analysis coupled with rigorous hydrological assessments.

The Vaal River System Analysis and other key water resource management activities that took place over the past thirty years are chronologically listed in the next section from which important lessons (do's and don'ts) were learned.

2. Chronological overview of planning activities for the Vaal River System

Table 1 provides a list of the key water resource planning activities undertaken since 1983 accompanied by a brief description of the activity and associated hyperlinks to the relevant documentation for easy access to supporting information and further reading.

Table 1. Chronological List of Primary Planning Activities

Year	Activity	Brief Description
1983	• Drought Analysis • Planning of the Orange-Vaal Weir Scheme.	• Performed cursory hydrological simulations using HEC model to assist with the management of the drought during the early nineteen eighties. • Assessed a scheme to augment the Vaal River from the Orange through a cascade of weirs (*58 Mbytes*), pump stations and pipelines.
1986	Lesotho Highlands Water Project Treaty.	• Signed the Treaty between South Africa and Lesotho in 1986. (An insightful World Bank Project Appraisal Document dated 1998 can be viewed here, providing a perspective from a lenders point of view.)
1990	Vaal River System Analysis (VRSA).	• Derived rigorous multi catchment hydrology. • Configured the integrated systems model (*50 Mbytes*) including water quality (salinity) for the first time. • Developed and calibrated the water quality salinity model. • Compiled the "Analysis Procedures Manuel" (*67 Mbytes*) for training and to guide future system analysis applications. • Developed "Multi-catchment stochastic" (**McKenzie & Pegram, 1991**) flow generation model enabling sophisticated hydrological risk analysis – first revision (Mark 2).
Since 1989	Integrated Vaal River System Annual Operating Analysis (AOA).	• Applied the system model for risk base system operations planning. See general guidelines and particulars for the Integrated Vaal River System. • Applied risk based planning, where simulation analyses results are compared against risk criteria to select appropriate target rules. • Cooperative planning with bulk water users through the System Operating Forum (SOF) - see example products of the SOF meeting held in May 2016 . • Developed monthly distributed monitoring information.
1996	Vaal Augmentation Planning Study (VAPS).	• Evaluated, compared and shortlisted water resource infrastructure development options to augment the Vaal River System. Paper. • VAPS recommended that a further phase of the LHWP and the Thukela Water Projects are comparable and should be investigated further.
2001	Vaal River System Analysis Update Study (VRSAU).	• This study was initiated due to the observations that the actual storage trajectory of the system during 1994-1996 was below the 99.5% exceedance probability projections. Link, download to view annotation. • Updated the systems models including full recalibration of the hydrology and water quality (salinity) models. See Summary Report (*60 Mbytes*) (**DWAF, 2001**).

Year	Activity	Brief Description
2001	Thukela Water Project (TWP) Feasibility Study.	• Identified the most feasible infrastructure water resource development option in the Thukela River System to augment the Vaal River System, see locality map.
2003	Thukela Water Project Decision Support Phase.	• Completed a bridging study incorporating the Ecological Water Requirements determined for the Thukela River.
2004	Internal Strategic Perspectives (ISP).	• Documented DWAF's perspective on water resource management for all catchments in South Africa. • Compiled reports for Upper, Middle and Lower Vaal Water Management Areas as well as the Overarching ISP (**DWA, 2004**).
2004	Vaal River Eastern Subsystem Augmentation Project (VRESAP).	• Compared various water resource infrastructure options to augment the Vaal River Eastern Sub-system. Pre-Feasibility Study Main Report (74 Mbytes) • Study led to the implementation of the Vaal River Eastern Subsystem Augmentation Pipeline by TCTA.
2007	Potential Savings Through WC/WDM in the Upper and Middle Vaal WMA.	• Undertook detailed investigation into the potential to reduce water use by implementing WC/WDM interventions. • Project 15% was established - one of the pillars of the Reconciliation Strategy 2009 (**DWAF, 2007**).
	Example of the application of the systems models in research.	• Integrated Modelling for Sustainable Management of Salinity in the Lower Vaal and Riet River Irrigation Areas Phd dissertation. (Armour, 2007).
2009	Vaal River System: Large Bulk Water Supply Reconciliation Strategy	• Formulated the Reconciliation Strategy to ensure sufficient water is made available for a 30 year planning horizon. See the strategy web page for background information and reports.
2009	Development of an Integrated Water Quality Management Plan for the Vaal River System.	• Compiled an Integrated Water Quality Management Plan. • Assessed options to deal with Acid Mine Drainage originating from the gold mines on the Eastern, Central and Western mining basins. • Assessed the eutrophication status and management measures of the Vaal River – focussing on pollution prevention.
2009 to 2015	Maintenance of the Vaal River Reconciliation Strategy.	• Predecessor of the current (2018) study and first strategy implementation phase. See 2018 below for the current processes.
2010	Comprehensive Reserve Determination: Integrated Vaal River System.	• Give effect to Part 3 the National Water Act (Act No 36 of 1998) for the Integrated Vaal River System. • See 2012 below for subsequent Classification process.
2010	Comparative Study Between LHWP Phase II and Thukela Water Project.	• This led to the decision to implement Phase 2 of the LHWP. • The findings of this study resulted in Parliament taking the decision to proceed with the negotiations with Lesotho for the implementation of Phase 2 of the LHWP.
2011	Extension of hydrological records up to the year 2004.	• Developed the ORASECOM Basin-Wide Integrated Water Resource Management Plan. • Extended the hydrological records to cover the period 1920 to 2004.
2012	Classification of Significant Water Resources (WMA 8,9,10).	• Following the promulgation of the National Water Resource Classification System in September 2010 the Vaal River System water resources were Classified - see suite of reports and the Water Resource Analysis Report reflecting the consistent application of hydrological data and simulation models.
2013	Feasibility Study for the Long-Term Solution to address the AMD from the Eastern, Central & Western mining basins.	• The study led to the decision to implement desalination as the long term solution to manage Acid Mine Drainage of the indicated underground basins.
2015	Continuation of the IVRS Reconciliation Strategy Study (Phase 1).	• Final Strategy Steering Committee meeting was held in June 2015. • The hydrological data applied in the risk analysis is summarised here. Note this linked report covers both the Orange and the IVRS.

Year	Activity	Brief Description
2016	Define the Resource Quality Objectives of Water Resources for Catchments in the Upper, Middle and Lower Vaal.	• Provided numerical and/or descriptive statements relating to the biological, chemical and physical attributes that characterise a resource for the level of protection defined by its Class. (See study web page for reports covering the three catchments.)
2018	Vioolsdrift / Noordoewer Dam Feasibility Study in the Lower Orange.	• Assessed the feasibility of yield replacement options in the Orange Senqu River Basin to offset the yield reduction of Polihali Dam (Phase 2 of the LHWP) on the Orange River Project. Study is currently in progress. (Motivation for planning this project can be found here.)
	Continuation of the Vaal River System Reconciliation Strategy Study (Phase 2).	The objective of the study is to: • Track progress with the implementation of the strategy actions. • Review key factors that influence the projected water balance. • Identify further water resource planning and management interventions deemed necessary to maintain a positive water balance for the next 30 years.

In 1983 the analysis techniques and computers available to undertake the analyses were significantly different to the current situation in many ways, as can be observed in the report of the hydrological analysis carried out at the time. The simulation computations could only be performed on large and expensive mainframe computers which had less computing power than a modern-day mobile phone. Graphs could only be viewed if plotted onto paper using large plotters which were only available at offices!

The severe drought during the early nineteen eighties (as droughts usually do) resulted in intensified planning activities and substantial resource allocation due to the realisation by decision makers that thing need to be done differently. At the time interventions in the form of physical infrastructure such as the Vaal Dam to Grootdraai Dam Weirs Scheme as well as the commissioning of the Lesotho Highlands Water Project were implemented. Section 3.3 in **Van Rooyen et.al, 2009** provides a chronological list of how the Lesotho Highlands Water Protect was developed.

Enhancing decision support methods also received a thrust of attention as part of the Vaal River System Analysis Study (**DWA, 1987** & **DWA, 1991**). It was through these activities that many lessons can be identified some of the most important are discussed in the subsequent text.

Lesson 1: *Money for planning and development increases when rain subsided, rivers don't flow and dams are low.*

As a measure to standardise methods during the Vaal River System Analysis and in anticipation that the methods, techniques and software products from that study would be applied in other systems in the country, the Yield Analysis – Terms and Procedures report (**DWA, 1987**) was compiled for use by managers and practitioners. The Vaal River System Analysis also gave rise to a book, Probabilistic Management of Water Resource and Hydropower System, (**Basson et.al, 1994)**.

Examples of the role out of the assessment methods to other systems in the country are: Crocodile (West) River System, (**DWAF, 1990);** Orange River System (**DWAF, 1991**); Western Cape (**DWAF, 1994a)**; and, Mgeni River System (**DWAF, 1994b)**, to mention a few.

Lesson 2: *New methods, techniques and software, employed for water resource planning, need to be prototyped, pilot tested, pier reviewed and should be accompanied by appropriate training material before it is rolled out to other areas.*

The simulation models, drought management methods and risk analysis techniques developed during the Vaal River System Analysis provided the Decision Support Systems (software and methods) required to enable risk based analysis for both short-term operational and long-term development planning purposes. This ensured a high degree of consistency since the same technology, hydrological database and drought restriction methods were applied to guide system operation and infrastructure development decisions.

Lesson 3: *The consistent application of rigorous hydrological information, analysis techniques and models focused the water resource management debates on the implications of the results of analysis as opposed to the input information or the results accuracy. The analysis outcomes provide the means to evaluate relative efficiency by assessing alternatives also referred to as scenario planning.*

The products from the Vaal River System Analysis gave rise to the Annual Operating Analysis which became an annual planning event since 1989 until today. The report titled Vaal River System: Annual Operating Analysis 2009/2010 (**DWA, 2009)** provides detailed information relating to the annual operating analysis and related processes, including:

- Schematic representations of the system network as it was configured in the model data files. Note that both the Integrated Vaal River System (see **Figure 1**) and the Orange River System were analysed as a single combined water resource system since they are interdependent and must therefore be operated together.
- Reference lists to the series of reports dating back from 1985 that illustrates the trail of knowledge contained in the Decision Support System as it exists today.
- Documentation illustrating the method of preparing the scenario risk based results, which at that time required generating graphs with a software utility coded in C using C-based libraries as CGM graphic files from the model simulation output that were imported into a drawing packages – all done by hand.
- The graphical products (see Appendix I) to track and monitor the actual system response (black lines) against the projected simulation results of the selected or target operating rule.

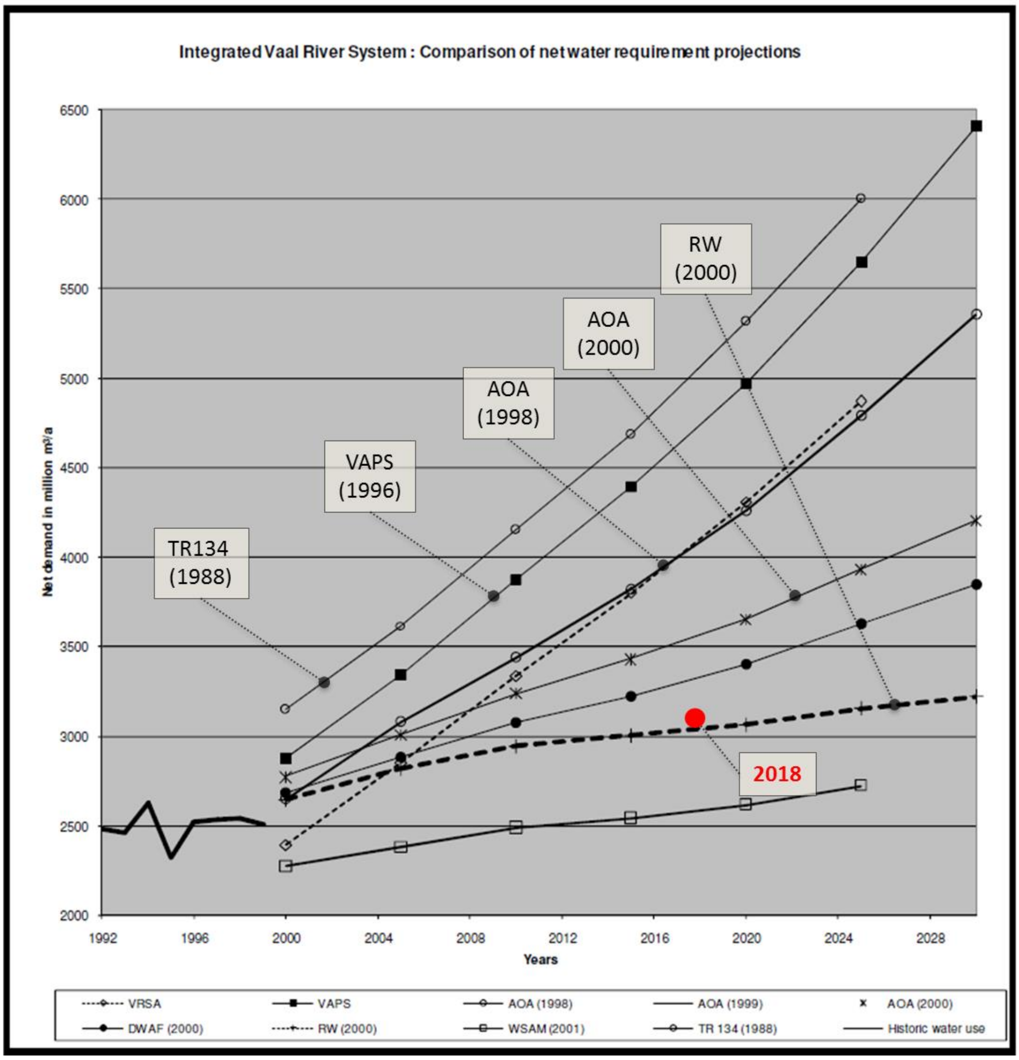
The Vaal River Augmentation Planning Study was a comprehensive planning endeavour commissioned by DWA and executed by several teams of Professional Service Providers through well-structured coordination. The purpose was to determine the most feasible development options to augment the Integrated Vaal River System by comparing alternatives involving; further phases of Lesotho Highlands Water Project in the Senqu River, Thukela River, Caledon River, Upper Orange River (South Africa System) as well as the Mzimvubu River System – the latter at a reconnaissance level of detail.

In 1996 the water requirement projection “VAPS (1996)” (one of the lines shown in **Figure 2**) defined the future water needs for which planning was to be carried out. Although the “VAPS (1996)” was a reduction compared to the “TR134 (1988)” projection, it was in hindsight still overestimating the future water needs in comparison with the other projections shown in in **Figure 2**. The current, 2018, net water require of the system is indicated as a red dot to be above 3000 million m^3 per annum.

Lesson 4: *Regular review of water use (measured data) against projections is essential for efficient planning. This monitoring is to prevent over or under expenditure on interventions whether those are managerial measures or infrastructure developments.*

During the 1990’s the political landscape of the country changed with the current constitution coming into effect on 4 February 1997 and the promulgation of the National Water Act (NWA) in 1998. Among the changes introduced was the water rights structural which prioritised water for the ecology, Ecological Reserve, to be the second priority use after the Basic Human Needs Reserve. In response to the introduction of the Ecological Reserve the water resource planners and analysts needed to cooperate with the water ecologist to find an approach and devise new methods to comply with the Act. Since the Act came into effect the methods to incorporate the Ecological Reserve has been maturing and a recent description of the Procedures to Operationalise Resource Directed Measures is provided in a suit of reports (scroll to the end of the web page), see (**DWS, 2017**) for the Main Report.

Figure 2: History of Water Requirements Scenarios (DWAF, 2007)



3. Drought risk – a key metric since 1989

In response to the large variability of rainfall and runoff along with long drought periods in the region, one of the stated purposes of the NWA of 1998, (see Chapter 1 Section 2(k)) is to "manage floods and drought", The mechanism to enforce restriction on water use is provided by Item 6(1) of Schedule 3 of the Act with the magnitude and timing of drought restriction left to be determined by water resource managers and stakeholders. Drought restrictions in the Integrated Vaal River System have been implemented only three times over the past three decades, in 1983-1987, 1994-1996 and recently in 2016-2017.

The drought restriction policy applied in the Vaal River System is based on three tiers or levels as defined in **Section 3.9** in **DWA, 2009, Section 5.4** of **Basson et.al, 1994** and in **Section C4.1** in **Appendix C** of **DWAF, 2006** - this is also known as the water user priority classification and assurance of supply criteria definition table. The application of the risk of drought restrictions criteria is illustrated in **Figure 5** where the red shaded areas indicate violations of the applied criteria (see **Section 6** for further discussion).

The implementation of different user priority groups or classes (low, medium and high), the ability to derive short term Yield vs. Reliability characteristic (**McKenzie & Allan, 1990**, & **Section 2.7.2** of **Basson et.al. 1994**) and the risk based projection analysis provides the following advantages:

- Ability to evaluate if the drought restriction rules (dependant on the storage in the dams, water requirements and water user priority classification and assurance of supply criteria definition) are stringent enough, to protect the dams from being completely depleted.
- Or, if there are large unused storage in the system, indicative that the restriction rules are too aggressive.
- The ability to simulate and analyse all the elements as an integrated system graphically (see schematic of IVRS modelled network in **Appendix A** and probabilistic graphical results in **Appendixes D** to **G** of **DWA, 2009,** *27 Mbytes***)** make it possible to eliminate shortfalls in any of the dams or identify where underutilisation of storage may occur.

Lesson 5: Water resource system operating rules, including drought restrictions should be tested though risk based simulation analysis.

The decision to implement drought restrictions in 2016 was based on the projected combined storage risk results of Vaal, Sterkfontein, Katse and Mohale dams (see Page 6 of the 2016 scenario results) which shows that there was a 0.5% probability that these dams **would be depleted** for consecutive years between 2020 and 2025 - prior to further augmentation from Phase 2 of the Lesotho Highlands Water Project which is scheduled to commence water delivery in 2025.

The above practice points to an additional risk criterion applied in the IVRS, namely that the dams which represent the 'last water' in the subsystems (Nooitgedacht, Jericho, Grootdraai and Sterkfontein respectively) should not be depleted at a 0.5% probability. If the simulation analyses show that this criterion is violated, adjustments must be applied to the default operating rules in the form of changes to the inter-basin transfers or alternatively the restriction rules must be intensified.

Lesson 6: Operating analysis for operational planning should cover a projection period twice the system's historical critical period. The critical period for the Integrated Vaal River system is more than 9 years (**DWAF, 2000**).

4. Stakeholder engagement

Stakeholder engagement to ensure cooperation, information exchange for effective planning intensified with the requirement set by the National Water Act, as stated in the preamble: 'Recognising the need for the integrated management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to **enable everyone to participate**'

The studies and processes undertaken by DWS since 1997 were carried out through a combination of the following stakeholder engagement processes:

Study Steering Committees: Guide the Department in the execution of studies or processes to ensure relevant current information is applied in the investigations and information on the study processes and outcomes are disseminated to the organisations represented at the meeting. Sharing of study products, presentations, reports, technical data and analysis results during the execution of the work is key to demonstrate the Department's commitment to cooperate with stakeholders.

Study Management or Project Management Committees: Coordinates the project management of a study and is usually attended by DWS officials from various Directorates and the Professional Service Providers. In some cases Water Service Providers such as Water Boards and/or Local Authority representatives also participate.

Technical Task Groups or Focus Groups: These coordinating groups are formed by relevant officials from various organisations to facility information exchange and engage with specific technical and scientific aspects that need to be dealt with in a study or process.

Strategy Steering Committee (SSC): The Study Steering Committee that guided the formulation of the Reconciliation Strategy 2009 (**DWA, 2009**) was converted to a Strategy Steering Committee to oversee the implementation of the strategy actions and to ensure the information, such as the water balance projection, remain relevant. The committee also provides advice to DWS on additional actions that may be required to ensure sufficient water is made available to all water users dependant on the Integrated Vaal River System. See minutes of the February 2018 SSC.

System Operating Forum: Forum led by DWS to coordinate the operation planning and monitoring activities. Examples of the proceedings and related monitoring products of this committee can be viewed through the hyperlinks.

Catchment Forums: There are 13 catchment forums in the Vaal River such as the, Blesbokspruit, Klip River, Leeu Taaibospruit, Riet/Modder and Vaal Dam Catchment Forums. See hyperlinks for typical forum activities.

To enhance cooperation and give effect to integrated water resource management approach, DWS ensures that cross representation of DWS directorates occurs with officials from relevant directorates partaking in the appropriate committees of a study or processes led by other Directorates. An example of this is shown in the Communication Framework for Resource Directed Measures, described in Section 12 and schematically illustrated in **Figure 12.1** of this document.

Lesson 7: One of the key success factors that have achieved high levels of integration and collaborations (a primary objective of Integrated Water Resource Management) in DWS's operational methods is the cooperation though cross attendance of PMC and Project Steering Committee meetings by officials from different DWS components.

5. Decision Support System – Software

The paper, Framework for Future Water Resource Analysis in South Africa (Coleman et.al, **2007**), presents a brief history, status and future application of the water resource management Decision Support Systems applied by DWS during the past three decades. The core simulation models in question are Water Resource Simulation Model WRSM2012, Water Resource Yield Model (WRYM), Water Resource Planning Model (WRPM) and the Water Quality Calibration Model (WQT) as briefly described below:

Water Resource Simulation Model WRSM2012
WRSM2012 is a network based rainfall-runoff calibration and land use process simulation model with the primary function of preparing naturalised runoff time series for river catchments. A cascading (upstream to downstream) network flow routing and continuity balance solving method is applied.

Water Quality (Salinity) Calibration Model (WQT)
The WQT model simulates Dissolved Major Solids (DMS) and Sulphate with the purpose of calibrating the various water quality modules. A network structure is defined to represent the river and catchment configuration of a particular water resource system. There are seven modules or simulation elements, each can be linked to the system network in according to the layout of the river system. A linear network solver with limited flexibility is applied as the network routing method.

Water Resource Yield Model (WRYM)
WRYM is a network based water resource system analysis model to determine the yield and hydropower capability of water resource systems using historical and stochastic (risk based) hydrology - typically applied for constant catchment development scenarios. The water distribution (routing) is performed by an "out-of-kilter" linear network solver with enables simulation of flexible drawdown and distribution rules of complex systems including multiple catchments, dams and abstractions from a river system.

Water Resource Planning Model (WRPM)
The Water Resource Planning Model (WRPM) performs risk based projection analysis for a 10 to 50 year planning horizon providing analytical support for development and operations planning of complex water resource systems.

The model contains a water resource allocation module with drought restriction algorithm, features to model time dependant system changes (operating rules and physical infrastructure), river system salinity simulation modules (similar to WQT) with a blending and dilution algorithm. It accounts for water requirements and return flow changes over time and applies the same network solver for flow routing as the WRYM.

The primary output from the model is projected annual risk of restrictions, monthly probabilistic storage volume and flow projections, hydropower energy projections as well as salinity concentrations in reservoirs, river reaches and abstraction routes.

Since about 2005 DWS has developed the **Water Resource Management Framework (WRMF)** (**Lillie & Watson and Nyland, & Watson, 2005** to provide information management of the data applied in water resource analysis processes. The WRMF serves as a Graphical User Interface with data entry Dialogs (windows) and result display methods from some of the simulation models. The WRMF provides information management for the following:

- WRYM and WRPM (excluding water quality).
- Rainfall (Rainfall data Information Management System).
- Stomsa (Stochastic streamflow model of South Africa).
- Daily Diversion (Determine monthly flow diversion efficiency characteristics using daily data analysis).
- Instream Flow Requirements Pre-processing (Prepare IFR – parameters for the ecological water requirements simulation element – also referred to as the Ecological Water Requirements.
- Rain Water Harvesting: Calculate how many days a family can be supplied with rainwater.

A description of the information flow and linkages between the above described and other software system can be found here. **Figure 3** below is an extract, showing the linkages among the three core simulation models.

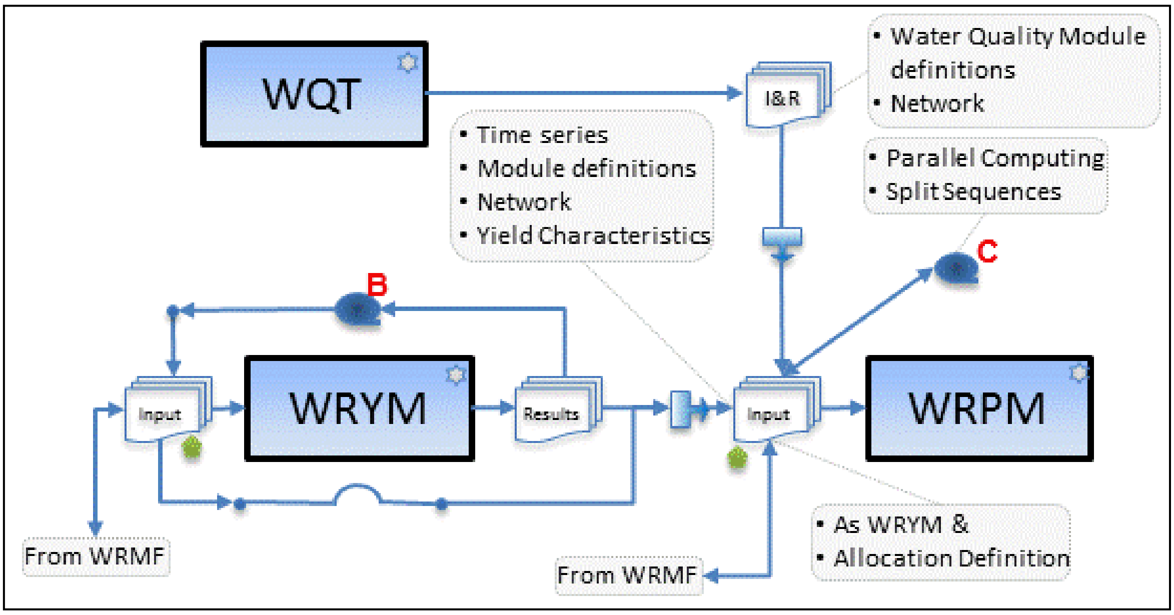


Figure 3: Linkages between the core simulation models

The above linked document shows three recently developed automation methods, with the following functionality:

- Automation of analysis to produce storage vs. yield results for selected recurrence intervals using an Excel utility and iteratively running the WRSM2015.
- Automation in an Excel utility to analyse multiple sets of inter reservoir operating rules for optimisation using WRYM. Recently analysed more than 4000 alternative operating rule scenarios for the Lesotho Highlands Water Project including the proposed Phase 2 infrastructure. .(See **B** in **Figure 3**)
- Undertake split sequences analysis to utilise multiple computer processes to run WRPM. (See **C** in **Figure 3**)

The drive to eliminate processing steps, reduce human (analyst) time-input and enhance methods has been a key endeavour in the initial development and renewal of these software systems over the years. The ability for automation has changed along with the progress in information technologies. In the 1980's analysts were excited to save time by running batch files to answer the tedious question of the Fortran based software for manual plotting. Today scripting in Visual Basic (and other languages) can open and change input files, run a model, click buttons, fill in dialogs, read results, prepare statistics or graphs and populate a report (yes that is possible!) for unlimited iterations as an uninterrupted process.

Lesson 8: *Supplementary to the recommendation noted in Coleman et.al, 2007, the recognition of the benefits of automation (to do more in a shorter time or to enhance current processing methods) coupled to the ability to use script (not executable utilities) must guide how these software assets are managed in future.* ***Then there is the internet, use it****: IVRS, Vaal Dam: Photos: a & b, Storage & data, Outflow & data.*

6. Integrated Vaal River System Status - 2018

The proceeding of the Strategy Steering Committee meeting held on February 2018 (status report and minutes) indicates that the current water requirements and the projected growth exceeds the supply capability until Polihali Dam and transfer infrastructure (LHWP Phase 2) is implement (expected to deliver water by the year 2025) and the yield replacement option in the Orange River is commissioned (estimated to the operational in 2030). This is illustrated in the projected annual water balance (**Figure 4**) and the supporting projected risk of restriction graph shown in **Figure 5**.

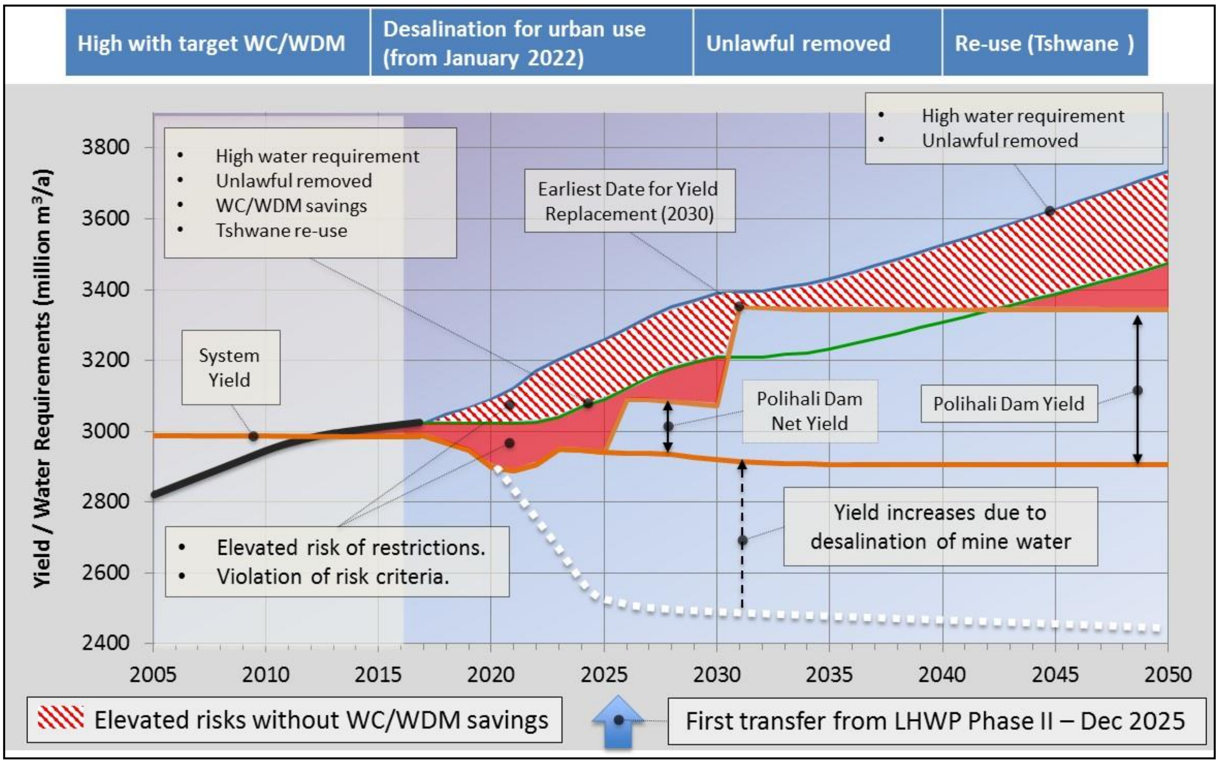
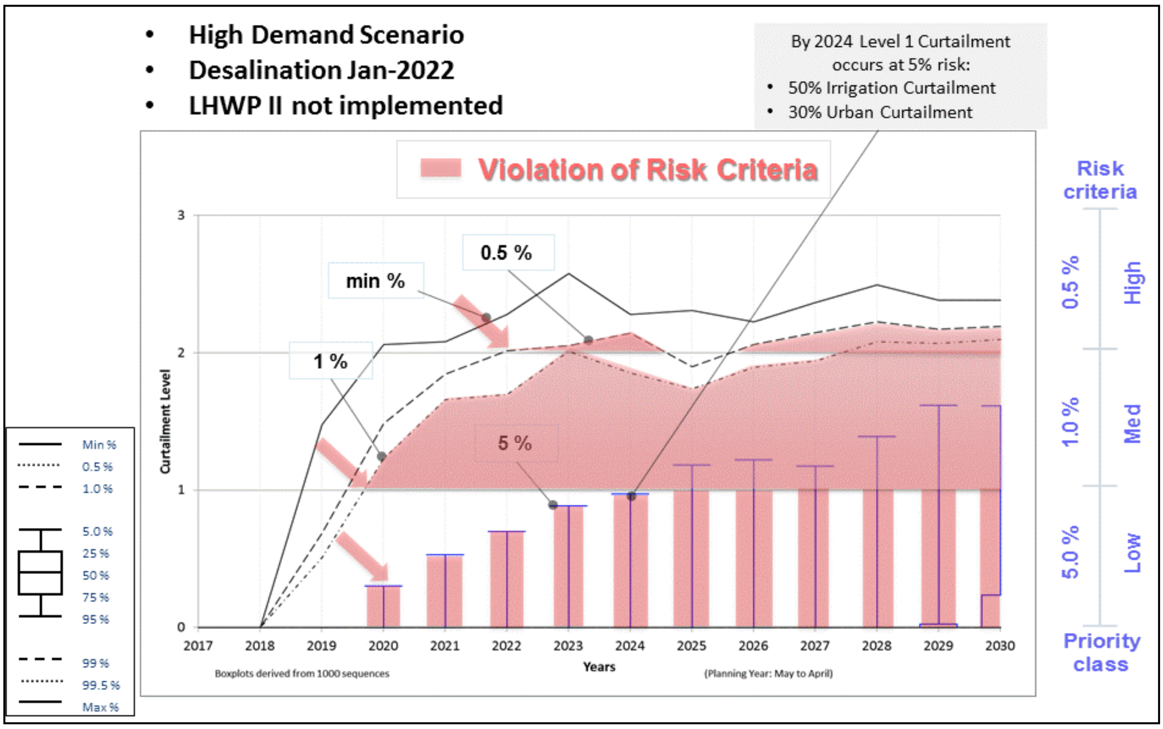


Figure 4: System balance for target reconciliation scenario (February 2018)



Note the Risk Criteria and Propriety Classes shown in blue at the right of the graph.

Figure 5: Risk of drought restrictions

The projected decrease in the Eskom Power Station water requirements supplied from the Vaal River Eastern Subsystem and in particular the Komati Subsystem will result in unutilised storage and yield as reflected in **Figure 6**.

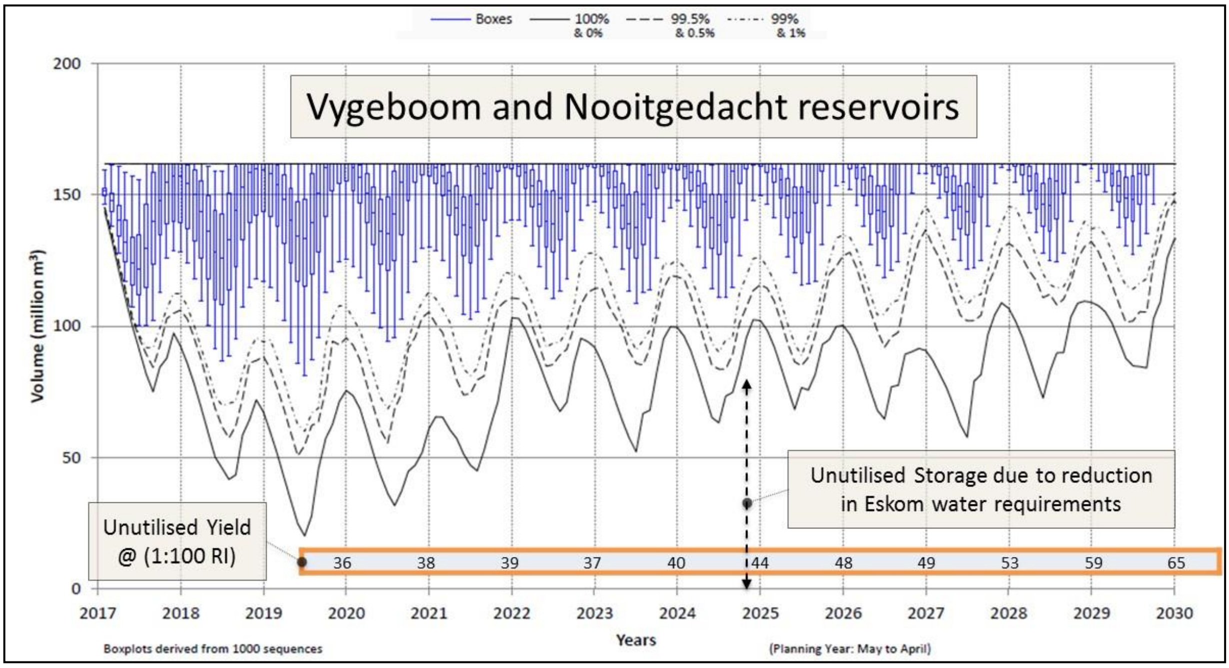


Figure 6: Storage projection of the Komati System

7. Conclusions

The discussion of the history of selected water resource planning and infrastructure development activities over the past three decades in the Integrate Vaal River System provides useful insight to formulate at least eight lessons that can be learned to guide future planning methodology. Most of the lessons are universally applicable for the management of water resource system.

It has been shown that methods and approaches of planning need to be flexible to adapt to changing policies, evolving legislation, changes in the future water needs and the continuous advancing of the information technology environment.

The value of consistent application of analysis methods, whether it is for operation, development or protection activities ensure stability in the messaging to top management, stakeholder and the public. The debate is about the implication of the outcomes of analysis as opposed to the accuracy of the input or results.

Continuous monitoring of the projected water balance (both water availability and water requirements) coupled with the application of risk based methodologies, which identify potential supply problems may years in advance, give planners the best change to avoid undesirable supply failures.

Allowing restriction during drought as a management method in accordance with clear risk criteria gives planners the ability to compare alternative though risk based scenario simulations to support planning and implementation decisions.

8. Recommendation to guide water resource planning in years to come

Lecturers: Ensure learners are exposed to these and other practical water resource planning, operation and management examples. This is to build their knowledge in order to avoid pitfalls of the past and further improve the efficiency in analysis, planning and management of water resource systems.

Learners: Water resource management and planning is a divers field, require knowledge of law, models, institutional arrangement, hydrology, data management, economics, ecological health, public participation and engineering. Reading the documentation that is referenced in this paper along with the wealth of other documents on the web will serve to build a thorough understanding of past and current water resource management approaches.

Practitioners: Look out for opportunity to make water resource planning more efficient by embracing new technology where practical, improve accuracies and understanding (do more with less), while staying on track with rigorous validation of facts.

Decision makers: Embrace the knowledge documented in this paper and elsewhere. The planning history of the Integrated Vaal River and other systems provide a foundation to move planning and management forward. Resource allocation, human capacity building and dedication to develop and protect the water resources in an efficient manner were, are and has to remain high on the agenda.

A key success factor in water resource planning will be to look out for disrupters that will influence how and where water is used, distributed or conserved and by developing flexibility water resource provision strategies that can accommodate known and unknown change.

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