WATER SUPPLY DEVELOPMENT DECISION-MAKING IN SOUTH AFRICA

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ABSTRACT

Balancing water demand and supply in South Africa involves high levels of uncertainty. The Department of Water and Sanitation (DWS) is responsible for making decisions to either increase water supply or decrease water demand so as to ensure that sufficient water is available, when and where it is needed. However, no retrospective analyses of such decisions have been found. One way to assess such decisions is to evaluate the associated costs and benefits thereof. Therefore the primary aim of this study is to evaluate the costs and benefits of selected water supply options, and of the decision-making associated with those options.

In order to achieve this purpose, four case studies were analysed within a mixed-methods research paradigm, which used both quantitative and qualitative methods, including unit reference value (URV) analysis, inter- and intra-case analysis and content analysis to examine the success of the decisions made. The four case studies were conducted on the Inyaka, Nandoni, Berg and De Hoop dams and their catchments. Firstly, estimated and actual project costs were compared using unit reference analysis and inter-case analyses. Secondly, the reduction of mean annual runoff (MAR) caused by invasive alien plants (IAPs) and the cost of clearing them in the dam catchments were evaluated using inter-case analyses.

Information thus gathered was used together with data from DWS documentation and the results of interviews with ten key specialists, to analyse the decision-making process that led to the decision to build De Hoop Dam (the most recent case study). The rational decision-making model (RDMM) was used as a framework within which to analyse and evaluate this decision-making process. This study has also demonstrated how the RDMM can be used to assess decision-making associated with water supply development.

The results of this study show that there is considerable variation of estimated costs (at the time that the decision to build the dam was taken) in relation to the actual costs of building the dams and that Ministers were not put in a position to understand the full long-term costs or the opportunity costs of the proposed dams. Furthermore, the most recent IAP data (2008) shows that the impact on water security by IAPs could not offset the water security resulting from building each of the four dams. However, if IAP management is not continued in these catchments, the projected reduction of MAR by IAPs will compromise water security within 45 years. Given the almost exponential spread and densification of

IAPs, together with their long-term impact on MAR and increased costs of controlling them, it is clear that IAP management should have been factored into water supply decision-making from the outset.

In the analysis of the decision to build the De Hoop Dam, the results show that while the decision-making process that culminated in the decision to build the dam did not follow the steps of the RDMM, DWS appears to have followed a somewhat similar approach. It was found that while there was a need for the provision of additional water in the Olifants catchment, this need was overstated and the resulting overestimation caused the scale and size of the dam to be larger than it could and probably should have been. Additionally, it appears that DWS's decision to build the De Hoop Dam themselves, rather than having it built by the private sector, may have been less than optimal.

It is recommended that, in future decision-making, DWS needs to incorporate multiple alternative options into the same solution, and to ensure that decision-makers are put into a position to make informed decisions, including adequate consideration of externalities. Furthermore, DWS needs to employ decision-making models such as the RDMM to facilitate retrospective analyses to improve their institutional knowledge.

Keywords: water resources management, dams, invasive alien plants, decision-making, unit reference values, rational decision-making model.

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LIST OF ACRONYMS

BRDDM	Bounded Rationality Decision-making Model
CBA	Cost-benefit Analysis
CPI	Consumer Price Index
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DSM	Demand-side Management
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ha	Hectare
IAP	Invasive Alien Plants
IBT	Inter-basin Transfer
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCA	Multiple Criteria Analysis
MMR	Mixed Methods Research
NIAPS	National Invasive Alien Plant Survey
NPC	National Planning Commission
NWRS	National Water Resources Strategy
O&M	Operations and Maintenance
ORWRDP	Olifants River Water Resources Development Project
PDMM	Political Decision-making Model
RDMM	Rational Decision-making Model
RID	Record of Implementation Decision
RSA	Republic of South Africa
TCTA	Trans-Caledon Tunnel Authority
URV	Unit Reference Value
WfW	Working for Water Programme
WMA	Water Management Areas
ZAR	South African Rands

CHAPTER ONE
INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND TO THE STUDY

South Africa is a water scarce, developing country (DWA, 2013b; King *et al.,* 2011; Ashton, 2002). Its water resources are limited; hence there is a definite supply limit which requires the innovative consideration of a broad range of water supply and resource management options in addition to dam construction, such as integrated catchment management and demand-side management (DSM) (King *et al.,* 2011; DWAF, 2009a).

Awareness of risks such as drought, climate change and deteriorating water quality are important, especially in the wake of evidence, that water catchments are degrading (King *et al.,* 2011). This evidence can be seen from examples such as pollution and wetland degradation (DWA, 2013b), unsustainable farming practices (Currie, 2007), soil erosion and sedimentation (Msadala *et al.,* 2010), as well as in other environmental damage from land and water abuse caused by under-priced water and lack of incentives to maintain catchment health (King *et al.,* 2008; King, 2004). Some of the implications of degrading catchments are: decreased water security, decreased water quality, the degradation of natural ecosystems such as rivers and wetlands, and a decrease in total useable and productive land (King *et al.,* 2011). Degraded catchments can also lead to a decrease in social welfare and economic growth, which impacts negatively on human well-being. In order to reduce and/or mitigate the degradation of catchments, a process is needed to plan and manage water, land and other environmental resources in a harmonised manner (De La Harpe & Ramsden, 2002). This is why an integrated water resource management (IWRM) approach is imperative in managing water supply in South Africa.

The South African Government has made major commitments to develop new water infrastructure such as new and raised dams, inter-basin transfers, bulk distribution schemes, and desalination plants (DWA, 2013b; National Treasury, 2013; NPC, 2012; Gordhan, 2012; DWAF, 2009a). These commitments have been made through the Department of Water and Sanitation (DWA, 2013b; DWAF, 2009a), the Minister of Finance's budget process (Gordhan, 2012) and the recommendations in the National Development Plan: 2030 (National Planning Commission, 2012).

Commitment to an infrastructure-led, supply-side approach to water management has been criticised for two reasons: firstly, as the result of a perceived lack of historical alignment between what decision-makers were told the new water infrastructure would cost and the actual cost (Asmal & Hadland, 2011); and secondly, for placing the emphasis on infrastructure development rather than careful inclusion of DSM and catchment management, where investments should first be made (DEA, 2014d; DWAF, 2009a). In light of these criticisms, it should be noted that the continued management, development and security of water supply cannot exist without water resource infrastructure (DWA, 2013b). It must also be pointed out that the Department Water and Sanitation's (DWS) has evolved to include DSM and catchment management measures such as public awareness and education, as well as starting the process of fulfilling the ecological Reserve (DWA, 2013b). The continued evolution of the Government's focus is evident in the laws and regulations that have been developed over the last 25 years such as the Environment Conservation Act (73 of 1989); The Constitution of the Republic of South Africa (Act 36 of 1996), the Water Services Act (108 of 1997), the National Water Act (36 of 1998), the National Water Resource Strategy (DWA, 2004), National Development Plan: 2030 (National Planning Commission, 2012) and National Water Resource Strategy: Second Edition (DWA, 2013b). Through the evolution of these laws and regulations – as well as others such as the National Environmental Management Act (107 of 1998) which repealed many sections of the Environment Conservation Act (73 of 1989) – a range of assessments has been developed to avoid, or at least lessen, harmful effects on the environment, that may otherwise have occurred from water supply management and development in South Africa.

One way to ensure better informed decision-making is to accumulate knowledge and experience into an institutional knowledge base of how past decisions were made. This can be done by retrospective analysis of past decisions and decision-making. Ex-post analysis reflecting the full costs and benefits of each potential water supply infrastructure option, for example a dam, could be used to conduct a sensitivity analysis with respect to the accuracy of the project costs and benefits, as captured within mainly environmental impact assessments.

These ex-post analyses should be done for at least the final dam site that was chosen, although prior assessments of all the potential dam sites could also be considered where data is available. If such retrospective analyses were done routinely, they would build an invaluable institutional memory and record that would inform future water resource decisions and improve the entire decision-making process. Past knowledge could then be used to avoid repeating mistakes and to make more equitable and sustainable decisions in the future.

Consequently, this study will be a retrospective, management and resource-economic evaluation of the costs and benefits of specific water supply options (i.e. dams and invasive alien plants management) and the decision-making that occurred in a newly built water resource infrastructure development project. This study attempts to fill an important gap, as the DWS does not have comprehensive retrospective studies of the costs and benefits, and decision-making of past water infrastructure schemes in South Africa (Legge, 2012). This study synthesises existing information and data, and provides impetus to further studies on the costs, benefits and decision-making that should be taken into account when faced with choices concerning the management of South Africa's finite water resources. This study also hopes to provide input to national policy debates, water supply development decision-makers and academic dialogue.

1.2 AIM OF THE RESEARCH

Given the water scarcity in South Africa and the lack of retrospective analysis on water supply development decision-making, and in an attempt to retrospectively analyse the costs of building selected dams in South Africa, the primary aim of this study is to evaluate the costs and benefits of selected water supply options and of the decision-making associated with those options.

To achieve the primary aim of this research study, the following objectives have been stated:

- To calculate and evaluate the variation between estimated and actual construction unit reference values (URVs) for a selection of water supply infrastructure schemes.
- To analyse the costs and benefits of a water-mix alternative (invasive alien plant management) in the context of the catchments of the selected water supply infrastructure schemes.

- To evaluate the decision-making process behind the building of De Hoop Dam using a decision-making framework.

1.3 RESEARCH DESIGN AND METHODOLOGY

In this study the mixed methods research (MMR) paradigm incorporates a methodology that involves collecting, analysing and combining quantitative and qualitative data in a single study (Johnson & Onwuegbuzie, 2004). Within the MMR paradigm a descriptive, multiple case study methodology is used to focus on explaining and understanding water supply development decision-making in South Africa (Yin, 2014; Collis & Hussey, 2009). The selected case studies are four dams (and their catchments) which were chosen from across South Africa using a range of criteria as detailed in Chapter Four. The selected cases are the Inyaka, Nandoni, Berg River and De Hoop dams and their catchments. Use of data and methodological triangulation (multiple data sources and collection methods) allows for a more in-depth understanding of the cases (Yin, 2014; Collis & Hussey, 2009).

Data collection methods included semi-structured interviews (Yin, 2014; Collis & Hussey, 2009), documentation and archival records (Yin, 2014), and data analysis methods including URVs (Van Niekerk, 2013), inter- and intra-case analysis and content analysis in analysing the decision-making process (Collis & Hussey, 2009). These methods are all briefly discussed below.

1.3.1 Unpublished documentation and Government reports

The documents consulted in this study were mainly from the Department of Water and Sanitation (DWS) and in the form of laws, regulations, national strategies, and various planning reports. Document analyses were particularly relevant to Chapters Four, Five and Six.

1.3.2 Archival records

Archival records including databases are used in Chapters Four and Five. The cost data used in both chapters came from DWS national and regional archives and databases. Additionally, Statistics South Africa’s consumer price index (CPI) archive (Statistics South Africa, 2015) is used to adjust the cost data (in Chapter Four) to December 2012 rand values, so that inflation is a controlled variable.

1.3.3 Semi-structured interviews

Semi-structured interviews were used in Chapter Six so that information could be gathered regarding different opinions and views of the decision-making that took place during the building of De Hoop Dam (Van Teijlingen, 2014; Collis & Hussey, 2009). The interview questions as provided in the interview guide (Appendix E) related to different stages of Zindiye's (2012) rational decision-making model as well as to perceptions of the decision-making models that were perceived to be used in making the decision to build De Hoop Dam.

A purposive sampling technique was used to select ten interviewees. The researcher chose interviewees according to personal judgement and advice taken, based on the strength of the interviewee's knowledge and experience of the subject being studied (Sekaran & Bougie, 2009). The decision of who to interview was made before any of the interviews were conducted. Purposive sampling was chosen because a limited number of people were involved in the project, and because the topic was sensitive in nature.

1.3.4 Unit reference value (URV) analysis

In Chapter Four, the difference between the expected and actual costs of building a dam were calculated, for all four case studies, using URVs, which are a type of cost-effectiveness analysis, used and developed in South Africa by the DWS (Van Niekerk, 2012). URVs calculate the cost per cubic metre of water over the lifetime of a water infrastructure project (for example, at the point where the water leaves the dam) by dividing the net present value of the capital, operating and maintenance costs by the discounted yield of the dam over its lifespan. The URV analysis made use of a recommended discount rate of eight per cent and sensitivity analysis of six per cent and ten per cent (Van Niekerk, 2013; Mullins *et al.,* 2007).

1.3.5 Inter- and intra-case comparisons

In Chapters Four and Five, four case studies were compared in respect of: firstly, the differences between expected and actual URVs in Chapter Four; and secondly, the potential increases in mean annual runoff (MAR) from invasive alien plant (IAP) management in Chapter Five.

Intra-case comparisons were used where additional data was explored: firstly, in the Berg River Dam case (in Chapter Five), in terms of a 45-year projection (the given lifespan of dams in South Africa) of the impacts on MAR if IAP management is not continued; and secondly, in the De Hoop Dam case (in Chapter Six), in terms of the decision-making that resulted in the De Hoop Dam being built.

1.3.6 Decision-making analysis

In Chapter Six, the decision-making process behind the building of De Hoop Dam (the most recent case study) was analysed using the rational decision-making model (RDMM) as a framework (Zindiye, 2012). Each of the seven steps of the RDMM was discussed using firstly, DWS planning reports; and secondly, responses to semi-structured interviews (Van Teijlingen, 2014; Collis & Hussey, 2009). These interviews were analysed using content analysis, which enables systemic ordering, structuring, and grouping large amounts of qualitative information by identifying themes and patterns (Collis & Hussey, 2009).

1.4 SCOPE AND ASSUMPTIONS

The scope of this study limited case studies to new dams (and their catchments) having been built during the past two decades in South Africa. Water quality is an important aspect of water supply management, however, it has not been considered in this study. Demand-side management (DSM) is consistently the option with the lowest cost per cubic metre of water supplied or saved when compared with other options such as water supply infrastructure development or water re-use (Van Zyl & Leiman, 2002). However, due to the lack of reliable and available data as well as scope limitations, DSM was not considered in depth in this study.

This study assumes that data received from the Department of Water Affairs is both reliable and accurate. Furthermore this study assumed that the continued management, development and security of water supply cannot exist without some infrastructure to store water as yield.

The government department responsible for South Africa’s water resources has had several name changes since its inception, (discussed further under 2.3.5). In this study, the Department will be referred to as the DWS unless otherwise specially stated (however, references will be labelled according to the name of the Department at the time of the relevant publication, for example DWAF).

1.5 OUTLINE OF THE STUDY

Chapter One has provided an introduction and background to this study, to its main purpose and research aims, its research design and methodology, as well as to the scope and assumptions of the study.

Chapter Two focuses on the background to South Africa's water supply. It is a theoretical chapter considering: the biophysical aspects of water supply generation in South Africa; the current and perceived future supply of, demand for water in a South Africa; and lastly the economics of water in terms of its pricing and value.

Chapter Three presents the study's research design and methods. The chapter centres on the mixed methods research paradigm, within which a case study methodology is presented. The case selection process is explained and the chosen and rejected cases are detailed. Thereafter the data collection and analysis methods used in this study are listed and explained. Finally, the quality criteria and ethical approval of the study are discussed.

The focus of Chapter Four is to calculate and evaluate the estimated and actual costs of building and operating water infrastructure for the cases (dams) selected in Chapter Three. The costs are evaluated using the URV analysis method. Thereafter a discussion of the results relating to the cases is presented. Finally, conclusions for the chapter are provided.

The emphasis of Chapter Five is on analysis of the case studies in the context of one DSM option, namely IAP management. The chapter begins by explaining IAP management as an alternative water supply option. Subsequently, other alternative water supply options are presented to provide context for IAP management. The current impacts as well as hypothetical potential impacts of not clearing IAPs in the case study catchments based on data from the *National Invasive Alien Plant Survey* (Kotzé *et al.,* 2010) are presented and discussed. Finally, conclusions for the chapter are provided

Chapter Six focuses on the decision-making process related to the construction of De Hoop Dam, which is the most recently completed case study. The chapter starts with a presentation of the RDMM within the context of a variety of decision-making models. Next the decision-making making documentation used in the De Hoop Dam case is listed. Thereafter, the seven steps of the RDMM are used as a framework to analyse the decision-making process. The analysis is based on the information gathered in the semi-structured interviews and the documentation referred to previously. The findings are augmented by the findings from Chapters Four and Five. Finally, conclusions for the chapter are provided

Chapter Seven presents a general conclusion of the whole study.

CHAPTER TWO
WATER SUPPLY IN SOUTH AFRICA

2.1 INTRODUCTION

Chapter Two provides the context for the analyses presented in Chapters Four, Five and Six. To understand the capacity for the generation of water supply in South Africa, bio-physical aspects of climate, soils and ecosystems are considered. Thereafter, the supply of and demand for water in South Africa are examined in terms of current and estimated future water supply and demand, including the management of supply limits. Subsequently, the economics of water are discussed regarding the pricing and value of water in South Africa, as well as the links to water resource development in South Africa.

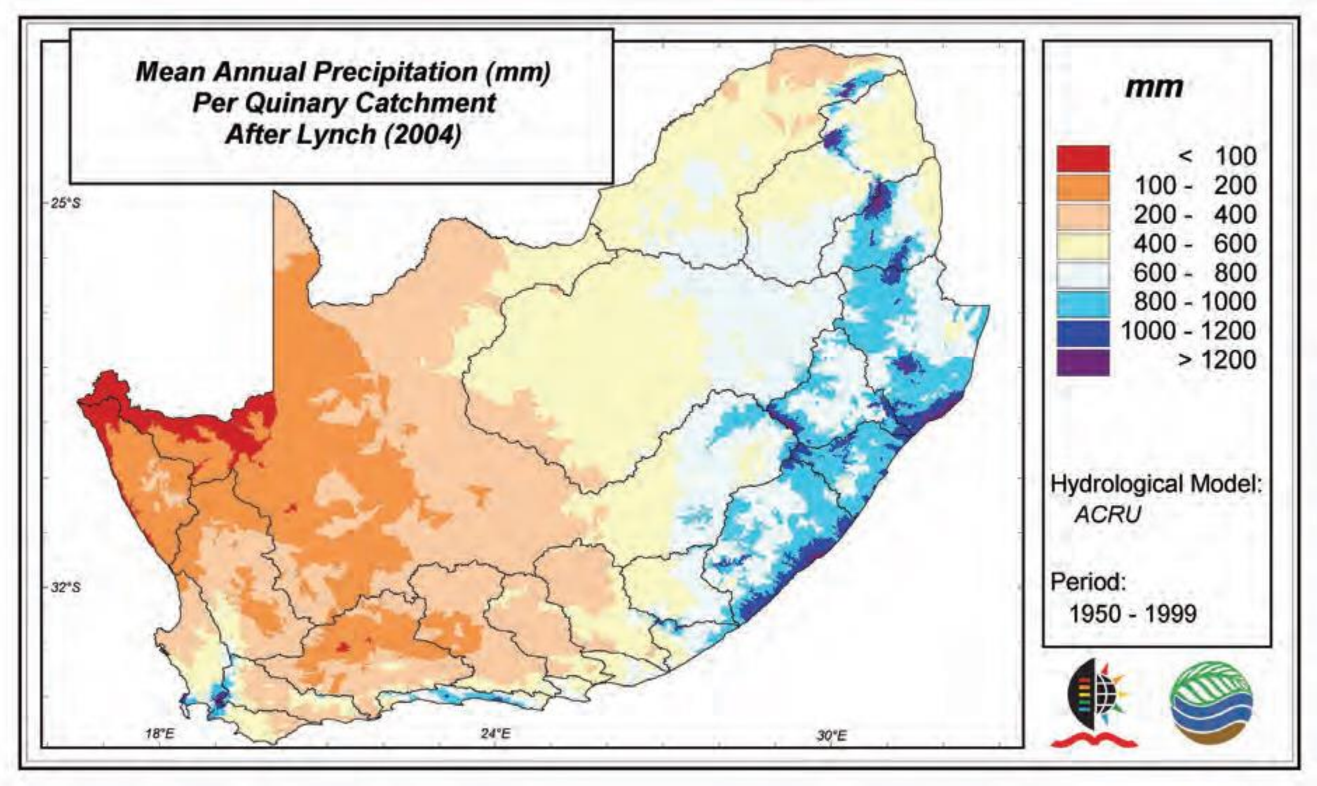
2.2 UNDERSTANDING THE BIO-PHYSICAL ASPECTS OF WATER SUPPLY GENERATION

The National Water Act 36 of 1998 defines water resources as all surface and groundwater resources in South Africa (RSA, 1998). The availability of water resources is dependent on a number of underlying bio-physical aspects, the most important of which are climate, topography, soils and ecosystems which regulate and limit when, where and how much water occurs, on average, in a specific area (DWA, 2013b; Driver et al., 2012, Le Maitre *et al.,* 2009).

2.2.1 Climate

While the global average rainfall is 860 millimetres per year, the average rainfall in South Africa is just 450 millimetres per year, making it the 30th driest country in the world (DWA, 2013b; King *et al.,* 2011). In addition to being lower than average, the rainfall (also known as mean annual precipitation or MAP) in South Africa, is also highly seasonal (Davies & Day, 1998). Thus rainfall, as shown in Figure 2.1, is unevenly spread both geographically and in time, both within a single year and over a period of years (DWA, 2013b; King *et al.,* 2011; Davies & Day, 1998).

Figure 2.1: Mean annual precipitation (MAP) of South Africa

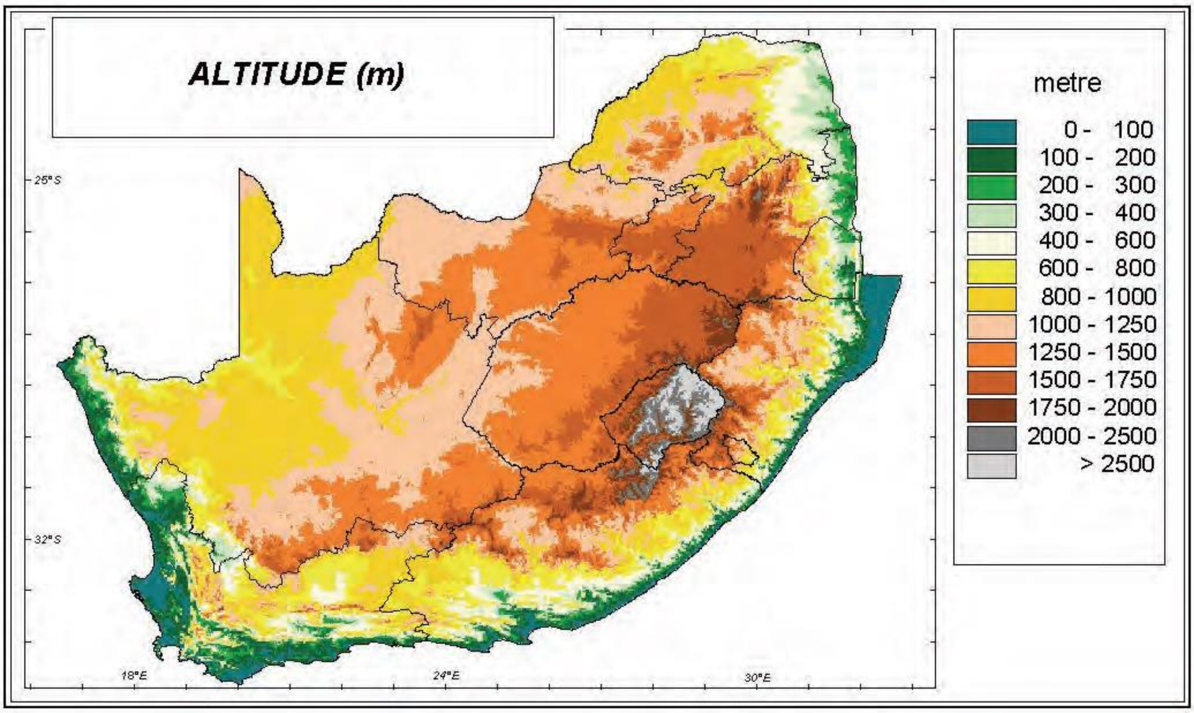


(Source: Schulze, 2012)

Rainfall variation is also partly influenced by the topography. Mountains form an almost continuous barrier between the wetter coastal areas, influenced by ocean currents, and the drier interior, as is apparent in Figure 2.2 (King *et al.,* 2011, Davies & Day, 1998). Two moisture-generating ocean currents flow along South Africa's coasts, namely the west coast's Benguela current (cold) and the east coast's Agulhas current (warm).

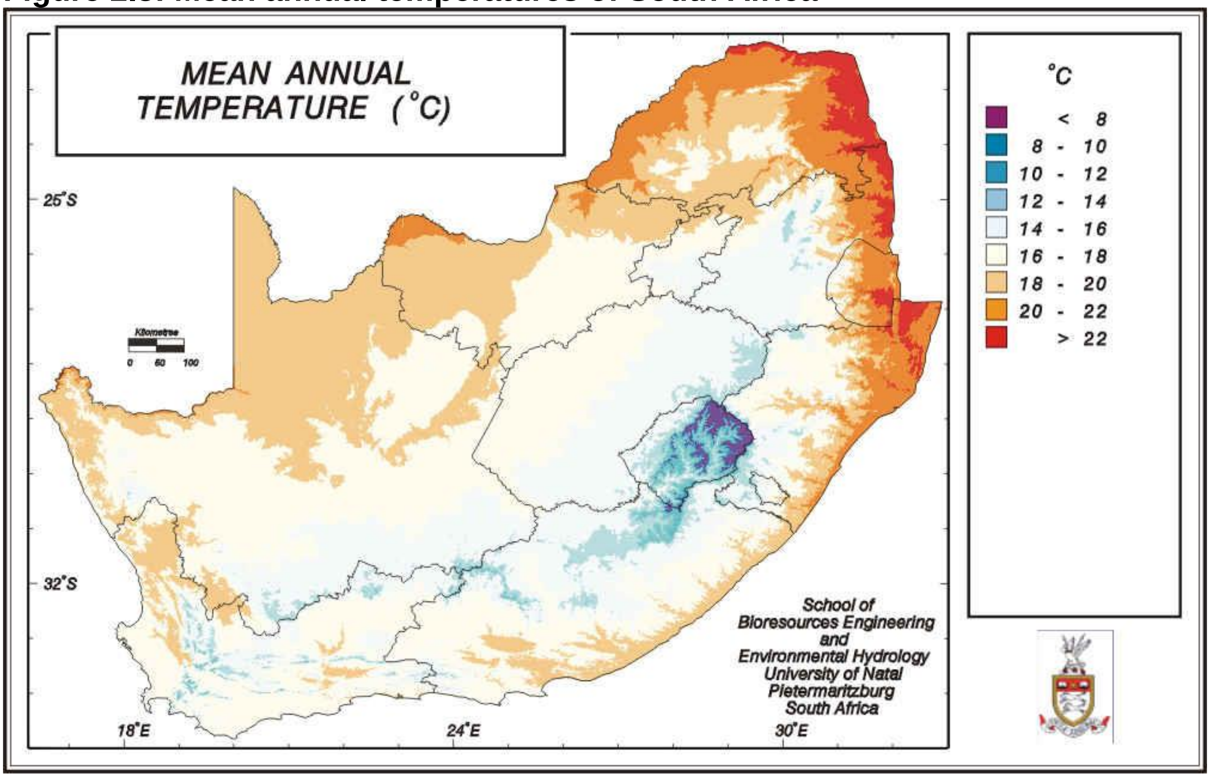
Additionally, rainfall variation in South Africa is enhanced by variability in average temperatures, as shown in Figure 2.3. South Africa also has high average temperatures and solar radiation, both of which cause high mean annual evaporation (MAE), especially in the drier western half of the country as shown in Figure 2.4 (DWA, 2013b; King & Pienaar, 2011; Davies & Day, 1998). MAE exceeds MAP in large parts of the country, resulting in water scarcity before any water is actually used.

Figure 2.2: Altitude map of South Africa



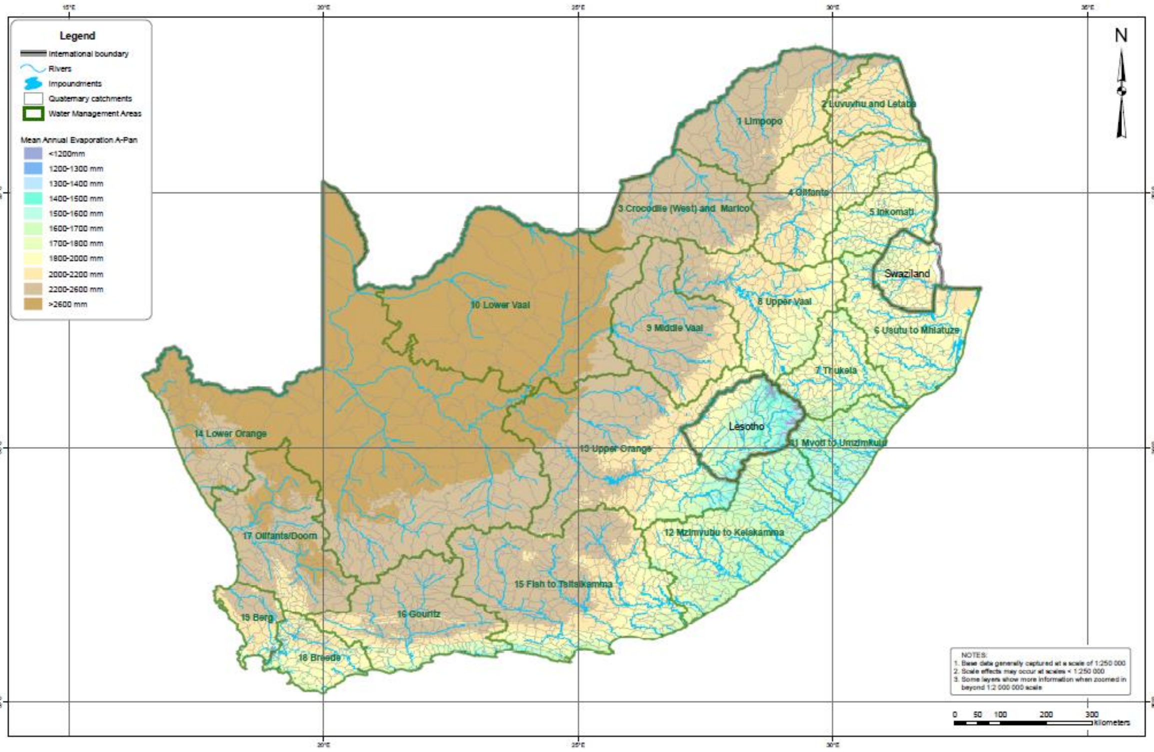
(Source: Schulze, 2012)

Figure 2.3: Mean annual temperatures of South Africa



(Source: Schulze, 1997)

Figure 2.4: Mean annual evaporation (MAE) of South Africa



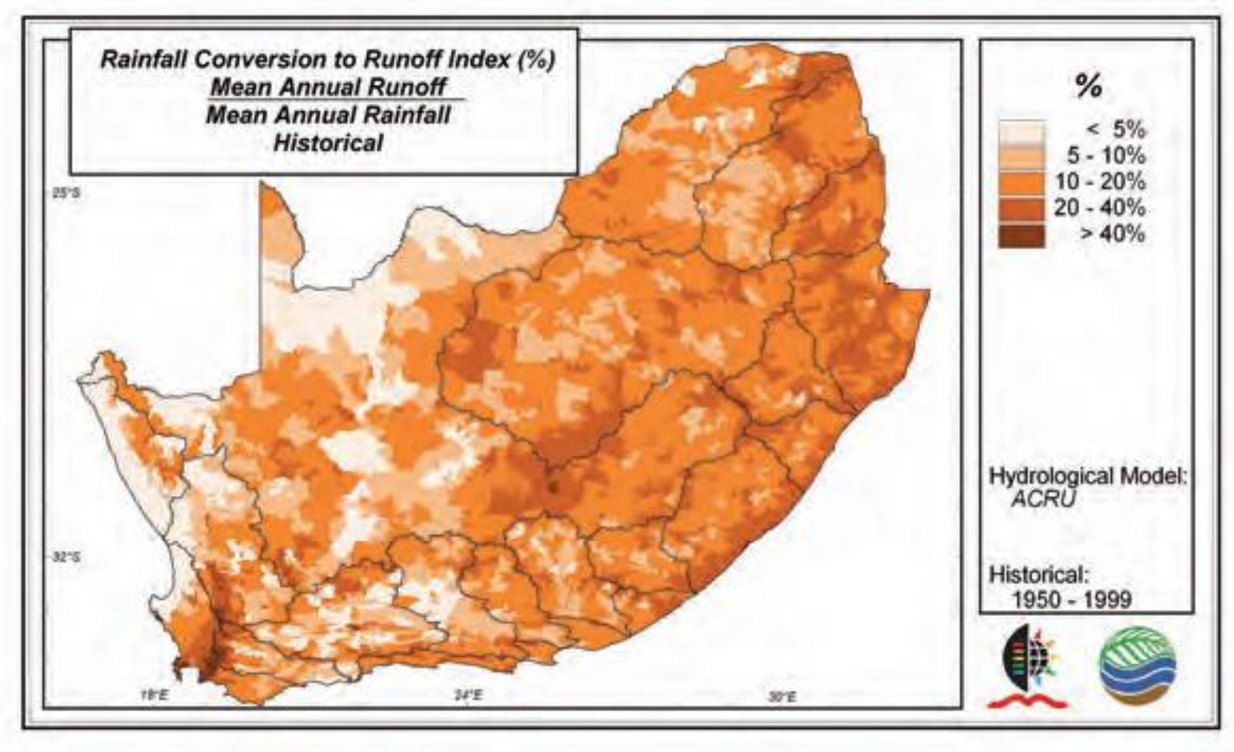
(Source: Middleton & Bailey, 2008)

High MAE results in the amount of water that runs into the rivers, dams and lakes (known as mean annual runoff or MAR), being about ten per cent of the MAP (DWA, 2013b; Schulze, 2012; King *et al.,* 2011). This low average conversion can be seen in Figure 2.5. Along with Australia, South Africa has one of the lowest rates of MAP to MAR conversion in the world (DWA, 2012a).

As a result of all these factors, MAR in South Africa is also highly variable (Figure 2.6). MAR is generally higher in the southern and eastern parts of South Africa and lower in the western and northern parts (DWA, 2012a). As a result of this variability, it is estimated that 50 per cent of MAR is generated on just eight per cent of the land area in South Africa (WWF-SA, 2013).

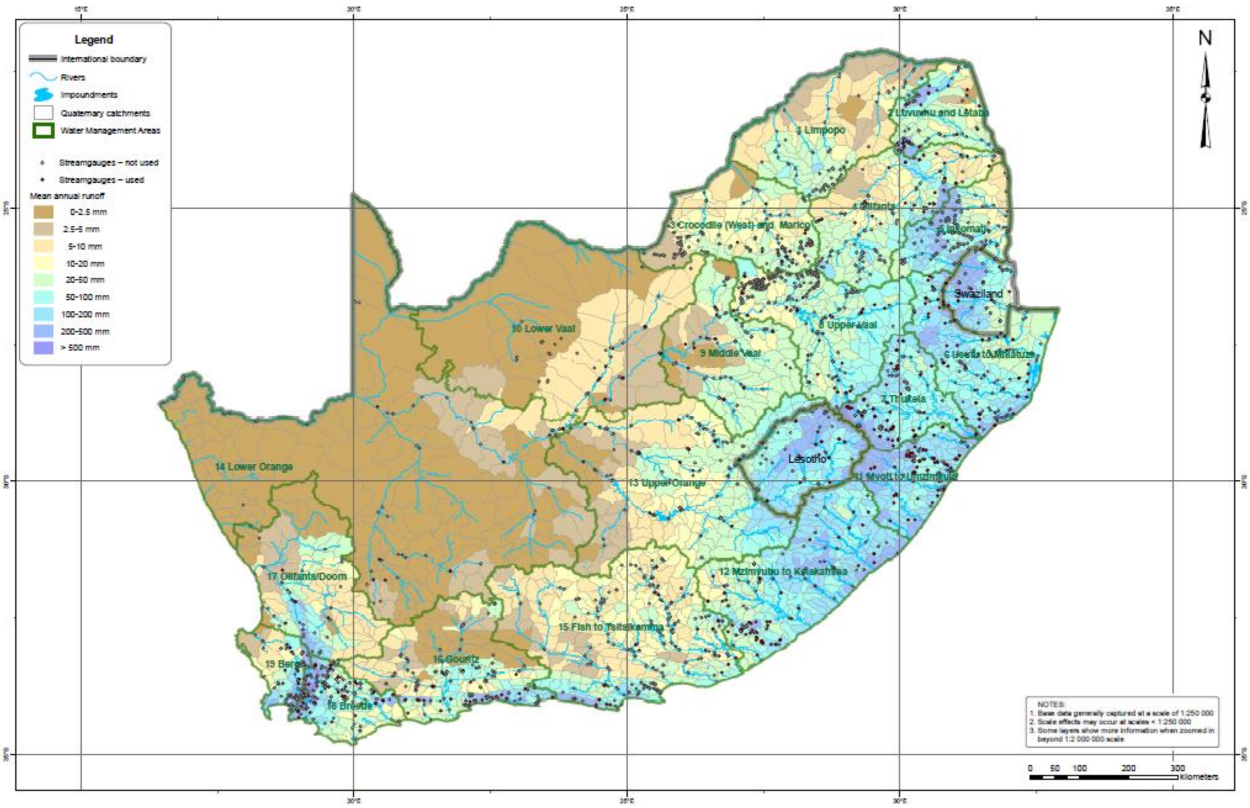
Lastly, climate change is expected to exacerbate climate-related water scarcity. It is expected that the western two-thirds of South Africa will likely become drier with shorter rainfall periods, while the eastern and southern coastline will become wetter due to more intense rainfall events (Schulze, 2012; Lumsden *et al.,* 2009; Colvin *et al.,* 2009).

Figure 2.5: Mean annual runoff (MAR) as a percentage of Mean annual precipitation (MAP)



(Source: Schulze, 1997)

Figure 2.6: Mean annual runoff (MAR) of South Africa



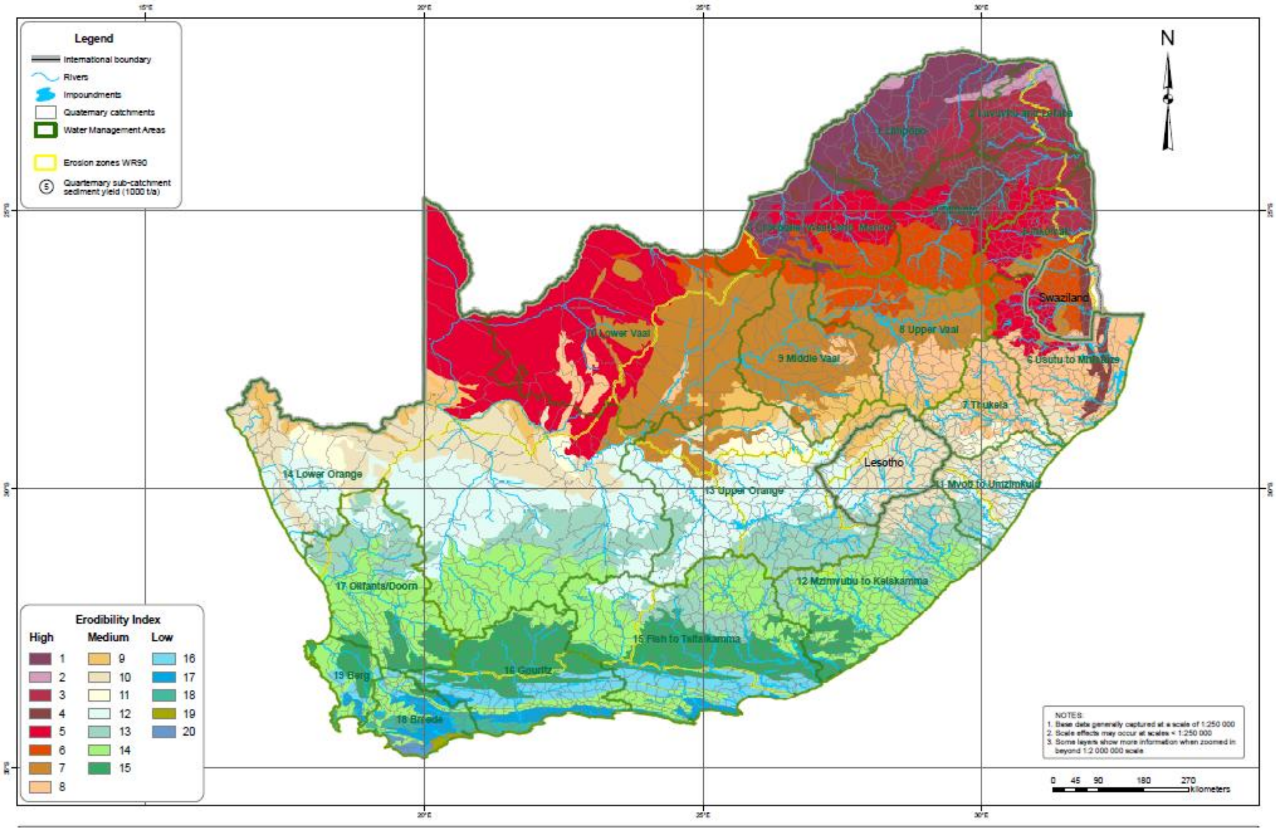
(Source: Middleton & Bailey, 2008)

2.2.2 Soils

South Africa is not only dry but its geology is old, diverse and has been exposed to steady erosion over time (Davies & Day, 1998). The geology and erosion has led to a diverse spread of soil types across South Africa (Fey, 2010). Many of South Africa's topsoils are vulnerable to erosion and this has led to nutrient-rich sediment flowing down South Africa's rivers to coastal ecosystems (Basson, 2008).

The severity of soil erosion depends on the combined cumulative and synergistic effects of climate, topography, land cover, land use and other soil erosion features, such as rainfall erosivity and soil erodibility (Msadala *et al.,* 2010). Erodibility is the likely potential for erosion and thus sedimentation to occur. High to low erodibility runs loosely from north to south, as observed in Figure 2.7.

Figure 2.7: Soil erodibility throughout South Africa



(Source: Middleton & Bailey, 2008)

Soil erosion impacts on the water supply when sediment accumulates in dams, reducing capacity (Msadala *et al.,* 2010; Basson, 2008). Gariep Dam, the biggest dam in the country, has half a cubic kilometre of sediment in it, from a capacity of roughly five-and-a-half cubic kilometres (Legge, 2012). This means nine per cent of the water storage capacity of the dam has already been lost to siltation, and this may also then increase the rate of evaporation through shallower water. This reduction in yield reduces water supply and security. Siltation has further economic impacts that are preventable, such as the cost of dredging a dam, as the Mount Fletcher Dam attests – having silted up 70 per cent in just four years (CSIR, 2013). An example of these impacts is the Mapochs Dam (shown in Figure 2.8), on the Mapochs River (that flows into De Hoop Dam), which is completely silted up (Dini and Legge, 2015). It has been de-silted before, but has silted up again through poor land-use practices by mining operations up-river from the dam (Dini and Legge, 2015). There are no water benefits from the dam, other than as a sediment trap for down-river water-abstraction options. It is estimated that there are 500,000 cubic metres of silt being held back by the dam wall, and that this poses as dam-safety risk that could see this silt being deposited into the newly constructed De Hoop Dam (K. Legge, personal communication, 14 April 2014).

Figure 2.8: Photos a) and b) show Mapochs Dam fully silted, upriver of De Hoop Dam

(Source: a - Researcher's own photo, 2014; b - Google Earth, 2014)

It is clear that building a dam which will rapidly silt up, as the Mapochs Dam has done, makes little economic sense. Before a dam is built, measures must be taken to ensure that sediment movement and siltation impacts are minimized, as far as possible. The DWS appears to have learned this lesson, in that it has commissioned a major catchment management initiative through the Department of Environmental Affairs' Working for Ecosystems programme, to prevent undue erosion into the dams to be built on the Ntabelanga Dam site on the Umzimvubu River in the Eastern Cape (in the same area as the Mount Fletcher Dam) (Zuma, 2014).

Poor soil management can also lead to an increase in land degradation, salinisation and increased levels of suspended solids (turbidity), which cause subsequent decreases in water quality and soil productivity (Flügel *et al.,* 2003; DWA, 1986). These decreases in water quality lead to higher operational and maintenance costs for water supply as a result of the need for additional water purification. Furthermore, poor soil management has social consequences, such as creating muddy drinking water for people who access drinking water directly from rivers, as well as accelerating the nutrient and toxic runoff.

Soils and geology of South Africa also affect the quantity and quality of groundwater. Aquifer-based water resources are sparsely distributed, can be difficult to abstract, and are less well quantified in South Africa than are surface water resources (DWA, 2013b).

Groundwater is used in many rural areas, small towns, mines, industries and by farmers in many areas (DWA, 2013b); however the lack of large aquifers in South Africa, poor water quality (natural and from pollution), slow recharge rates as well as lack of knowledge and information have limited the use and potential growth of groundwater as a water supply (Davies & Day, 1998; DWA, 2013b). There is also still uncertainty around issues such as how much groundwater contributes to low flows in rivers (King *et al.,* 2011). Groundwater, as a relevant water resource in South Africa, is quantified under 2.3.1 in this chapter.

When new water supply alternatives (including groundwater options) are being considered, the decision-makers should ask questions with reference to the impacts of soil erosion and sedimentation. An example would be: what are the short-term and long-term costs and benefits of rehabilitating the land?

2.2.3 Ecosystems

The Millennium Ecosystem Assessment (2005, p.29) defines an ecosystem as follows:

> *An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit. Humans are an integral part of ecosystems. Ecosystems provide a variety of benefits to people, including provisioning, regulating, cultural and supporting services.*

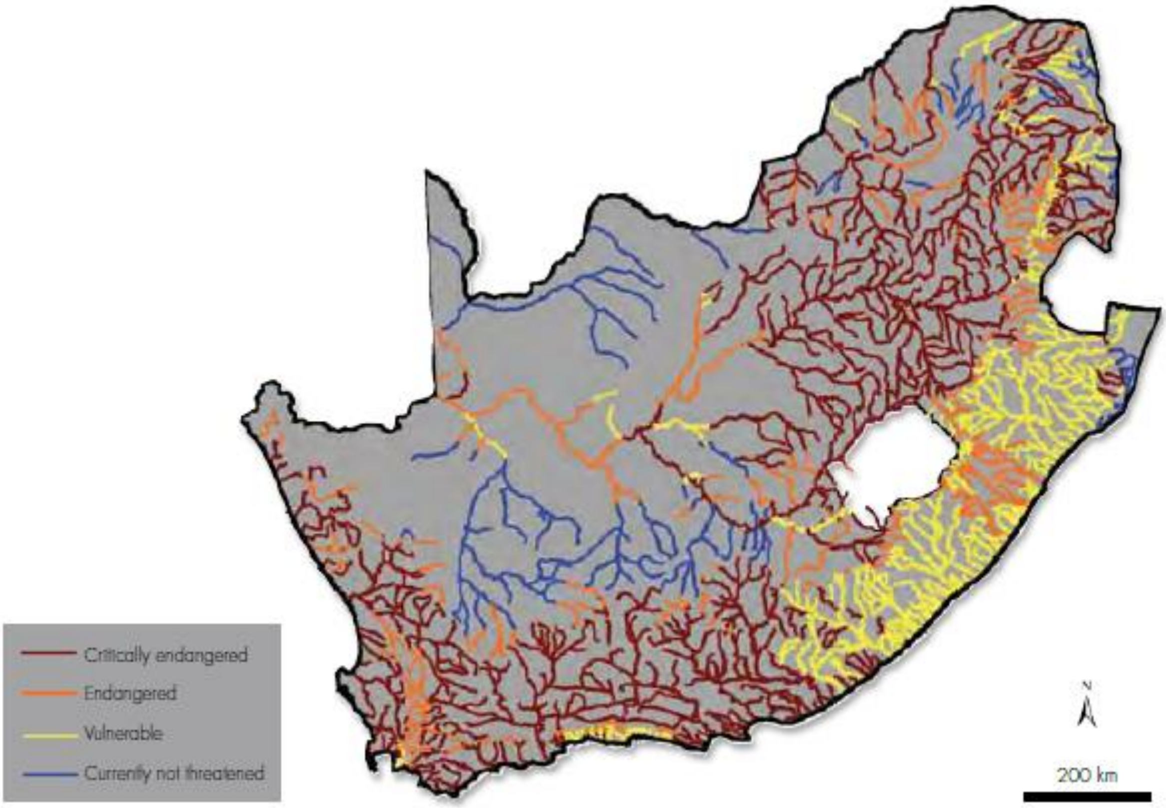
Aquatic ecosystems range from coastal to wetland to inland water, and from relatively naturally functioning to highly impacted. While the coastal ecosystems do add to the national water supply through desalination, the majority of the national water supply occurs as part of the inland water ecosystem, primarily through rivers, weirs, dams and inter-basin transfers (IBTs).

The state of rivers in South Africa is not good, with 60 per cent of rivers classified as threatened, while 25 per cent are critically endangered (DWA, 2013b). The state of wetlands is even worse: 65 per cent are classified as threatened of which 48 per cent are critically endangered (DWA, 2013b). Rivers and wetlands are classified as endangered when there is little of the river still in good health (Driver *et al.,* 2011).

This deterioration in river health, shown in Figure 2.9, is largely due to poor surface water management; altering the flow of rivers (for example, through building weirs); over-abstraction and decreased dilution capacities (through abstraction, dams, inter-basin transfers and return flows); growing levels of pollution and eutrophication (especially from failing waste treatment works, agricultural runoff, industry and mines); poor land management practices (including destruction of river banks and the impact of IAPs); and invasive alien fish (DWA, 2013b; Driver *et al.,* 2011; CSIR, 2010; Le Maitre *et al.,* 2009; Currie, 2007).

When implementing water supply alternatives, decision-makers need to be aware of the generally poor state of rivers in South Africa and the specific causes of the poor health, so that the underlying conditions can be improved (or at least not exacerbated) by the selected alternative. Decision-makers should be able to compare not only the short term costs and benefits of all the alternatives but the long-term ones too.

Figure 2.9: Inland water ecosystem health in South Africa



(Source: CSIR, 2010)

2.3 WATER SUPPLY AND DEMAND IN SOUTH AFRICA

Following on from discussion of the biophysical aspects of water-supply generation, Section 2.3 provides insights, within a South African context: the currently available water resources; the current demand for water; and the current and perceived future water supply limits. The Department of Water and Sanitation's response strategy to these limits is discussed.

2.3.1 Available water resources

Surface water is the main source of water in South Africa and provides many times more water than return flows or groundwater do (DWAF, 2004). The breakdown of water sources used in South Africa is approximately: 77 per cent surface water, fourteen per cent return flows and nine per cent groundwater (DWA, 2013c). A further water source is desalination which occurs on a limited scale, due to high costs and energy consumption (DWA, 2013b). While currently limited, the DWS in its second *National Water Resources Strategy* (DWA, 2013b), considers desalination to be an important future source of water for coastal communities.

Return flows contain treated or untreated waste water that returns to stream flows (or groundwater); either directly or indirectly, after initial use (DWA, 2013b). Return flows are usually re-used by a different user for a different use than its initial use, for example domestic waste water being used for irrigation (DWA, 2013b). Return flows originate from urban, irrigation mining and industrial water users (DWAF, 2004).

Available surface water is estimated as the MAR of just over 49 000 million cubic metres per annum (DWA, 2013a; DWA, 2013b; Middleton & Bailey, 2011). This MAR figure includes water that drains into South Africa from Lesotho and Swaziland. Not all of the MAR is available for human use however, as water is allocated by legal priority to remain in the rivers to meet the ecological Reserve (DWA, 2013b; RSA, 1998).

The Reserve is made up of ecological and basic human needs components. It is the only water guaranteed by law, and it has a prior right to water access (King *et al.,* 2011; Palmer *et al.,* 2002; RSA, 1998). The ecological Reserve is the quantity and quality of water that is set aside for river ecosystem maintenance, protection and to support ecological functioning (King *et al.,* 2011; De La Harpe & Ramsden, 2002; RSA, 1998). The ecological Reserve varies, depending on the health of the river and the resource quality objectives that are aimed for.

However, the ecological Reserve has not yet been fully implemented since it is part of an incompletely determined suite of resource directed measures which include classification of South African rivers (which determines the present ecological state), ecological water requirements and water user needs, together with setting resource quality objectives (Palmer *et al.,* 2004). Other barriers include skills and capacity limitations, and a lack of information about the state of some rivers (DWA, 2013b; Brown, 2009). In a few areas where preliminary ecological Reserves have been quantified, they have not been implemented due to the water in the catchment being nearly completely allocated or already over-allocated (DWA, 2013b; Brown, 2009).

Only some of the remaining MAR is captured by dams and inter-basin transfers and is available to be designated as yield (DWA, 2013b). This is because the DWS defines yield as water that can be abstracted for a guaranteed 98 out of every 100 years (King & Pienaar, 2011; DWAF, 2004). As a result of the uncertainty and variability of rainfall and runoff in South Africa, surface water yield is estimated to be 10 240 million cubic metres per annum or approximately 20 per cent of the MAR (DWA, 2013b and see item 4.2.2). The importance of dams is emphasised by yield accounting for approximately 20 per cent of MAR, while dams store about 70 per cent of the MAR (CSIR, 2010).

While groundwater only accounts for a small part of the water used in South Africa (9 per cent), it is a strategic resource as it is the only water source for approximately 65 per cent of the population (CSIR, 2010). The DWS estimates that current groundwater use in South Africa is approximately 2 000 million cubic metres per year, that it has a potential sustainable yield of around 7 500 million cubic metres per year and that there needs to be more focus on groundwater as part of a conjunctive strategy with surface water (DWA, 2013b and 2013c).

The World Bank (2006) states that groundwater has the following benefits:

- It normally has excellent microbiological and chemical quality, avoiding the added financial burden and logistic complexity of a water treatment facility. (As noted in DWA, 2013b however, in some parts of South Africa, salinisation is an issue).
- It provides natural storage and drought resilience, eliminating the need for construction of expensive surface water-storage facilities.
- It can be widely distributed, facilitating phased development close to demand location, reducing the scale of distribution infrastructure with the implication of lower (and flexible) investment requirements.

In the South African context, groundwater has a number of these benefits including development of potential, geographic diversity, greater efficiency as it is not as vulnerable to evaporation, the ability to hold surplus surface water through artificial recharge, and the fact that it offers security during dry periods when surface water supply is stressed (Braune, 2009). Groundwater management is outside the scope of this research, however it should be taken into consideration by the Minister when making water supply decisions.

2.3.2 Demand for water

In South Africa there are six main water users (not including water transferred out) requiring water in different quantities and of differing quality. They are agriculture (including varying seasonal requirements), urban, rural, mining (including bulk industrial), power generation, and afforestation (Table 2.1) (DWA, 2013b; CSIR, 2010).

Table 2.1: Water allocation by water user sector for the year 2013

Water user/sector	Proportion of allocation (%)
Agriculture	67
Urban	18
Rural	4
Mining	5
Power generation	2
Afforestation	3
Transfer out	1

(Source: Adapted from DWA, 2013b)

Agriculture is the dominant water user in South Africa; however, urban and rural water use have continued to increase as the DWS attempts to provide everyone with access to safe potable water (King *et al.,* 2011). The growing economy and population continue to increase the demand for water (DWA, 2013b). A knock-on effect of the growing population is an increased food requirement, which has led to an increase in agriculture water use (DWA, 2013b).

Not only is South Africa a dry country with limited water resources, but it also uses more water per capita than some of its drier neighbours, such as Botswana and Namibia (Hedden & Cilliers, 2014). Coupled with this inefficient use of water, it is estimated that nearly 37 per cent of water is classified as non-revenue water, meaning loss in physical leaks and commercial losses as well as unbilled authorised consumption, for example, firefighting (Mckenzie *et al.,* 2012). While this loss is at the same level as the global average, it is much higher than in similarly water-scarce countries such as Australia, whose losses are about ten per cent (Mckenzie *et al.,* 2012).

2.3.3 Current and future water supply limits

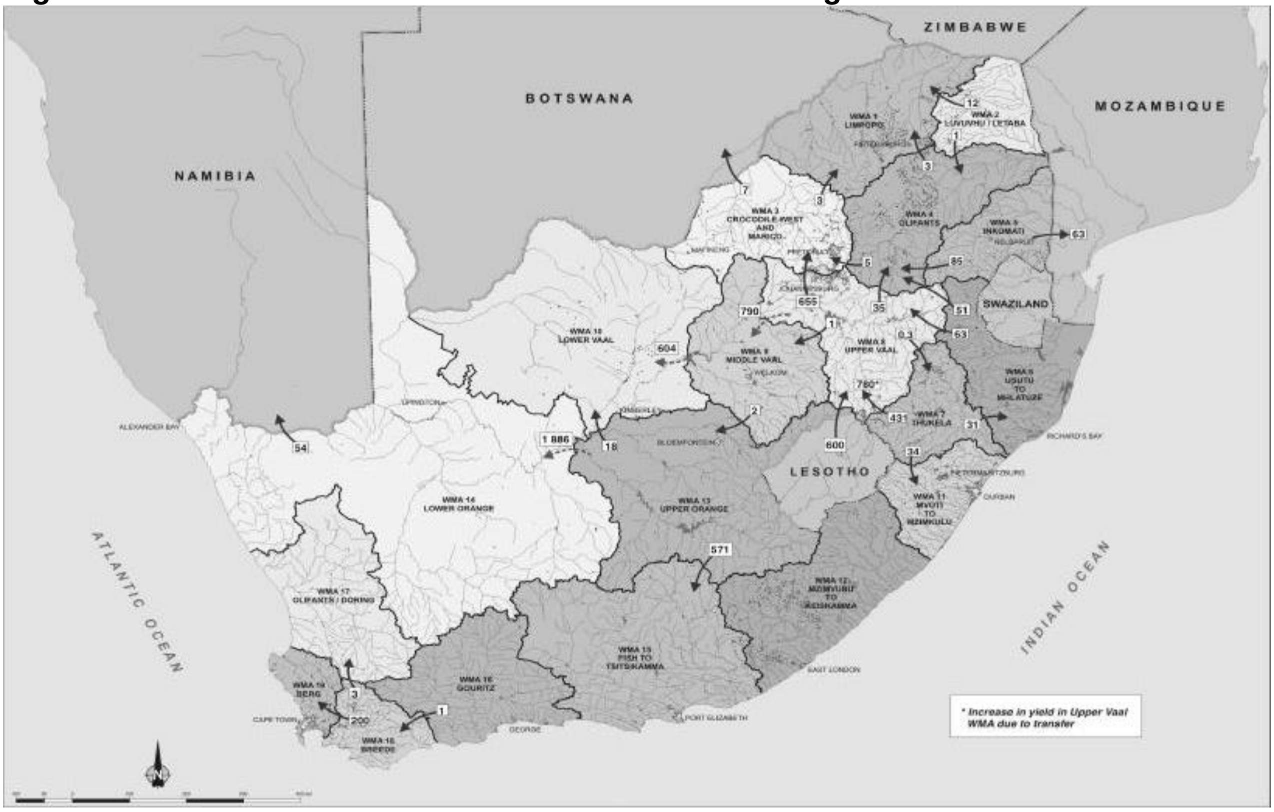
Water scarcity in South Africa is as much a result of physical limits as it is of poor management and inefficient usage (DWA, 2013b). This is despite world class regulatory frameworks such as the *National Water Act* (RSA, 1998) and two editions of the *National Water Resources Strategy* (DWA, 2013b; DWAF, 2004) which have been developed since the end of apartheid in 1994. In theory, the purpose of the DWS's supply-side orientated strategy (Van Zyl & Leiman, 2002) as outlined in the *National Water Act* (RSA, 1998) is firstly, to fulfil the Reserve to supply both ecological and basic human needs; secondly, to fulfil international obligations; and thirdly, to supply water to users such as irrigation, industry and domestic users, above the level of basic human needs.

Through this supply-side orientated strategy, it was estimated that, as of 2005, over 95 per cent of South Africa's water resources had already been allocated (CSIR, 2010; Van Zyl & Leiman, 2002). Water resources in South Africa are highly developed, used and regulated to deal with the country's growing water requirements (DWAF, 2004). Consequently many rivers have been heavily altered by water resource infrastructure such as dams, weirs and inter-basin transfers.

An issue affecting water current and especially future water supply limits is the lifespan of water resource infrastructure. Many of South Africa's dams were built more than 40 years ago. Considering the fact that the civil works sections of a dam have an economic lifespan of 45 years, and that the mechanical and electrical works have lifespans of 30 years – frequent maintenance and repairs and planned upgrading and development are critical to ongoing water security in South Africa (DWAF, 1996b). This is a concern in South Africa as there is currently a considerable backlog of water infrastructure repairs, maintenance and upgrades, especially when the infrastructure is owned by municipalities (DWA, 2013b).

Further issues relating to current and future water supply limits include climate change, water quality degradation (as a result of many sources of pollution) and the spread of IAPs (WWF-SA, 2013, DWAF, 2004). For example, the DWS has estimated that IAPs alone have already reduced the national yield by an estimated 695 million cubic metres (DWA, 2013b). Reconciliation studies carried out by the DWS indicate that surface water alone will be insufficient to support the economy as it grows (DWA, 2013b; CSIR, 2010). This is despite numerous inter-basin transfers (shown in Figure 2.10, where the arrows show the direction of each transfer scheme), dams and other water resource infrastructure developments having been undertaken throughout South Africa to enhance water security (DWA, 2013b, DWAF, 2004).

Figure 2.10: Inter-basin transfers between water management areas



(Source: DWAF, 2004)

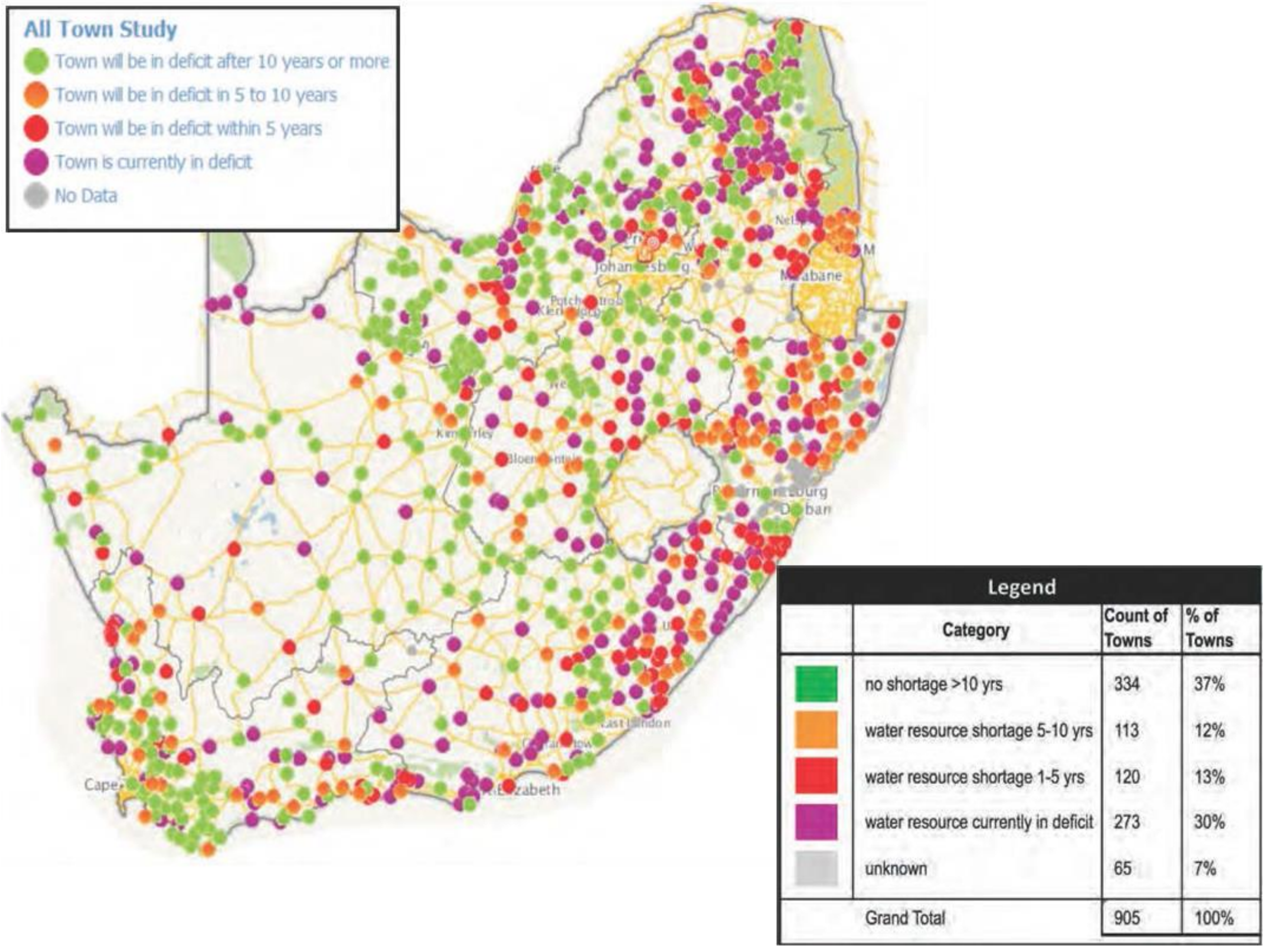
The gap between demand and supply of water is already extensive. As indicated in Figure 2.11, for example, 30 per cent of all towns and cities in South Africa are already experiencing water deficits, with a further 25 per cent of towns forecast to experience water deficits within the next ten years (DWA, 2013b).

There are very few water management areas in South Africa which still have the potential for economically viable water development. These areas, such as the Pongola basin (near the Mozambique border), are all located far from where the demand is highest, and long distances between water source and demand lead to higher water prices due to the increased transport costs (DWA, 2013b).

Nevertheless, Hedden and Cilliers (2014), Van der Merwe-Botha (2010), the CSIR (2010) and Herold (2009), all indicate that a water crisis is looming, if not already underway. Hedden and Cilliers (2014) maintain that there is already a gap between water demand and supply and that it will continue to grow unless drastic measures are taken to reduce demand, increase supply and improve water use efficiency and quality. In their second *National Water Resources Strategy* (NWRS 2 – DWA, 2013b, p. 7), the DWS state that

"South Africa does not face a water crisis at the moment, but is at risk if water is not taken seriously and interventions not applied timeously."

Figure 2.11: Forecast water deficits in South African towns and cities



(Source: DWA, 2013b)

However the DWS also acknowledge in their 2013 *Strategic overview of the water sector in South Africa* (DWA, 2013a) that water usage exceeds reliable supply (i.e. yield at 98 per cent assurance) and that a drought would cause large-scale water restrictions. The same document goes on to declare that the three best ways to solve this problem are additional bulk water infrastructure development (despite the NWRS 2 (DWA, 2013b) stating that there are very few economically viable dam sites left), reconciliation studies (to better understand demand), and, water conservation and demand management (DWA, 2013a).

To meet future water demands, the DWS states that South Africa will need to invest in alternative solutions; because South Africa's water systems have already been nearly fully developed, there are not many supply-side potential solutions left. The focus needs to be on maintaining the supply the country does have at recommended quality levels, on advancing water technology to be more efficient and effective (though fixing the problem of non-revenue water), and on promoting demand-side management.

2.3.4 Managers of the water supply limits

The DWS has, under different names and mandates, long been responsible for managing South Africa's water resources. This entails managing the quantity and quality of water available for society to use, how the water is used and what effects this may have on the aquatic ecosystems of South Africa (King *et al.,* 2011). According to the National Water Act (36 of 1998), the current strategic focus is to protect, use, develop, conserve, manage and control the water resources of South Africa using the guiding principles of sustainability and equity for all South Africans, to ensure that water supply (of acceptable quality) exceeds demand (DWA, 2013b). The strategic focus has changed since the days of Water Act (54 of 1956), when government participation in water resource management was limited to the development of water supplies for irrigation purposes (DWA, 2012a; Rowlston, 2011).

Before the 1912 Water Act, water resources were managed separately by each of the four colonies (Transvaal, Natal, Cape and the Orange Free State) (Legge, 2009; Tewari, 2009). Water Act No. 8 of 1912 created the Union Irrigation Department, which would become the Department of Water Affairs in 1956, when the Water Act (54 of 1956) was passed. This Act was legislated in recognition of the Department's extended scope (Tewari, 2009). Decades later, the Department was linked with forestry to become the Department of Water Affairs and Forestry. In 2009 the Department of Water Affairs and Forestry was divided when Forestry moved to the Department of Agriculture, Forestry and Fisheries and the name of the department reverted to the Department of Water Affairs. In 2014, the name of the Department was again changed from Department of Water Affairs to Department of Water and Sanitation (Sithole, 2014). Table 2.2 reflects this transformation, together with selected changes in water law, strategic focus and water thinking over the past century.

Table 2.2: A timeline of events selected in relation to their impact on water infrastructure development

Event	Name of Department	Purpose of legislation and the institutional response by DWA
Irrigation and Conservation of Water Act (8 of 1912)	Union Irrigation Department	Consolidation and amendment of the use of water from public streams for irrigation, domestic and industrial purposes. The Act also stimulated the building of water supply storage infrastructure (i.e. dams).
Vaal River Development Bill (Act 38 of 1934)	Department of Irrigation	The first steps towards ownership of water by the government were made.
End of World War II (1939–45)	Department of Irrigation	Fundamental change in water management thinking occurred. Emphasis changed from flat tariffs to pro-rata tariffs as the mix of water users changed. The fact that water supply is limited was accepted for the first time.
Water Act (54 of 1956)	Department of Water Affairs	The Act tried to apply the water rules of wetter European countries to a drier South Africa. Government made all the decisions with an authoritarian, centralised approach. The Act specifically stated that public water could not be privately owned, with the exception of groundwater. Agricultural, industrial and urban water use was roughly equalised. Design and planning tasks were separated in the Department and a hydrological division was created. Land-owners were given water rights because agriculture was the most important focus of the 1956 Act. This Act was heavily based on water rights, benefiting white farmers and excluding all non-white South Africans. This Act repealed the Irrigation and Conservation of Water Act (8 of 1912).
1994 – first democratic elections	South African Government	In 1994 the first democratically elections were held after many decades of minority rule and the first democratically elected government came into power.

Event	Name of Department	Purpose of legislation and the institutional response by DWA
Constitution of the Republic of South Africa (Act 108 of 1996)	South African Government	In 1996 a new constitution became law. In the Bill of Rights of the Constitution of South Africa, there are three fundamental objectives for managing water resources in South Africa. These are equitable access to water, sustainable use of water, and effective and efficient use of water. Water is first recognised as a basic human right in the Constitution.
Water Services Act (108 of 1997)	Department of Water Affairs and Forestry	The main aim of this Act is to ensure the right to basic water supply and sanitation. It contains rules on setting national tariffs and the setting of a regulatory framework for water services institutions.
National Water Act (36 of 1998)	Department of Water Affairs and Forestry	The main objectives of the National Water Act (NWA) are to protect, use, develop, conserve, manage and control the water resources of South Africa using the guiding principles of sustainability and equity. The NWA recognises that water is a natural resource that belongs to all people. The NWA recognises two rights to water which are basic human needs and water for the environment, and a priority to take account of international agreements. The NWA is built on 28 principles as laid out in the 1997 White Paper on a National Water Policy in South Africa. The NWA recognises that South Africa is water scarce and that water is unequally dispersed. This Act repealed the Water Act of 1956 (54 of 1956).
National Water Resource Strategy (2004)	Department of Water Affairs and Forestry	The purpose of this strategy was to develop and utilise a framework for managing water resources and the preparations of catchment management strategies. It also provided information about the current and expected future demand for and supply of water.

Event	Name of Department	Purpose of legislation and the institutional response by DWA
National Water Resource Strategy 2 (2013)	Department of Water Affairs	This strategy reviews and updates the strategy from the National Water Resource Strategy of 2004 with a strategic focus to protect, use, develop, conserve, manage and control the water resources of South Africa using the guiding principles of sustainability and equity for all South Africans. It further links the development goals from the Water for Growth and Development framework (DWAF, 2009a). It also provides information about the current and expected future demand for and supply of water.

(Researcher's own construction based on: DWA, 2013b; Van Vuuren, 2012; Rowlston, 2011; Tewari, 2009; Legge, 2009; DWAF, 2004; De La Harpe & Ramsden, 2002; RSA, 1998; RSA, 1997; Triebel & Van Niekerk, 1994; DWAF, 1986)

The monumental changes that came about politically from the first free democratic elections in South Africa in 1994 and from the new progressive South African Constitution in 1996, laid the platform for a comprehensive evaluation of water policy and legislation in South Africa. This evaluation led to the fundamental principles and objectives for a new water law in 1996, followed by a white paper on national water policy in 1997 (DWAF, 1997) and finally the National Water Act (NWA) in 1998 (RSA, 1998) which was a substantial improvement on past water legislation (Rowlston, 2011; DWAF, 2004).

Rowlston (2011) states that, due in large part to the measures taken to protect the aquatic ecosystem, the NWA is seen to be one of the most progressive pieces of water legislation in the world. Rowlston (2011) continues, noting that although the intention to implement the protection measures exists in the NWA, there is no common understanding on how to implement certain aspects of the NWA. For example, in the policy and principles upon which the NWA is built, the ecological Reserve has a "priority of use, by right", but there is no unambiguous statement in this regard in the NWA. Furthermore, in the *National Water Resource Strategy* (NWRS – DWAF, 2004), the ecological Reserve is listed at the top of a guide on priorities for water use, but further on in the same report, it is asserted that the order of the list may differ under certain conditions.

The NWA, like the Constitution on which it is built, may incur conceptual complications because it is human-centred (Rowlston, 2011; Tewari, 2009). The NWA establishes the National Government as the public trustee of South Africa's water resources to protect them and uphold the environmental principles, but because of the human-centeredness, the aquatic environment only has important NWA status because of its usefulness to humans (Rowlston, 2011; Tewari, 2009). The DWS needs to constantly stress and promote the message to the public, and especially to decision-makers and policy-makers, that aquatic ecosystems are virtually impossible to replicate, even with modern technological advances. The DWS promotes the message through NWA-enforced public consultations (Rowlston, 2011).

2.4 ECONOMICS OF WATER

In the previous section, the supply of and demand for water were quantified. The economics of water are now discussed in terms of the pricing and value of water.

2.4.1 Pricing of water

DWS's water pricing strategy has four main objectives, namely social equity (correcting past imbalances), ecological sustainability (effective aquatic ecosystems), financial sustainability (enough revenue to cover maintenance, development and management costs), and economic efficiency (reflecting the value of water and its scarcity) (DWA, 2012a). In South Africa, water prices (known as tariffs or charges) are regulated from source to tap, in order to be both pro-poor and appropriate (DWA, 2013b; DWA, 2012a). These regulations have resulted in raw water tariffs being kept low artificially, which creates an under-recovery of costs (DWA, 2013b). Raw water tariffs, known as first tier tariffs, are prices for the use of untreated water and do not include water servicing pricing such as bulk or distribution tariffs, which are second and third level tariffs (DWAF, 2007b). Raw water charges are split into water resource management charges and water resource development charges and vary by geographic area, water use, water user and by water supply infrastructure project (DWAF, 2007b). As an example, variation by water supply infrastructure project is shown in Table 2.3.

Table 2.3: Domestic, industrial, and irrigation raw water charges for selected cases

Province	Scheme ID	Scheme Description	SMP ID	SMP Description	Sector	2012/13 Domestic & Industrial Raw Water Charges (c/m³)	2012/13 Irrigation Raw Water Charges (c/m³)
Western Cape	360	Berg River Project (Berg River Dam	784	Raw water from Berg River Dam to exising users from system	D&I	13.85	12.87
Western Cape	360	Berg River Project (Berg River Dam	785	Raw water from Berg River Dam to third party users	D&I	13.85	12.87
Western Cape	360	Berg River Project (Berg River Dam	783	Raw water from Berg River Dam to the City of Cape Town	D&I	13.85	-
Mpumalanga	352	Sabie River (Inyaka Dam)	756	Releases from the dam to downstream river users	D&I	30.27	5.10
Mpumalanga	352	Sabie River (Inyaka Dam)	757	Supply directly from the dam pump station	D&I	30.27	5.10
Limpopo	298	Sabie River (Inyaka Dam)	535	From Nandoni Dam and the river downstream of the dam	D&I	78.05	16.51

(Source: DWA, 2012a)

There is considerable water price variation around South Africa and the tariffs are not always based on the volume of water used (DWA, 2013b). As a result, the operations and maintenance of infrastructure has deteriorated despite government subsidies (DWA, 2012a). A further consequence of keeping the price of water low is that it does not accurately reflect the scarcity of water in South Africa, nor does it fully cover the management costs (DWA, 2013b; DWA, 2012a). There is also no economic regulation (or independent regulators) of water tariffs in South Africa (DWA, 2012a). A risk of low costs is that they may suddenly be raised as a result of insufficient quantity or quality (DWA, 2012a). The pricing strategy is inconsistently applied across South Africa, largely due to the historical situation and its sporadic evolution (DWA, 2012a).

In attempting to solve these issues, the DWS has revised their pricing strategy by aiming to directly link charges to costs in order to cover the full costs of the water and improve water use efficiency (DWA, 2013b; DWA, 2012a). The DWS further recommends that implementation of an appropriate pricing structure, through improving billing and revenue collection at local government level, could also help significantly (DWA, 2013b). Further recommendations include scheme-based pricing so that prices reflect the costs and the strengthening of economic regulation in particular, throughout the water's journey from source to tap (DWA, 2012a).

2.4.2 Value of water

Water has much more than a monetary value; it is priceless, because life would cease without it. The real value of water is not fully reflected in the pricing of water, especially if the value of healthy, functioning ecosystems is taken into account (DWA, 2013a).

Nevertheless, the DWS defines the full value of water as the economic value plus its intrinsic value (DWA, 2012a). While it is difficult to quantify the intrinsic value of water in monetary terms, it is much easier to quantify its economic value (DWA. 2012a). According to the DWS, the economic value of water can be broken down into four parts: the value to the users (quantified by willingness to pay), the net benefits of return flows (such as recharging groundwater), the net benefits from indirect use, and adjustments for social objectives such as poverty relief (DWA. 2012a). The DWS further suggests that the full value and the full costs should conjunctively be used to determine water allocations, and that decisions about water resources should be distinct from decisions about how to finance the allocation (DWA. 2012a).

2.5 SUMMARY

This chapter has provided the context on which this study is premised. The amount of water available in South Africa is limited first and foremost by bio-physical aspects. The amount of water available in South Africa is further limited by the sources used and the present infrastructure.

Water scarcity in South Africa thus exists as much from physical limits as it does from poor management and inefficient usage, despite the world class regulatory framework that exists (DWA, 2013b). Current pricing strategies do not promote promised social equity, ecological sustainability, financial sustainability or economic efficiency. Raw water costs are being kept artificially low; there has been an under-recovery of costs, which has led to the operations and maintenance of infrastructure deteriorating despite government subsidies, and the low costs do not accurately reflect the scarcity of water in South Africa (DWA, 2013b; DWA, 2012a)**.**

The real value of water is not fully reflected in the pricing of water, especially if the value of healthy, functioning ecosystems is taken into account (DWA, 2013a). It is therefore vitally important for water resource management decisions to be undertaken in the best possible manner.

The research design and methodology are discussed in the following chapter (Chapter Three).

CHAPTER THREE
RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

Research is a process of investigating and exploring in order to find solutions to a specific problem in a structured and orderly manner, so as to increase knowledge, and in organisations, to increase the quality of the decision-making (Sekaran & Bougie, 2009; Collis & Hussey, 2009). Quality research is dependent on rigorous, logical and organised research design, methodology and methods to frame the question and produce valid conclusions from results (Sekaran & Bougie, 2009).

In this study, the mixed methods research (MMR) paradigm (Johnson & Onwuegbuzie, 2004) provided the overall framing, and is appropriate for selecting a case study methodology (Johansson, 2003). Within this framing, data collection methods included semi-structured interviews (Yin, 2014; Collis & Hussey, 2009), documentation and archival records (Yin, 2014), and data analysis methods including unit reference values (URVs - Van Niekerk, 2013), inter- and intra-case analysis and content analysis in analysing the decision-making process (Collis & Hussey, 2009). Finally, at the end of this chapter, quality objectives and ethical considerations are discussed.

3.2 RESEARCH PARADIGM AND METHODOLOGY

A research paradigm is a structure of fundamental thinking and understanding, about the world and the essence of knowledge, which indicates how a particular research study will be undertaken (Morgan, 2014; 2007; Bryman, 2004). Paradigms can be defined as "shared belief systems" that show how research can be undertaken in specific fields (Morgan, 2007).

In this study, the MMR paradigm incorporates collecting, analysing and combining quantitative and qualitative data in a set of related case studies (Yin, 2011; Johnson & Onwuegbuzie, 2004). Quantitative and qualitative research are combined to provide a better understanding of the research problem, through the increased number of perspectives that are analysed (Yin, 2011). Multiple perspectives ensure that pre-existing assumptions are less likely to influence the outcomes, while promoting the strengths of the two approaches and strengthening their validity. When the research question addresses a broad issue, it is often useful to focus the research effort by selecting case studies to demonstrate possible developments in knowledge. Additionally the case study methodology is consistent with the MMR paradigm (Yin, 2014; 2011).

Case study methodology focuses on explaining and understanding a phenomenon in a real-life setting (Yin, 2014; Collis & Hussey, 2009). In designing a case study, the type of case study used and the number of cases analysed, are important (Yin, 2014; Collis & Hussey, 2009). Yin (2014) classifies case studies into three main types; explanatory, exploratory and descriptive. This study makes use of the descriptive, multiple-case study design to explain the decision-making processes in water-supply development in South Africa. Descriptive research engages in explaining or classifying the attributes of a phenomenon or population (Collis & Hussey, 2009). Multiple-case study design considers multiple units of analysis within several cases (Yin, 2011). Data collection and analysis methods are embedded consistently within each case study; the multiple-case design allows exploration of the similarities and differences between and within cases, and the evidence is considered to be robust and reliable (Baxter & Jack, 2008) while aiming to reproduce conclusions across different cases (Yin, 2014). The selection of multiple case studies used in this study is discussed in the next section.

3.3 CASE SELECTION AND EXCLUSION

The process of selecting case studies (dams) for this study was revised iteratively to ensure it was rigorous. The selection process and criteria used in selecting the four cases for this study are explained in the next section. An explanation for the exclusion of certain dams and the inclusion of the four selected dams is also provided.

3.3.1 Criteria for selecting dams

To be selected, the dam needed to be in the DWS's Dam Safety Office's list of registered dams. To increase the likelihood of good, reliable data, selection was limited to Category 3 dams (those with a dam wall height of at least twelve metres, a storage volume of one million cubic metres or more, and a high hazard potential in terms of economic loss and loss of life (Cullis *et al.,* 2007)). As of September 2013, there were 288 Category 3 dams registered in South Africa (DWA, 2013a).

The following steps set out the process of, and criteria for, the selection of dams:

a. Consider dams built after 1990 because, according to the DWS, there is limited dam-cost data before 1990 (Legge, 2012).
b. Ensure that there is reliable cost and yield data on the selected dams. Only dams that increase the yield in their catchment are considered. Examples of dams that are rejected are mine tailings dams used for holding the mix of leftover materials from mining processes (for example, Merriespruit Tailings Dam near Virginia, Free State.), flood-attenuation dams built to control floods and remaining empty most of the time (for example, Qedusizi Dam near Ladysmith, Kwazulu-Natal), and hydro-electric/pumped storage scheme dams such at the Palmiet Pumped Storage Scheme.
c. Include at least one dam from winter and summer rainfall areas, to ensure that different climatic conditions are included.
d. Include a variety of wall types in order to eliminate the cost bias of different wall types.
e. Ensure reliability and availability of the selected dams. Dams must be preferably impounded and handed over (or at least 95 per cent complete), so that actual post-construction costs are available. In the case of an incomplete dam, the most recent, expected final cost of the dam, as calculated by the DWS, must be used.
f. Ensure a variety of uses of the dam water, so as to prevent water-use bias (for example, agricultural, industrial, and domestic uses).
g. Include a variety in terms of size (full-supply capacity) and dam wall height to eliminate size bias.
h. Exclude dams where the yield is manipulated by upstream infrastructure, such as inter-basin transfers, as this does not allow for separation of costs with sufficient confidence.
i. Use only existing dams where the wall has not been raised, as a wall-raising does not necessarily mean an increase in full supply capacity or yield (for example, Stompdrift Dam). This is typical of the DWS's dam safety rehabilitation programme whereby the non-overspill crest level of embankments (the part of the dam wall above the water line when the dam is at full supply capacity) is raised to improve stability.
j. Select dams on the availability of data regarding the surrounding catchment area (studied in Chapter Four).
k. Take into account the dams in which there is a policy-maker demand or interest, so that there is more information available for future studies and decision-making, as well as increasing the benefits and usefulness of this study.

In selecting the dam schemes that were most appropriate to this study, six iterative steps were followed, as summarised in Table 3.1. As the study developed, the selection process changed from an informal selection, to a selection based on more rigorous process, using all of the criteria listed above. The sixth iteration resulted in the final selection of dams.

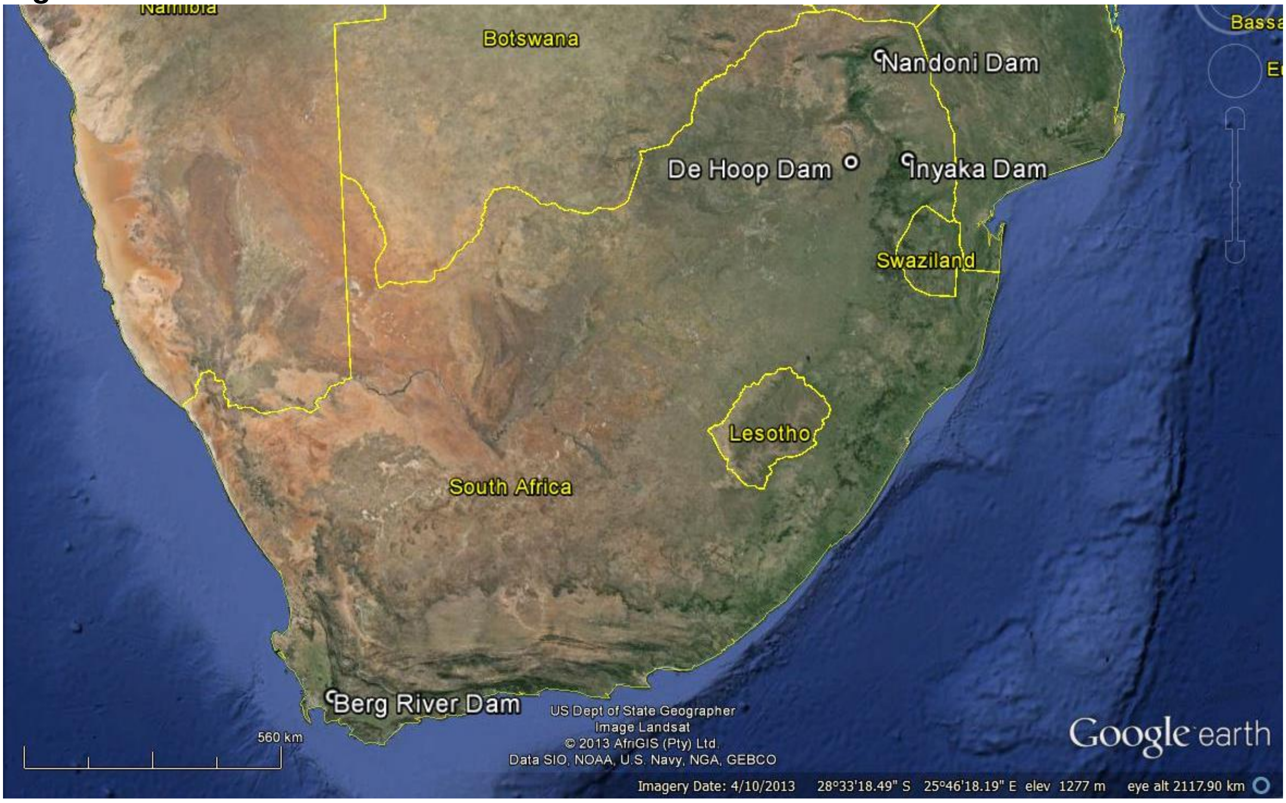
Table 3.1: Changes in the selection process and selected dams

Level	Reason for selection change	Selected dams as a result of the change
1	All major dams built since 1980 in South Africa	870 Dams
2	Studying all dams built since 1980 was not feasible due to scale and lack of data availability	Five to eight major dams in South Africa
3	Refined to Category 3 dams, as classified by the DWS (DWA, 2013a) and dam wall raisings only.	Berg River Dam; De Hoop Dam; Flag Bashielo Dam; Inyaka Dam; Koster Dam; Kromme River Dam; Nandoni Dam; Qedusizi Dam; Welbedacht Dam; Woodstock Dam.
4	Refined to post-1990 dams due to the lack of available cost data on pre-1990 dams.	Aloe Cove Dam; Berg River Dam; Bloemhoek Dam; Bridle Drift Dam; Flag Bashielo Dam; Inyaka Dam; Masinger Dam; Nandoni Dam; Paris Dam.
5	Dam wall raisings excluded due to lack of change in yield.	Berg River Dam; De Hoop Dam; Inyaka Dam; Midmar Dam; Nandoni Dam; Spring Grove Dam.
6	Final selection: dams downstream of other infrastructure (for example, IBTs) excluded.	Berg River Dam; De Hoop Dam; Inyaka Dam; Nandoni Dam.

(Source: Researcher’s own construction)

Based on the criteria and Table 3.1, the following four dams were selected and included in this study, namely: Inyaka Dam, Nandoni Dam, Berg River Dam and De Hoop Dam. The locations of the four selected dams are shown in Figure 3.1.

Figure 3.1: Location of the selected dams



(Source: Google Earth, 2013)

3.3.2 Excluded dams

The dams listed below were excluded at Levels 4, 5 or 6 of the selection process.

A. Flag Bashielo Dam

Flag Bashielo Dam is situated on the Olifants River in Limpopo Province. The Olifants River is the most over-subscribed river in the country in terms of demand and has enormous water quality and pollution concerns as a result of (*inter alia*) the industrial and mining pollution in the upper part of the catchment (Ashton & Dabrowski, 2011). Owing to the high demand for water from the Olifants River, the Flag Bashielo Dam was raised to increase the yield of the dam by 16 million cubic metres in 2004. Construction of the raised embankment was completed in 2005.

The catchment is highly developed with upstream reservoirs of Witbank Dam, Loskop Dam, Rhenosterkop Dam, Flag Bashielo Dam, De Hoop Dam (currently under construction on the downstream tributary of the Steelpoort River), Blyde River Dam, and Massinger Dam in Mozambique.

This option of the Flag Bashielo Dam raising was thus excluded from the list of schemes because the yield is manipulated by the upstream developments of the Witbank and Loskop Dams, which have a significant influence on increased yield. Furthermore, this "marginal" raising is actually dependant on a system of development for which costs of components are untraceable, for example, the costs of the Loskop Dam and its 1974 dam wall raising.

B. Massingir Dam

Massingir Dam is located on the Mozambican section of the Olifants River and was built with foreign funding with the intention of raising the dam using radial gates. It is similar to Midmar Dam in that the original construction included building the earth flanks to make provision for a future raising of the dam wall. The recent raising would thus not be a realistic reflection of development costs for increased yield, even if the costs were known. Because the dam is built in a foreign country and because of its construction differences and unknown costs, Massingir Dam was excluded from the list of selected dams.

C. Bloemhoek and Bridle Drift Dams

Bloemhoek Dam is situated on the Jordaan Spruit, near the town of Kroonstad in the Free State, while Bridle Drift Dam is situated on the Buffalo River, near East London in the Eastern Cape. Both of these dams were excluded because they had their walls raised. Dam wall raisings do not necessary mean an increase in full supply capacity or yield, for example where dam safety rehabilitation has raised the walls. Furthermore, dam wall raisings are difficult to compare with dams that have been newly built, as the cost of a dam wall raising is a fraction of the cost of building a new dam.

D. Aloe Cove Dam

Aloe Cove Dam is located on a tributary of the Crocodile River, near the town of Krugersdorp in Gauteng. Aloe Cove Dam has been excluded for a number of reasons (Shaw, 2013): it has no yield and its value is for recreation purposes; no real construction records were kept; and the dam was built in stages from money generated from the profits of the Heia Safari Ranch Hotel.

E. Paris Dam

Paris Dam is situated on the Bivane River in northern Kwazulu-Natal near the town of Vryheid. Paris Dam was built by and is owned by the Impala Irrigation Board. Paris Dam was excluded because the DWS did not build or subcontract the dam to be built and because there was a lack of detailed and reliable financial cost data.

F. Midmar Dam

Midmar Dam is situated on the Umgeni River in central Kwazulu-Natal near the town of Howick. It was designed and built for a future wall raising by way of mechanical (radial) gates. The embankments were built originally to make provision for future raising. The costs for this raising are thus quite distorted as the majority of the cost of the increase in yield was actually spent during the original construction.

Another reason why Midmar Dam was excluded is because it is downstream of an IBT. This IBT brings water into this catchment from the Mooi Umgeni Transfer Scheme Phase 1 (MMTS1) and the Spring Grove Dam further up the Mooi River.

G. Spring Grove Dam

Spring Grove Dam is currently (as of February 2014) under construction on the Mooi River in Kwazulu-Natal as Phase 2 of the Mooi Mgeni Transfer Scheme. Spring Grove dam is being built by the Trans-Caledon Tunnel Authority.

Spring Grove Dam was excluded from the list of selected dams because firstly, there is an upstream ITB; and secondly, there was no reliable estimate of the actual cost of the dam because it was less than 95 per cent finished at the time of the selection process (early 2013).

3.3.3 The selected dams

The cases being analysed in this study include the following four dams, namely the Inyaka, Nandoni, Berg River and De Hoop dams, and their catchment areas. In order to achieve insights into the decision-making processes of dam construction, each case study is analysed in terms of a) evaluating the efficiency of water delivery in terms of infrastructure development costs (using unit reference value analysis), as discussed in Chapter Four; and b) the management of invasive alien plants as a catchment-based option to increase the water yield of the catchment, as discussed in Chapter Five. Furthermore, one case (the De Hoop Dam) examines the process of decision-making in more detail, as discussed in Chapter Six. The insights from the various case studies are brought together in the overall considerations of focus and depth on appropriate decision-making criteria in water supply development in Chapter Six.

The stages in a case study are identified as case selection, initial investigations, collection of data, analysis of data and writing the report (Collis & Hussey, 2009). As the case selection and initial investigations have already been dealt with, data collection and analysis methods are discussed in the next section.

3.4 DATA COLLECTION AND ANALYSIS

Using data and methodological triangulation (multiple data sources and collection methods) allows for a more in-depth understanding of the cases (Yin, 2014; Collis & Hussey, 2009). Each data collection method and analysis, described in this section, is linked to the chapter in which it is used.

3.4.1 Documentation

The documentation used in Chapters Four, Five and Six was gathered mainly from the DWS. The documentation was mostly in the form of laws, regulations, national strategies, and various planning reports. Other documentation was collected from sources other than the DWS such as the Agricultural Research Council (Kotzé *et al.,* 2010), and research papers from academic institutions such as Couzens and Dent (2006).

3.4.2 Archival records

Archival records including databases are used in Chapters Four and Five. The cost data used in both chapters came from DWS national and regional archives and databases. Additionally, Statistics South Africa's CPI headline index was used to adjust the cost data (in Chapter Four) to December 2012 rand values, so that inflation is a controlled variable (Statistics South Africa, 2015). The CPI headline index is shown in Appendix B. A further database used (in Chapters Four and Five) in the collection of MAR information was the *Water Resources of South Africa, 2005 study* (Middleton & Bailey, 2011).

3.4.3 Semi-structured in-depth interviews

An interview approach (used in Chapter Six) was selected to gather different opinions and views of people involved in the decision-making process that took place during the building of De Hoop Dam (Van Teijlingen, 2014; Collis & Hussey, 2009). Semi-structured, in-depth interviews were used to elicit responses to focused subjects as well as additional broader issues. Semi-structured, in-depth interviews consist of a list of predetermined questions, where the order and wording of questions can be altered (depending on perceived appropriateness) and explanations can be given (Van Teijlingen, 2014; Collis & Hussey, 2009).

The purposive sampling technique was used to select interviewees. Where the researcher chose interviewees based on personal judgement and advice taken, these were based on the strength of the interviewee's knowledge and experience of the subject being studied (Sekaran & Bougie, 2009). Purposive sampling was chosen because there were a limited number of people involved in the project, and because the topic was sensitive in nature.

Potential interviewees were contacted through an introductory email, asking them if they would agree to be interviewed. In a covering letter, it was explained that the interviews were voluntary and that they would be anonymous and confidential, to induce interviewees to speak freely. Before each interview started the interviewees were asked to sign an informed consent form (an example of the covering letter, the consent forms and the interview guide are available in Appendix E).

Consequently, ten people involved in the management (at various levels) and decision-making concerning the planning and construction of the De Hoop Dam were interviewed. Of the ten, nine worked for the DWS directly and one was a heavily involved consultant. The interviewees have been labelled P1 to P10 to maintain their anonymity. Five interviewees (P4, P6, P7, P9, and P10) were involved in the planning (including design) stage of ORWRDP Phase 2A and the other five (P1, P2, P3, P5 and P8) were involved in the construction stage.

Interviews were conducted at the convenience of interviewees. Five of the ten interviews were face-to-face; however, due to unavoidable circumstances, three interviews were conducted telephonically and two by email. Interviews lasted from 45 to 90 minutes, depending on how much detail was provided by the interviewee and the extent and focus of the interviewee's involvement. Interviews were captured in handwritten notes by the researcher, who acted as the interviewer. The researcher emailed a typed transcript to each interviewee, and asked each to ensure that the transcript was a true and fair reflection of the interview, in order to verify the transcripts and provide construct validity of the interview process (Yin, 2011; Riege, 2003). Any changes that the interviewees made were captured and the transcripts were then accepted. Some of the interviewees provided documents as additional source materials.

3.4.4 Unit reference value (URV) analysis

URVs are used in Chapter Four and offer a type of cost-effectiveness analysis, used and developed in South Africa by the DWS (Van Niekerk, 2012). These URVs are a calculation of the cost per cubic metre of water over the lifetime of a water infrastructure project (for example, at the point where the water leaves the dam). As part of a multiple criteria analysis (see section 4.2.7), planners in the DWS use URVs to sort water-resource developments from most effective to least effective in terms of the cost per cubic metre of water (Van Niekerk, 2013). URVs can also be used to optimise the size of a water resource development such as the height of a dam wall and compare the result to other options, such as raising the wall in the future (Van Niekerk, 2013).

The recommended discount rate used in the calculations, in Chapter Four, is eight per cent (Mullins *et al.,* 2007) and the recommended sensitivity analysis used is six per cent and ten per cent (Van Niekerk, 2013; Fuguitt & Wilcox, 1999). Thus, URVs can be calculated using the following formula, shown in Figure 3.2:

Figure 3.2: URV equation

$$Unit\ reference\ value\ (R/m3) = \frac{Net\ present\ value\ (NPV) of\ lifecycle\ costs}{Discounted\ yield\ of\ the\ dam\ over\ its\ lifespan}$$

$$Life\ cycle\ costs = PV\ of\ capital\ costs + PV\ of\ operating\ and\ maintainance\ costs.$$

(Source: Van Niekerk, 2013)

The assumptions necessary for calculating the URVs of the selected dams are provided below:

a. Construction costs are ring-fenced to be able to compare all cases equally and include direct construction costs of the dams. An example of an excluded cost is the delivery system cost of pipelines and pumping stations.
b. Estimated and actual construction costs are shown in December 2012 rand values to eliminate inflation bias as far as possible. Costs are adjusted using the CPI headline index (Appendix B).
c. Operational and maintenance (O&M) costs only commence in the year after the last year of construction and are shown in Appendix C.
d. Actual O&M costs from the DWS, available and complete, are used in the URV calculations. Furthermore, for comparison purposes (and where DWS data is unavailable or incomplete) estimated and actual O&M costs are calculated using the DWS guidelines (DWAF, 1996b and Appendix A). The guidelines split the O&M costs into civil works costs and mechanical and electrical costs due to their different economic lifespans. Civil works have an economic lifespan of 45 years and are depreciated at 0.25 per cent per annum, while mechanical and electrical works have a lifespan of 30 years and are depreciated at four per cent per annum (DWAF, 1996b).
e. Yield also only commences in the year that O&M expenses begin because the dam will not reach full supply capacity before then (at which time the benefits of the dam begin).
f. The construction costs are spread equally over the construction lifespan of the dam and the O&M costs are spread evenly over the post-construction lifespan of the dam except for the thirtieth year after construction finishes. In the thirtieth year the O&M costs are calculated as ten per cent of the cost of construction in order to replace the mechanical and electrical works, which have a lifespan of 30 years.
g. In line with DWS practice, a discount rate of eight per cent will be used to calculate the URVs with six per cent and ten per cent also calculated as a sensitivity analysis.

Based on the above equation and assumptions, the URVs for the expected and actual costs of the four dams can be calculated. The URV calculations are shown in Appendix C and the results are shown in section 4.5. A history of URVs is presented in section 4.2.6.

3.4.5 Inter- and intra-case analysis

Inter-case analysis was used in Chapters Four and Five. Four cases are compared in respect of the differences between expected and actual construction costs, primarily using URVs (in Chapter Four) and in terms of the 2008 impact of invasive alien plants (IAPs) on MAR as well as the potential impact to MAR over 45 years if IAP management is not continued (in Chapter Five).

Intra-case analysis was used where additional data was available in the De Hoop Dam case (in Chapter Six), in terms of the decision-making that resulted in the De Hoop Dam being built. The De Hoop case was chosen for further analysis because it was still under construction when this study started (in 2013), it is the latest major dam to be completed (in 2015) in South Africa, there is more information available on the De Hoop Dam than for most other dams (a problem encountered during case selection), and because the majority of managers and personnel involved in project decision-making were still accessible.

3.4.6 Decision-making analysis

In the governmental decision to build De Hoop Dam, it is evident that politics, and therefore to some degree the political decision-making model, played a role. However, because of their complexity, limitations and need for additional data-gathering, the political and bounded rationality decision-making models will not be used as frameworks to analyse the decision to build the De Hoop Dam. Instead, the RDMM is used as a framework, as discussed in Chapter Six. The RDMM was chosen by the researcher based on personal judgement, advice taken, and the strengths of the RDMM – which include the fact that it is most likely to result in the decision-making of a group or individual being reliable and logical, it is a logical step-by-step process, the limitations of the rational model (such as the steps not being followed in order when innovative decisions are made) are not as severe as those of the bounded rationality or political models, and because the rational model actively takes external forces into account at every step (Zindiye, 2012).

Each of the seven steps of the RDMM is discussed using DWS planning reports and responses to semi-structured interviews (Van Teijlingen, 2014; Yin, 2011; Collis & Hussey, 2009). The DWS planning documents used in Chapter Six are all part of the series of reports for the detailed planning phase of Phase Two of the ORWRDP.

The transcriptions from the semi-structured, in-depth interviews (Chapter Six) were analysed using content analysis which enables systematic ordering, structuring, and grouping of large amounts of qualitative information by identifying themes and patterns (Collis & Hussey, 2009). Each transcription was read through twice and relevant phrases were identified and then linked to the seven steps of Zindiye's (2012) rational decision-making model.

3.5 QUALITY CRITERIA

According to Collis and Hussey (2009), there are two aspects of research that reflect the credibility of research findings: validity and reliability. Validity refers to the level of accuracy of the findings in relation to what is supposed to occur (Collis & Hussey, 2009). Validity is more difficult to measure in qualitative studies than in quantitative studies because there are no generally accepted guidelines to test for validity (Struwig & Stead, 2001). Therefore, in order to give greater confidence in the validity of the interviews, the researcher made use of participant validation. This was achieved by emailing each of the interviewees with their interview transcripts and asking them to read through and comment on them.

Research is said to be reliable if someone else repeats the research and obtains consistent results (in a quantitative study) or similar findings and inferences in a qualitative study (Collis & Hussey, 2009). Furthermore, reliability of the qualitative aspects of this study, such as the interviews, can be evaluated by assessing their credibility, transferability, dependability and conformability (Collis & Hussey, 2009; Pitney & Parker, 2009). Credibility relates to how well the findings are supported by the collected data. Credibility is addressed through data source and collection triangulation, and frequent debriefing during supervisor meetings (Collis & Hussey, 2009). The credibility of this study was strengthened through methodological triangulation through the use of semi-structured interviews; documentation and archival records (Yin, 2014; Collis & Hussey, 2009; Sekaran & Bougie, 2009). Transferability relates to whether the findings can be applied to other, similar studies (Pitney & Parker, 2009). While transferability rests with the reader, the researcher needs to supply sufficient information in order for the reader to be able to do so (Pitney & Parker, 2009). The research procedures and methods used in this study have been clearly detailed in order to strengthen potential transferability. Dependability closely relates to reliability in quantitative research, focusing on whether research processes are methodical, meticulous and ably recorded (Collis & Hussey, 2009). Dependability is addressed through the detailed explanations of the research paradigm, methodology and methods used within this study. Conformability relates to whether the research process has been adequately recorded so that the reader may ascertain if the findings arise from the data (Pitney & Parker, 2009). Conformability is addressed by ensuring consistency in data collection by using an interview guide (Appendix E), and in data analysis by using recognised methods of analysis (Collis & Hussey, 2009).

3.5 ETHICAL CONDUCT

Yin (2014) emphasises that protecting human participants in case study research is essential. Sekaran and Bougie (2009) contend that ethical conduct should characterise data collection and analysis, as well as the writing and publishing of the information. In order to protect participants, special care should be taken to gain informed consent, protect the participants from harm (such as through misrepresentation of the nature of the research), protect participants' privacy and confidentiality, ensure voluntary participation, and conduct the research with dignity (Yin, 2014; Sekaran & Bougie, 2009; Collis & Hussey, 2009).

In this study, the researcher carefully explained the research and ethical aspects to potential participants prior to their agreeing to participate. The explanation was conducted through an introductory email with a covering letter (shown in Appendix E). The email made it clear that participation was voluntary and that the interview would occur at a time that was convenient to the participants. Furthermore, it was explained that the interviews would be recorded by hand and that a typed transcript of the interview would be sent to the participant, in order to verify the transcripts and provide construct validity of the interview process (Yin, 2011; Riege, 2003). Potential participants were made aware that the interviews would be completely anonymous and confidential, and that they would not receive any remuneration for their participation. Additionally, participants were informed that the interview data would be used for research purposes only and would be handed to the supervisor after submission, for private storage.

Before each interview started, participants were informed again that their participation was voluntary, anonymous and confidential. Confidentiality was protected by assigning each transcript a different number (from P1 to P10). Additionally, each participant was asked to sign a consent form prior to the start of the interview (shown in Appendix E). In the case of three interviews that were not conducted face-to-face (two were conducted by telephone and one by email), the participants were first asked to send the researcher an email consenting to the interview. Lastly, participants were informed that they could withdraw from the research study at any stage without penalty.

This research complied with all ethical requirements of the Rhodes University Department of Management's Human Research Ethics Committee.

In the following chapter (Chapter Four), an analysis of estimated and actual URVs of the four case studies, is presented.

CHAPTER FOUR
THE COST OF DAM CONSTRUCTION AND COMPARATIVE COSTING

4.1 INTRODUCTION

In Chapter Two, water supply generation in South Africa was explored in terms of bio-physical considerations, the national water supply and demand, the management of water supply limits, and finally the pricing and value of water. Chapter Four now looks at the first objective of this study, which is to calculate and evaluate the variation between estimated and actual construction unit reference values (URVs) for a selection of dams.

Chapter Four addresses the first research objective by retrospectively exploring the costs of building (as seen in Figure 4.1) and operating selected water infrastructure schemes (dams) in South Africa, and analyses important financial and economic criteria used by the DWS in their decision-making. The evaluation of costs compares the estimated costs – at the time when the proposal to develop each selected dam was approved by the then Minister of Water Affairs and Forestry – with the actual costs following the construction of each of the dams (after adjusting the costs for inflation).

Figure 4.1: The De Hoop Dam under construction

(Source: Young, 2014)

Chapter Four thus questions whether ministers were put in a fair position to make an informed decision about the costs and benefits of a dam. Furthermore, it explores the quality of data being kept by the authorities on the costs and benefits (such as yield) of completed dams.

The National Water Act (36 of 1998: p.51) stipulates in section 109, that the Minister of Water and Sanitation "may acquire, construct, alter, repair, operate or control government waterworks in order to protect, use, develop, conserve, manage and control the nation's water resources in the public interest". Government waterworks are developed to meet an identified demand and may comprise infrastructure for bulk water storage and conveyance from the resource to the place of use (typically including a mix of: dams, pipelines, canals, pump stations, electricity supply works, access roads, telecommunications, minor office and accommodation). This study refers to the waterworks infrastructure – excluding pipelines transferring water away from the dam, but including the land on which it is situated as a dam – although it is understood that this refers to the collective infrastructure from source to supply for the specific yield. It is noted that this definition of a water supply scheme to meet an identified demand is limited to bulk water and excludes the user infrastructure costs such as municipal infrastructure for distribution to individual properties.

4.2 UNDERSTANDING COST-BENEFIT ANALYSES OF WATER SUPPLY DEVELOPMENT OPTIONS IN SOUTH AFRICA

Section 4.2 explores the motivations, reasons and the decision-making behind the construction of dams in South Africa. Furthermore, it explores the financial decision-making criteria that are applied when deciding whether or not to build a dam. These criteria include cost benefit analyses (CBAs), URVs and multiple criteria analysis (MCA).

4.2.1 Making decisions

Decision-making concerning infrastructure projects is often difficult and uncertain as authorities try to find optimal solutions to developmental needs. There have been many voices raised in questioning the sustainability of the outcomes of the infrastructure choices that have already been made (Hay *et al.,* 2012; National Planning Commission, 2012). The costs of many infrastructure projects are questioned (Flyvbjerg, 2009; 2005). Allegations of corruption and collusion in many of the big infrastructural projects – such as sports stadiums, roads, railways, power supply, water supply, land reform, and other large projects that get put out to tender – have also been made. Examples of this are the Lesotho Highlands Water Project (Thamae & Pottinger, 2006; Darroch, 2004), land reform programmes (Dardagan, 2012), and the collusion of construction companies working on the Berg River Dam, Cape Town Stadium, the Gautrain and other projects nationwide (Gedye, 2013; Nicholson, 2013; SAPA, 2013; Steyn, 2011; SAPA, 2009).

Arguably one of the best ways to address the challenges of corruption and collusion is to require independent CBAs for infrastructure projects. This will not address the corruption threat in the sense of who is awarded the tender, but rather it addresses whether or not the project should go ahead on the basis of the benefits outweighing the costs. Requiring CBAs for infrastructure projects will also be likely to have a positive effect on public policy by providing improved information and by holding public officials more accountable for the outcomes (Guasch & Hahn, 1999).

In practice, CBAs are popularly used when comparing infrastructure projects where all the components have monetary values that are easy to calculate (see, for example, Mullins *et al.,* 2007). However, it is often the case that water supply infrastructure projects have components that are difficult to quantify economically, such as some environmental and social costs (Redford & Adams, 2009; MEA, 2005). Examples of these difficult-to-cost components include calculating the monetary value of the water quality benefits of a healthy wetland (such as trapping silt, improving water quality and flood attenuation) or the full costs of relocating communities (such as relocating graves or maintaining livelihoods in a changed environment) away from a selected infrastructure site. Even though obtaining or calculating some of the environmental and social costs is difficult, it does not mean that the value of components (whether costs or benefits) is low or zero. There is a risk that some of these environmental and social values may be undervalued or completely overlooked when deciding on the site of an infrastructure project.

Such an analysis does not negate the need for dams (as is raised in section 4.2.2). Water supply decision-making invariably involves trade-offs. It is inevitable that some costs (as well as opportunity costs) are necessary to obtain the planned benefits. At issue is whether we can weigh up these costs and benefits when making decisions. It is also important to understand who pays and who benefits (albeit to different extents) from the outcomes.

Decision-making and trade-offs are not limited to building dams; they are also important in water security alternatives such as DSM (discussed further in Text Box 1 below) and catchment management. It has not been possible to obtain an estimate of the proportion of the budget of the water sector that has been spent on building dams as a source of water supply, versus the proportions spent on other options such as DSM or catchment management (conserving the supply of water). Take, for example, the Western Cape Systems Analysis (DWAF, 1996a) which ran between 1989 and 1995. The WCSA consisted of 24 predominately supply-side alternatives to enhance the supply of water to Cape Town and the surrounding area. These alternatives were contrasted with the Palmiet Phase 1 scheme that was under consideration at the time in terms of yield and relative cost. It has not been possible to obtain accurate comparative figures here either, but it is clear that the bulk of the alternatives were supply-side options (DWAF, 1996a).

Text Box 1: Demand-side management (DSM)

DSM, also called water demand management, is a strategy implemented by a water institution or water user to limit the anticipated water use to meet objectives such as the sustainability of water supply and economic efficiency (DWAF, 2004). It is often linked with water conservation strategies. An example of DSM is encouraging and educating people on how they can save water in their homes by using low-flow showerheads and taps as well as by fixing leaking pipes and taps. Another example of DSM is raising the price of water, as it would serve as an incentive to conserve water use. This however is not true for all water use due to limited cost recovery. In areas where the cost of water is not recovered, increasing the price to limit water abuse has zero impact.

Internationally, DSM has been implemented in many countries as part of integrated water resource management approaches. The examples of Namibia, Israel and Australia (Sydney) show that DSM is not new and that it is still being implemented successfully. Namibia, the driest sub-Saharan country in Africa, implemented DSM measures in 1990, and over a seven-year period, water consumption did not increase, while population increased by 35 per cent (Van der Merwe, 1999). More recently, Israel launched a multimedia awareness campaign and reduced consumption by ten per cent by the end of 2009 (Thivet & Fernandez, 2012). Since 2002, Sydney's water use has decreased in seven out of nine years between 2002/2003 and 2011/2012. This has been due to the implementation of water efficiency programmes such as "Water Wise Rules", to encourage water saving behaviours (Sydney Water, 2013).

While DSM is a necessary and useful water management tool that needs far more emphasis (Van Rooyen & Versfeld, 2010), it is outside the scope of this study.

DSM was not even listed as an option in the systems analysis of the Western Cape (DWAF, 1996a), which contained a separate, short, superficial section listing a few suggestions on how water could be saved, without giving cost or quantity of water saved estimates.) The Skuifraam (now Berg River) Dam was the preferred "next scheme to be built" in the WCSA (DWAF, 1996a); however, the Minister of the DWS at the time, Professor Kadar Asmal, put the Berg River Dam on hold until 1999, as he wanted water conservation and demand management programmes to first be implemented (Pottinger, 1999). The absence of DSM in the Western Cape Systems Analysis illustrates a focus on supply-side options, especially the building of dams.

A supply-side contribution to conserve supply is to fix aging infrastructure. Yet the massive cost of replacing aging water infrastructure (indicated by former DWS Minister Edna Molewa to be R58 billion per annum over a ten-year period (Donnelly, 2012)) clearly indicates that some of the choices made between building new water supply options and conserving existing water supply options should be retrospectively questioned. For example, McKenzie *et al.* (2012) estimated that 36.8 per cent of the water that enters the national system is classified as non-revenue water. Non-revenue water is made up of physical water losses (for example, a burst pipe) and commercial water losses (for example, billing errors) and unbilled consumption (for example, water for firefighting) (McKenzie *et al.,* 2012). The cost of repairing aging infrastructure relative to supplying additional water through augmentation such as with a dam, is a vital consideration in certain parts of the country. CBAs can be used to compare the costs and benefits of repairing aging infrastructure in relation to building new infrastructure.

CBAs can also be used in retrospective assessments, which attempt to ascertain whether the actual costs and benefits are in line with what was estimated. By retrospectively assessing decisions, analysts and decision-makers can improve decision-making by comparing their expectations with the actual outcomes (Guasch & Hahn, 1999). This may also help to create a functioning institutional memory and appropriate document archiving; both severely lacking currently in the DWS, based on the extreme difficulties experienced in this study in tracking down data relating to decision-making on the selected dams (and more so with the dams that could not be included in this study, for lack of accessible data).

4.2.2 The South African water dilemma

As explored in Chapter Two, South Africa is a water-scarce country that has already made use of most of the economically located surface water options to increase water supply in the country. Increasing the water supply of the country means increasing the amount of water that can secured as “yield”. Yield is discussed in Text Box 2.

Text Box 2: Water yield

The assured water supply is the amount of water that is abstracted from the system (the total yield) at different levels of assurance. Yield is the guaranteed supply of water at a 98 per cent level of assurance (DWAF, 2004; King *et al.,* 2011). This means that the water (yield) is guaranteed, on average, in 98 out of 100 years (DWA, 2013b). The DWS's planning directorate uses a 98 per cent assurance of supply in their planning when calculating available water supply. However, the level of assurance that water users get depends on the water use. Water use assurance ranges from 100 per cent assurance of supply for strategic industrial use (such as Eskom's power generation) down to a minimum of 70 per cent assurance of supply (for irrigation). Domestic, industrial and mining have a minimum of 90 per cent assurance of supply (RSA, 2007).

Since yield is calculated at a 98 per cent assurance, the yield of a dam is always much less than the total amount of water held when the dam is full (called full supply capacity or FSC). For example, De Hoop Dam has an estimated yield of 64 million cubic metres and a FSC of 347 million cubic metres. Another reason for the big difference between yield and FSC is because the water that is needed for the ecological Reserve (as required by The National Water Act 36 of 1998) is not regarded as available for other uses (DWAF, 2004). The amount of water defined as yield could be increased if the level of assurance was decreased but the risk of water shortages would increase, undermining water security. Without changing the level of assurance, the main ways that yield can be increased are through:

- construction or raising of dams (reservoirs) and weirs (by increasing storage capacity);
- construction of desalination plants (to turn sea-water into drinking water);
- increasing of abstraction of water from rivers;
- management of "water factories": catchments and riparian areas with high water-generating potential (for example, through the control of IAPs (Van Wilgen *et al.,* 2008), land- and wetland-management (Le Maitre *et al.,* 2009);
- additional groundwater abstraction.

Transferring water into one area from another, known as an IBT (or inter-basin transfer) will increase yield in the receiving catchment, but will of course deplete yield in the catchment from which it is taken. There are costs and benefits associated with these IBTs. These include the potential social and economic benefits in the receiving catchment, which stem from meeting increased water demand, as well as generating hydropower (WWF, 2007). One of the major costs would be financial as IBT projects are frequently large, expensive and complicated. Other costs include energy costs of pumping, when the movement of water into another catchment cannot be provided by gravity alone, and the legal and political costs of an IBT in a trans-border catchment (WWF, 2007). One of the impacts that is internationally cited from IBTs is the movement of fish and other fresh-water biota (including plants) into areas in which they previously did not occur (Davies and Day, 1998). These can become invasive in the systems into which they are introduced, disrupting biological diversity and the ecological functioning of the systems. Another long-term cost that is seldom recognised is the reduction of the assimilative capacity of the river from which the water is removed.

The siltation of dams and rivers is a further major factor in water yield. De-silting dams, and reducing the levels to which silt will enter a dam, will lessen the loss of yield. This too has costs and benefits that should be assessed. For example, it was estimated at the end of 2012 based on 500 000 cubic metres of silt in a 25 metre high concrete dam, that the cost of dredging a dam to remove the silt would cost R75 per cubic metre, compared with building new dam storage which costs approximately R20 per cubic metre (Legge, 2014). The cheapest option would be to stop sediment entering into the river system in the first place (Legge, 2012), which in this case was not costed.

Options to reduce evaporation are clearly important for water yield. The conjunctive use of ground and surface water (Foster *et al.,* 2010) can realise greater yield than would be possible from using just one source . There will be costs and issues (such as separate management for surface and groundwater) for these benefits, but the fact that conjunctive use is so seldom employed suggests that the costs are perceived to outweigh the benefits.

Evapo-transpiration is also an important consideration in terms of yield. For example, evapo-transpiration by waterweeds such as water hyacinth (*Eichhornia crassipes*) can increase natural evaporation levels by up to 3.2 times (Marlin, 2010). It has also been shown that invading trees (such as pine trees) within a riparian area will use significantly more water through evapo-transpiration than the same trees will away from the riparian zone (Le Maitre *et al.,* 2015; Dzikiti et al., 2013).

As has been mentioned, water conservation though the repairing of defective pipes and canals (and leaking reservoirs), would also effectively increase the actual yield. The costs and benefits of this are addressed in the main body of the text.

A main goal of the DWS is to develop a water supply reserve (so that supply is greater than demand). In aiming for this supply reserve there is also a need to consider whether water is lost to the system (consumptive use, for example, when watering your garden in the middle of a windy day, when evaporation levels can be far higher), or whether it is being returned to the system (non-consumptive use, for example, through the sewerage system when taking a bath) (Berger & Finkbeiner, 2010; DWAF, 2004). There are water storage, purification and pumping costs connected with such “non-consumptive use” that should also be considered. However, these seem to be more academic arguments than practical considerations in water security, if the lack of such points in selected planning documents (of all spheres) is at all representative.

The quality of water may also be considered to be a factor for water yield. In certain circumstances, additional water is needed for dilution (for example, when highly salinated). Yield, in the end, is what can actually be used. Once again, there are costs and benefits that need to be understood, and acted upon. The salinisation of soil through inappropriate irrigation methods has been shown in the Free State (Le Roux *et al.,* 2007), in the so-called “bread basket” of the United States of America (Pitman and Läuchli, 2002), and along the Murray-Darling River in Australia (Save the Murray, 2007). Large-scale irrigation can also lead to the salinisation and contamination of groundwater through the absorption by soils of a mineralised residue left over by evaporation (Van Weert & Van Der Gun, 2012). Furthermore, the World Commission on Dams (2000) found that 20 per cent of irrigated land has been lost to salinisation. Decision-makers should consider which choices to prioritise, and where impacts are irreversible, these should be acknowledged as high risks.

Dams are a necessary part of the water supply in most parts of the world (Scudder, 2005; World Commission on Dams, 2000). In a country like South Africa, with variable climate and rainfall, periodic droughts, uneven spread of demand for water (both seasonally and geographically), and general water scarcity (only 450 mm of rainfall per annum, on average), dams are necessary for water security. Dams are also an option to regulate the uneven supply of water that is a reality in South Africa, as well as to match the development goals set out by Government in documents such as the National Water Resources Strategy: Second Edition (DWA, 2013b) and National Development Plan: Vision for 2030 (National Planning Commission, 2012).

In the National Water Act (36 of 1998), section 117(c)(1) stipulates that all dams with a storage capacity of more than 50 000 cubic metres and a wall height of more than five metres have to be registered with the DWS (there are many thousands of smaller dams that are not registered with the DWS (Legge, 2014; Davies & Day, 1998)). With over 5 000 registered dams in South Africa, as shown in Table 4.1, there has clearly been a perceived need for dams in the country (DWS, 2014a). These dams (registered and unregistered) all delay the flow of water in South Africa’s rivers at the start of the rainfall season. What gives rise to a retrospective study like this one, is looking at dams that have been built, to see if they were in fact necessary at the time, or if there were more effective alternatives options that existed at the time these dams were built.

Table 4.1: Classification of registered dams in South Africa

Size class	Number	%
Small (less than 12m)	3775	75.0%
Medium (12m – 30m)	1079	21.5%
Large (30m and above)	176	3.5%
Total	**2030**	**100**

(Source: DWS, 2014a)

The need to address alternatives applies to DSM and the conservation of supply as well. For example, when the Lesotho Highlands Water Scheme was being proposed, a study was done by a Mr Larry Farwell (a water specialist seconded by the USA to work with the late Professor Kader Asmal), looking at water use in the Department of Water Affairs’ own building. He found that over 90 per cent of the water being used in the “Sedibeng” building was being lost to leaks (L. Farwell, personal communication, 8 October 2012). He argued that there are already existing dams that supply water to Gauteng, and questioned the need to build an additional dam supplying water to Gauteng, when DSM and conservation of supply (leak management and unaccounted-for water) had clearly not been addressed.

The bottom line of this argument is that while the building of new dams and IBT schemes are inevitable in South Africa, the opportunities are limited (DWA, 2013b). However, even in these cases, it is necessary to consider environmental and social impacts. But, as the Mount Fletcher Dam attests – having silted up 70 per cent in just four years (CSIR, 2013) – even the building of new dams requires an assurance that there will be water, not silt, to fill the dam in the long term.

In this respect, it is important to look at not only the relative costs of dams and their alternatives, but also at the timing of interventions. There may be lower risks of a gap between water supply and demand if some interventions are prioritised over others. Text Box 3 further discusses the timing of interventions and the long-term costs of dams.

Text Box 3: The long-term costs of dams

The timing of interventions is an important consideration. South Africa typically borrows money at interest rates requiring a need to be prudent (Gordhan, 2014). It may make sense, then, to build infrastructure when it is most needed, and to optimise the limited period of its lifespan. (This would take into account inflation costs of building dams.) As can be seen from the table of options in the Western Cape Systems Analysis (Table 4.1; DWAF, 1996a), there are several dam options that can be considered. These dams have been largely considered on the basis of financial costs alone, and not including economic costs. Even so, it is clear that as the best options/sites for dams are taken, more marginal options/sites must be considered, and the cost-benefit ratio is less favourable.

By looking at DSM, maintenance of infrastructure (as part of the conservation of supply), and catchment management, considerable savings can be made with timeous action. For example, the Working for Water programme in the Olifants Catchment (Limpopo / Mpumalanga Provinces) is estimating a doubling period of about seven years for the black wattle (*Acacia mearnsii*) (Kotzé *et al.,* 2010). The cost to clear does not increase in a linear manner; rather it depends upon considerations such as slope, soil, accessibility and other factors (Marais & Wannenburgh, 2008), and thus may double in less than seven years. The water impact of the IAPs would also more than double in that period, as it is not just the spread of the plants, but also the growth (and therefore higher levels of evapo-transpiration) of each tree. It may then make sense to clear the catchment as soon as possible, for economic reasons (Görgens & Van Wilgen, 2004). The same would be true of making timeous repairs to canals, pipes and other infrastructure for the distribution of water.

The argument is to advocate prioritisation of factors such as catchment management, and to delay the building of dams. If the authorities could eliminate the need for the last (and most marginal/expensive) dams on the list, there could be significant savings.

Table 4.2: A 1996 list of potential options to augment the Cape Town's water supply

PROPOSED SCHEME	YIELD (million cubic metres of water per year)	RELATIVE COST OF WATER (compared to the Palmiet Phase 1 scheme)*
Newlands Aquifer Scheme	7	0.5
Palmiet Phase 1	31	1
Alien Vegetation Control	approximately 20	1.1
Voëlvlei Augumentation Scheme	15	1.6
Eerste/Lourens River Diversion	15	1.6
Molenaars River Diversion	35	1.9
Wit River Dam	12	1.9
Cape Flats Aquifer Scheme	18	2.2
Skuifraam Dam Scheme	56	2.4
Lower Hangklip Dam	100	2.6
Upper Campanula (Phase 1 and 2)	73	3.1
Brandvlei Dam to Theewaterskloof Dam	100	3.1
Skuifraam Supplement Scheme	19	3.5
Lower Berg River Aquifer Scheme	78	4.0
Voëlvlei Augmentation (Phase 2)	110	4.6
Upper Campanula (Phase 3)	20	4.9
Misverstand Dam	70	5.3
Sewage Effuent Exchange	20	6.3
Keerom Diversion (Olifants River)	90	6.9
Platrug Dam (Diep River)	12	7.9
Direct Re-use of Sewage Effluent	36	10.6
Desalination of Seawater	more than 100	20
Rain Water Tanks	9	20
Importation by Tanker	more than 100	50

(Source: DWAF, 1996a)

4.2.3 Background and motivation for the construction of a dam

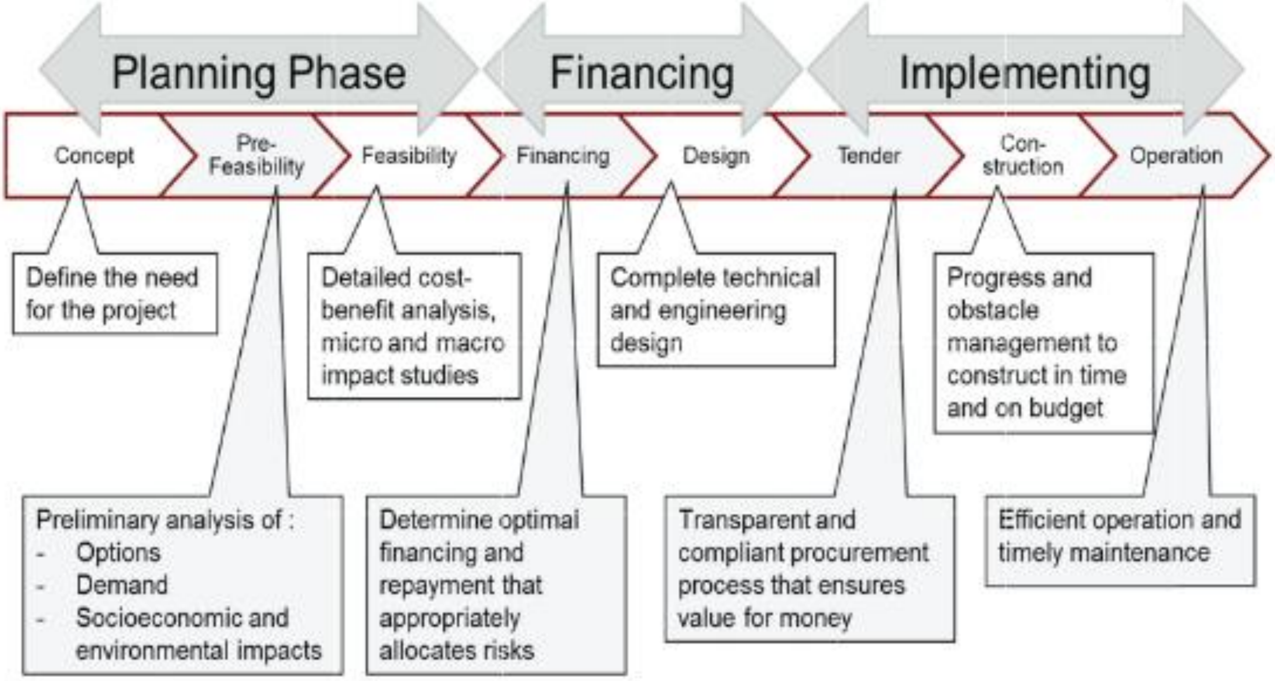
A decision to build a dam is driven by a perceived need for greater water security in an area or region, together with consideration of where a dam is perceived to be the best option for meeting that need. Other reasons for building a dam include flood attenuation, recreational benefits (although not given as a reason in itself) and the hydroelectric energy benefits that are often linked with the building of dams. Hydroelectric dams are, however, more common in countries with higher assured runoff – where hydroelectricity is sometimes the main purpose for building a dam – than they are in South Africa (World Commission on Dams, 2000).

Before a decision to build a dam is made, substantial planning processes are required. This includes comparisons of alternative options, analyses of locations and infrastructure size, trade-offs (environmental, social and other) and a need to provide answers to the following questions: What is the projected demand for water? What options are available to meet the demand with sufficient assurance of supply? What are the relative costs and benefits of the different options?

While some of the questions are perhaps obvious – where to build the dam, what type of dam to build, what size of dam to build, what impacts, environmental and social, will building the dam have, how much will it cost; and what alternative options are available – the answers are invariably subtly different and difficult to evaluate.

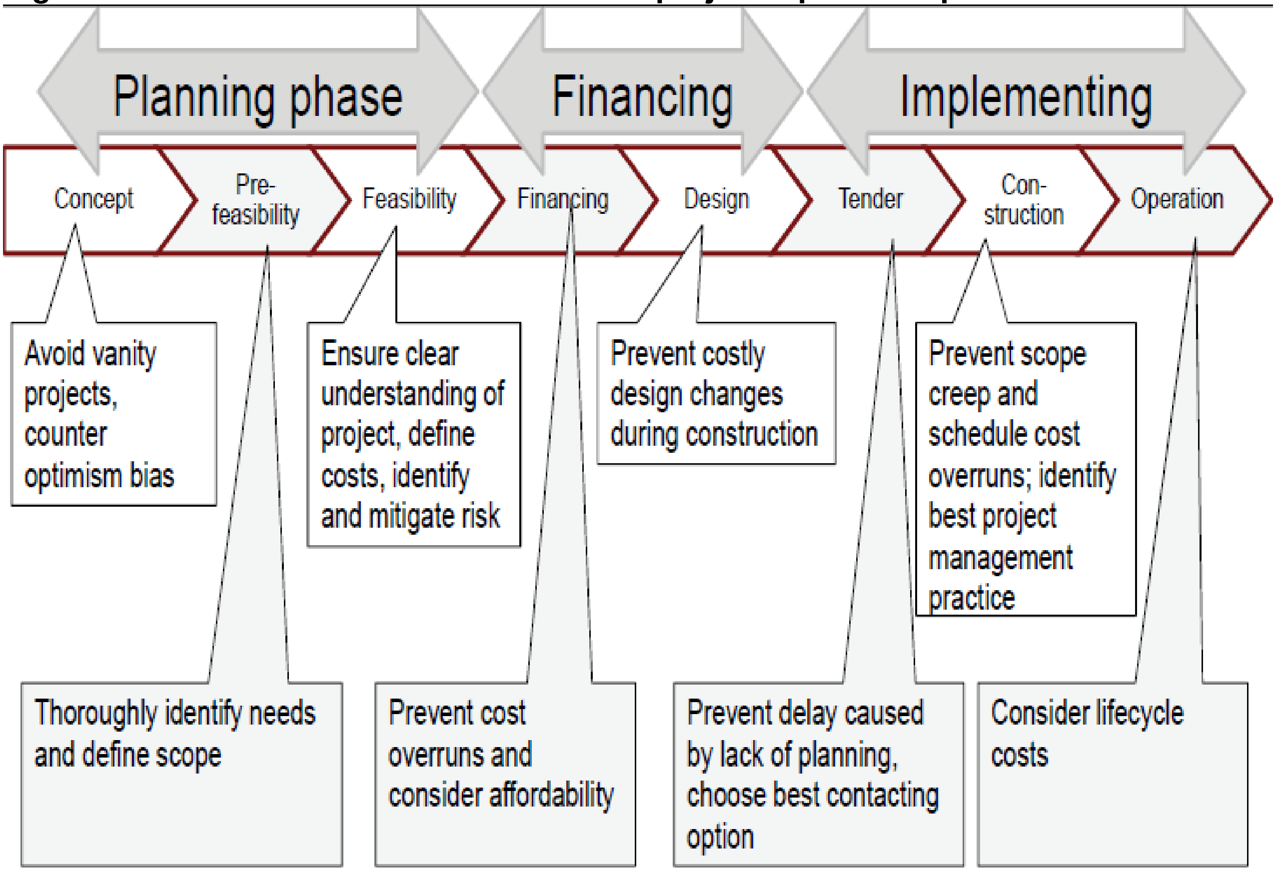
The National Treasury has produced frameworks for government infrastructure projects that show respectively the different steps (and their explanations) which projects are supposed to follow (see Figure 4.2), together with their potential pitfalls (see Figure 4.3). The National Treasury expects projects like building dams to follow these frameworks.

Figure 4.2: Framework of an infrastructure project's life cycle



(Source: National Treasury, 2012)

Figure 4.3: Framework of an infrastructure project's potential pitfalls



(Source: National Treasury, 2013)

The planning that the National Treasury requires entails looking at the current assured supply of water in contrast to current and future expected demand. The assured supply is the amount of water that is already abstracted from the system (the total yield) at different levels of assurance. The DWS's planning directorate uses a 98 per cent assurance of supply when calculating available water supply. This means that water (yield) is guaranteed, on average, in 98 out of 100 years (DWA, 2013b). The level of assurance that water users get depends on the use of the water and it ranges from 100 per cent assurance of supply for strategic industrial use (such as Eskom's power generation) down to a minimum of 70 per cent assurance of supply (for irrigation). Domestic, industrial and mining have a minimum of 90 per cent assurance of supply (RSA, 2007).

Demand for water continues to increase around South Africa for a number of reasons. These include human population growth and movement of population (largely from rural to urban areas); the continued issue of providing water for the basic human needs component of the Reserve to alleviate inequality of access of water, as laid out in the National Water Act of 1998 (RSA, 1998) and the National Development Plan (NPC, 2012);

and the continued growth of agricultural, mining and industrial water needs from new and expanded businesses. Other reasons for an increase in the demand for water include droughts, possible climate change and catchment degradation. Water loss would be an additional reason, involving aging infrastructure, leaks and unaccounted-for water. So too might deteriorating water quality, and the need to dilute polluted water to reach acceptable standards. The National Water Act requires that water be allocated to maintain the ecological component of the Reserve. This quantity of water does not, however, increase (RSA, 1998) although climate change may become a factor (Hedden & Cilliers, 2014).

If the demand for water is likely to surpass supply, then either supply must increase (through harnessing additional yield in the catchment, bringing the water in from another catchment through an IBT, or options such as desalination) or demand must decrease (through DSM, catchment management, or the conservation of supply such as reducing unaccounted-for water). This will prevent water shortages and the economic, environmental and social consequences of a prolonged water shortage, including unequal access to supply (such as, people “at the end of the pipe” getting no water).

It is clear from White Papers (such as DWAF, 1998a; DWAF, 1998b; DWAF, 1994), systems analyses (for example, DWAF, 1996a) and other planning documents (such as DWA, 2013b; DWAF, 2009a; DWAF, 2007a) of the DWS, that substantial research and planning does guide decision-making to ensure water security. It could be argued that this focus is within a framework that is predominately supply-side oriented. However, historically there has been less exploring of options such as DSM, catchment management and effluent water recycling (King *et al., 2011*). Only recently has there been greater emphasis on the conservation of existing supply, especially in terms of leaks and aging infrastructure (DWA, 2013b; DWAF, 2004).

One aspect that may be a factor in the apparent focus on dams, rather than on alternative options, is that the Constitution has made the work of the DWS a national function, and the building of dams is something that can be managed in its entirety by DWS. By contrast, DSM is a function of local government. Because there are now the three largely autonomous spheres of government, rather than the hierarchical “tiers” of government in the past, the national DWS must work through and with local government for DSM. This has its difficulties, as the efforts to address both water supply and especially sanitation have shown (Van der Merwe-Botha, 2010; Herold, 2009). Similarly, catchment management is a “concurrent responsibility” (mainly within provincial government), and has the added complication of DWS needing to work in partnership with other departments, notably the Department of Environmental Affairs, the Department of Agriculture, Forestry and Fisheries, and the Department of Rural Development and Land Reform.

Although co-operative government and governance is required in all aspects of work, it is clear that the DWS has far greater autonomy in the building of dams than it does for many of the alternatives. It should be recognised, however, that these institutional challenges were not always the case, and that the DWS (including its previous names and mandates) has always had a tendency to pursue the building of dams rather than exploring other alternatives. The profound changes in water law, policy and the structure of the DWS that have occurred in the last twenty years in documents such as the National Water Act (RSA, 1998), the National Water Resource Strategy (NWRS) (DWAF, 2004), the NWRS Second Edition (DWA, 2013b) and the Water for Growth and Development Framework (DWAF, 2009a, DWAF, 2009a), are trying to lessen this tendency.

In the DWS, Strategic Planning, detailed planning (called Options Analysis), Construction, and Water Resource Information Operations Management are all in distinct units called chief directorates. It can be expected that tensions occur between these units, as it is well documented in many organisations (Duze, 2012; Nuttall, 2012; Knight *et al.,* 2008). There is no way of being able to question the contribution of intra-departmental tensions in this study, but it is raised as a possible reason for the difference between planning cost estimates by the DWS and the final costs.

4.2.4 Financial decision criteria applied to a decision to build a dam

When a decision to build a dam is made, a number of scenarios are developed to provide decision-makers with information. These scenarios vary according to aspects of the dam such as height of the dam wall or wall type selection. One of the main results of the variation in each scenario is that the financial costs will differ. These costs may be direct and easy to calculate (such as the cost of the dam wall), or they may be indirect and more difficult to calculate. These indirect aspects are often called ‘externalities’ and can be social/environmental costs (such as the loss of natural beauty) or social/environmental benefits (for example, provision of new recreational opportunities such as sailing on or fishing in the dam). Related to this are opportunity costs – the alternative options for which the resources could have been used. Also applicable when comparing scenarios are the associated cumulative impacts.

Many costs and other variables can be difficult to quantify and therefore require subjective judgement. Decisions are always value-based, and decision-makers can purposely fail to take account of particular decision implications, so that their preferred choice is selected.

It may be expected that archived documentation would provide the detail necessary to make an informed decision. Merely providing a financial analysis will not do so. For example, strategic environmental assessments, URVs and economic CBAs are all helpful and even necessary, but on their own are inadequate. That is why water planners make use of MCAs, to contrast and compare alternative options.

4.2.5 Cost-benefit analyses (CBAs)

The financial implications of options are calculated and compared through mostly financial analyses in the planning stage to determine the optimal solutions. One of the main types of financial analysis is the CBA (also known as benefit-cost analysis) which determines and then compares the benefits and costs of various project options.

CBAs are used to compare and rate different projects and/or different alternatives in the same project (for example, comparing the cost of different dam wall heights when planning a dam). The total financial and economic costs to the total financial and economic benefits are stated in rand (monetary) terms. This comparison results in a ratio. If the ratio is less than one-to-one (meaning that benefits are greater than costs), the project is worth pursuing further. If the ratio is more than one-to-one, the project is considered non-viable. If there are multiple projects or alternatives for the same project, the project or alternative with the lowest CBA is selected, so that the return on investment is as high as possible.

As a CBA relies on putting monetary values on the components, it means that those which can easily be given a rand value (for example, the cost of a house to be flooded by a dam) are at risk of being given higher importance than things which are difficult to give a rand value to (for example, loss of a family graveyard, or home).

There may be many variables, some of them not obvious at the start of a CBA, which should be factored into the CBA in order to have a more accurate calculation of the relative cost of different options. The value of a human life is often used as an example of where CBAs are vulnerable (Kernohan, 2012). CBAs are also vulnerable in that costs are generally short-term in nature, while benefits are long-term in nature (Gruber, 2010). This further complicates the comparison. Where there is compensation involved, the value ascribed to variables is complex, and is vulnerable to being manipulated.

CBA should include or be supplemented by risk assessments (Mullins *et al.,* 2007). Dam safety standards have been significantly enhanced over the past two decades (DWA, 2012b; RSA, 1998), and these additional potential costs and risks need to be taken into account. But some risks are not well-understood. For example, the invasive Yabby crayfish (*Cherax destructor*) burrows into earthen walls of dams and can lead to a failure of the wall, with the resulting dangers not only in terms of disaster management, but also in terms of water security from the failed dam (Withnall, 2000). Similarly, poor water quality from agricultural runoff of nitrates and phosphates, coupled with human waste through failed sewage treatment, may lead to eutrophication and the growth of toxic algae in a dam. This has happened at Hartbeespoort Dam (Venter & Ledger, 2010). Addressing eutrophication incurs significant costs, which may not have been included in the original planning figures (Marshall, 2014).

Another type of risk that one might expect in a CBA for water development is the introduction of invasive or potentially invasive species through IBTs. A local example is the transfer of the sharp-tooth catfish (*Clarias gariepinus*) (Kadye & Booth, 2013; Bruton, 1988). Consideration of risks such as aquaculture development (DAFF, 2014) raises one of the most important questions that should be established in a CBA, namely “Who benefits, and at whose cost?”

In most choices, there are ‘winners’ and ‘losers’, and there is a need to balance how those who benefit compensate those who lose. Sometimes the winners and losers are different over time, and some losses cannot be recompensed, further complicating the considerations. For example, a decision to build a dam may give water security and profit from the productive use of land to specific land-owners (an accusation often made during the apartheid era, regarding for example, the Pongolapoort Dam) while taking away options from others (for example, the poor communities in the Pongola flood plain who relied on the annual flooding of the river for food security) (Van Vuuren, 2009). There are almost always different costs and benefits for different stakeholders resulting in uncomfortable trade-offs.

The discount rate used in CBAs is another challenging aspect of the work. The discount rate is a weighting process similar to an interest rate that reflects the value of a cost or benefit over time (Mullins *et al.,* 2007). As will be discussed in the next section, the DWS has settled on an eight per cent discount rate (Mullins *et al.,* 2007), with six per cent and ten per cent being used as a sensitivity analysis (Van Niekerk, 2013). However, for many variables, people will argue that this eight per cent discount rate is inappropriate – in other words, that the value of something is halved within nine years (known as the rule of 72) (Kernohan, 2012; Moles *et al.,* 2011). An example of this would be that higher discount rates lead to environmental benefits being reduced in value and therefore appearing less efficient – with the cost of environmental damage being reduced in magnitude, and therefore being more likely to be overlooked (Fuguitt & Wilcox, 1999).

From an analysis of some of the early assessments being done after democracy in South Africa, it is clear that the promotion of equity and job creation were not formal factors in many CBAs. When a comparison was made in the Western Cape Systems Analysis (DWAF, 1996a), and the Working for Water option of clearing IAPs in the catchment was evaluated against the Skuifraam Dam (Berg River Dam) option, the impounded water was judged as being almost three times as expensive as the savings from clearing invasive plants. However, a construction budget was approved that was many times more than the cost of clearing the invasive plants (DWAF, 1998a). Job creation was not considered, nor was an assessment made of who would benefit and who would pay.

The challenge with CBAs, then, is less the technique of how to weigh up costs and benefits, and more how to put a rand value on many of the components.

4.2.6 URVs

URVs offer a type of cost effectiveness analysis, used and developed in South Africa by the DWS (Van Niekerk, 2012). URVs calculate the cost per cubic metre of water over the lifetime of a water infrastructure project (for example, at the point where the water leaves the dam). As part of an MCA (section 4.2.7), planners in the DWS use URVs to sort water-resource developments from most effective to least effective in terms of the cost per cubic metre of water (Van Niekerk, 2013). URVs can also be used to optimise the size of a water resource development, such as the height of a dam wall and compare the result to other options, such as raising the wall in the future (Van Niekerk, 2013).

In order to calculate a URV, the net present value of the capital costs and the operational costs are needed as well as the discounted yield. In order to calculate net present values, a discount rate is needed. In South Africa, it has been found that a discount rate of eight per cent is suitable as it is the recommended discount rate by international organisations such as the World Bank (Mullins *et al.,* 2007:67-68). However, it must be stated that choosing an appropriate discount rate has caused much debate in literature (Gruber, 2010; Boardman *et al.,* 2006). This is because an eight per cent discount rate has been higher than inflation (at six-and-a-half per cent as at February 2014) over the past decade and that it is also higher than the social discount rate (Gruber, 2010; Mullins *et al.,* 2007). A further issue is long-term environmental impacts, since an eight per cent discount rate will render the amount insignificant over any long period of time due to compounding interest (Mullins *et al.,* 2007). A solution to this problem may be the use of discount rates that decline over a period to a percentage approaching zero, so that the costs and benefits to future generations are more realistic and fair (Mullins *et al.,* 2007). This solution would also be in line with the National Water Act (RSA, 1998) where the two main principles are equity (fairness to the current generation) and sustainability (fairness to future generations) (Palmer *et al.,* 2002).

It has become the norm to do a sensitivity analysis by doing additional URV calculations using discount rates of six and ten per cent to offer a comparative context for the different options. (Van Niekerk, 2013; Fuguitt & Wilcox, 1999). This is done to show the sensitivity of the present value to different discount rates as well as showing if the selected project is still the best option at other discount rates. Even though six and ten per cent are the norm it is difficult to understand why, say seven and nine per cent are not used. According to Mullins *et al.,* (2007), lower discount rates would then result in capital-intensive construction techniques being used more often. Since the recommended discount rate in

South Africa is eight per cent and the recommended sensitivity analyses are six and ten per cent, that is what is used in this study.

In Britain, a cost-effectiveness analysis called the discounted unit cost was developed in the 1970s to reduce the number of options for a water scheme (Herrington, 2006). Van Niekerk (2013) noted that the British discounted unit cost is fully equivalent to the South African URV.

Van Niekerk (2013) describes the standard incremental approach to calculating URVs (see Figure 3.2 in section 3.4.4) as inadequate for calculating the URVs for IBTs because it does not take the condition of the catchment receiving the water into consideration, nor does the standard URV approach take variable costs (directly linked to the amount of water transferred) into consideration. Instead, Van Niekerk (2013) proposed and developed a new method for calculating URVs called the 'comprehensive approach' shown in Figure 4.4. This approach splits the present value (PV) of life-cycle costs into PV of capital costs plus the PV of operating and maintenance (O&M) costs. Where this approach differs from the standard approach is in the breakdown of the PV of O&M costs. In the comprehensive approach, the PV of O&M costs is equal to the PV of maintenance costs plus PV of fixed operating costs plus PV of variable operating costs.

Figure 4.4: Comprehensive URV approach

$$\text{URV} = \frac{PV\ of\ life\ cycle\ costs}{PV\ of\ quantity\ \ of\ water\ \ incrementally\ \ \ assured}$$

where

$$PV\ of\ life\text{-}cycle\ cost = PV_{\ capital\ costs} + PV_{\ O\&M\ costs}$$

and

$$PV_{\ O\&M\ costs} = PV_{\ maintenance\ costs} + PV_{\ fixed\ operating\ costs} + Expected\ PV_{\ variable\ operating\ costs.}$$

(Source: Van Niekerk, 2013)

While Van Niekerk's work was focused on using URVs in IBTs, he concluded that the comprehensive URV was not limited to IBTs but that it could be used in other water-related operations such as desalination schemes; however no mention of use in dam schemes was made. The reason for not using Van Niekerk's comprehensive URV approach in comparing different dam schemes, is that dam operational costs are not as variable as

IBTs, since IBTs transfer different amounts of water for different reasons at different times of the year. In calculating the URV for an IBT using the standard and comprehensive methods on the same example, Van Niekerk (2013) showed that the standard method has a bias towards variable costs and this leads to considerably different URV outcomes when compared to using the comprehensive method. These differences could lead to less-than-optimal decisions being made.

More accurate analyses make for better decision-making; however, in calculating the URVs in section 4.5 (Appendix C), the standard URV method is used. This is because it has long been the preferred method used in water resource infrastructure projects and because, despite numerous attempts, it has only been possible to obtain O&M costs for the Nandoni and Berg River Dams, as the De Hoop Dam does not yet have actual O&M costs, and estimated costs were not forthcoming from the DWS. No estimated or actual O&M costs for Inyaka Dam (the oldest of the four cases) were forthcoming, despite the fact that the O&M costs should be budgeted for and spent on an ongoing long-term basis.

Van Niekerk (2013) does not ask the question of how the URV works over the long term. If DSM could delay the building of a dam, it may be that subsequent dams to supply the same area may also be delayed, and then the last potential dam may never need to be built. That would result in a significant saving (especially as the last potential dam would likely be the least favourable and most expensive option – the best options having been already implemented). It is difficult to see how this consideration is factored into the decision-making process. The question, then, is whether this focus on URVs takes into consideration the long-term costs and benefits of different options.

4.2.7 Links to multiple criteria analysis (MCA)

Also known as multiple criteria decision-making or multiple criteria decision analysis, MCA is a formal process which identifies and ranks a set of options using multiple and sometimes conflicting measures where no single ideal solution exists, so that a decision can be reached (UK Department for Communities and Local Government, 2009; Mendoza & Martins, 2006). A MCA can assist decisions made by groups or single persons where various measures are weighted according to the decision-makers' preferences, so that a single solution can be reached. Different MCA methods exist and the choice of suitable methods is critical. MCAs may improve the validity of the selected solution by making the process more transparent (Mendoza & Martins, 2006). The MCA methods include, but are not limited to, financial analysis, CBA and cost-effectiveness analysis (UK Department for Communities and Local Government, 2009). URV calculations are one of the many methods used in MCAs. However, data availability and scope preclude the use of MCAs in this study.

4.3 METHODS

The data collection methods used in this chapter includes documentation (see section 3.4.1) and archival records (see section 3.4.2). The data analysis method used in this chapter is the URV analysis (see section 3.4.4). In the data analysis, all the costs are adjusted to December 2012 rand values, using the CPI historical index (shown in Appendix B), so that inflation is a controlled variable (Statistics South Africa, 2015). The methodology and methods have been explained in more detail in Chapter Three.

4.4 OVERVIEW OF THE SELECTED SCHEMES/DAMS

Following the selection of case studies in Chapter Three, an overview of the cases is now presented in the order of their construction – the Inyaka Dam, the Nandoni Dam, the Berg River Dam, and finally the De Hoop Dam.

4.4.1 Inyaka Dam

Inyaka Dam (also spelt Injaka Dam) is located on the Marite River, a tributary of the Sabie River in Mpumalanga Province. Inyaka Dam was constructed as part of the first phase of the Sabie River Government Water Scheme (Figure 4.5).

Figure 4.5: The Inyaka Dam over-spilling

(Source: bigal-sa, 2006)

The purpose of Inyaka Dam is to supply water for domestic and irrigation uses in the surrounding areas. Inyaka Dam was constructed between 1995 and 2002. A summary of the main features of Inyaka Dam is shown in Table 4.3.

Table 4.3: Summary of the main features on Inyaka Dam

Date of construction:	
(a) Year of completion	2002
(b) Duration of construction (in years)	7
(c) Public or private design	DWA
(d) Public or private construction	Group 5
Storage data and use	
Anticipated storage volume in m^3 (Full Supply Capacity)	120,000,000
Live storage volume in m^3 (FSC)	123,700,000
Volume of sediment in reservoir	0
Planned users	Irrigation / domestic
MAR	
(a) Natural catchment (m^3)	101,000,000
(b) Developed catchment (m^3)	78,947,000
Yield	
(a) When planned (m^3/annum)	41,200,000
(b) Revised	Not revised
Further data	
Pre-development approvals	White Paper
Current use	Primary water
Catchment area (sq. km)	209
Wall type	Composite dam (concrete spillway / earthfill)
Wall height (m)	53
Spillway type	Ogee
Crest length (m)	550

(Source: Adapted from DWAF, 1994)

In 1994, a White Paper (DWAF, 1994) was issued by the Acting Director-General, Mr M Erasmus of the then Department of Water Affairs and Forestry, on “Proposed Sabie River Government Water Scheme”. In the introduction to the White Paper, it is stated:

To the Minister of Water Affairs and Forestry

I have the honour to present herewith my report on the proposed Sabie River Government Water Scheme (First Phase: Injaka Dam and Bosbokrand Transfer Pipeline), prepared in terms of Section 58 of the Water Act (Act 54 of 1956).

The following costs, in Table 4.4 are detailed in the White Paper for the scheme, including the cost of the Inyaka Dam. The costs are shown in March 1994 prices, and then adjusted to December 2012 prices using the CPI (see section 3.4.4 and Appendix B).

Table 4.4: Breakdown of the estimated cost of Inyaka Dam

White Paper description	Costs at Mar 1994 (in rand values)	Adjusted for Dec 2012 (in rand values)
Townships and works buildings	10,000,000	31,250,000
Temporary roads	900,000	2,812,500
Permanent access roads	1,000,000	3,125,000
Excavation	15,930,000	49,781,250
Embankment: fill	25,340,000	79,187,500
Embankment: drainage	5,100,000	15,937,500
Embankment slope protection: upstream	4,850,000	15,156,250
Embankment slope protection: downstream	510,000	1,593,750
Spillway and outlet works: mass concrete	81,600,000	255,000,000
Spillway and outlet works:rReinforced concrete	11,290,000	35,281,250
Mechanical and electrical works and instrumentation	9,260,000	28,937,500
Reservoir cleaning	1,500,000	4,687,500
Fencing of reservoir	100,000	312,500
Gauging weir on Sabie River	2,262,000	7,068,750
Construction site clearance and landscaping	4,011,000	12,534,375
Miscellaneous items	500,000	1,562,500
Permanent accommodation	1,500,000	4,687,500
Contingencies	3,500,000	10,937,500
Relocating existing road, bridge, power lines, water treatment works and pipelines	41,727,000	130,396,875
Environmental (social and natural) programmes, land values and compensation	13,500,000	42,187,500
Total (March 1997 prices):	**234,380,000**	732,437,500

(Source: Adapted from DWAF, 1994)

In July 2013, The DWS confirmed the actual cost of the Inyaka Dam, through the final payment certificate (No 76), dated 25 June 2002, to be R305 000 000 (VAT included). The adjusted cost of this amount in December 2012 prices is R536 971 831. Unfortunately, no breakdown of the actual costs can be found. This means that a detailed comparison of the estimated and actual costs of Inyaka Dam is impossible. There is also a risk that some of the expected costs have not been factored in to the actual costs, and it is not then a comparison between like and like.

In the construction completion report of Inyaka Dam (DWAF, 2003), it is reported that Group 5 Roads Africa (the company contracted to build Inyaka Dam) finished the work in December 2001, two years after the target date. The main reasons for the extended construction time were reported to be 250 days of work lost to rain, six metres of extra excavations needed for all concrete structures and then filled with concrete, and numerous changes of design throughout the construction period (DWAF, 2003). The extended construction time, design changes as well the costs of claims granted to the contractor were reported to be the main reasons for increase in the cost of the dam (DWAF, 2003).

Not only has there been no breakdown of the capital costs, but it was only possible to secure limited information from the DWS regarding the O&M costs of the Inyaka Dam since its completion. This was despite the extensive efforts that were made to secure this information from the DWS. The O&M costs for the first six years of the operation of the dam (2003 to 2008) were not forthcoming; however, the following five years of O&M costs (2009 to 2013) were secured. The reported O&M data was not used in the Inyaka Dam URV calculation because it is an incomplete time series and, as shown in Table 4.5, it has high volatility between years. Instead, the O&M costs were calculated using the DWS's O&M guidelines, as equal to 4.25 per cent of the capital cost of the project (DWAF, 1996b & Appendix A).

Table 4.5: Actual O&M costs of Inyaka Dam

Year	O&M cost in 2012 rands (in million ZAR)	Cost as a % of capital cost	O&M Cost in 2012 rands calculated using DWS guidelines (in million ZAR)	Cost as a % of guideline O&M costs
2009	1.00	0.19	21	4.37
2010	1.42	0.26	21	6.22
2011	1.77	0.33	21	7.76
2012	2.47	0.46	21	10.81
2013	2.04	0.38	21	8.93

(Source: Adapted from DWS, 2014b)

It is indicated in Table 4.5 that the reported O&M costs are equal to eleven per cent (at most) of the O&M costs as calculated using the DWS guidelines. This indicates that either the actual cost data may be incomplete or that DWS guidelines are unrealistic. Financial management requirements would dictate that such O&M costs should be captured before payments can be made (Public Finance Management Act, No 1 of 1999). The lack of a fulltime series of O&M cost data weakens the attempts of this study to understand the real costs and benefits of water supply options.

4.4.2 Nandoni Dam

Nandoni Dam (which was formerly known as Mutoti Dam) is located on the Luvuvhu River, which flows into the Limpopo River in Limpopo Province. Nandoni Dam, as shown in Figure 4.6, was constructed as part of the Luvuvhu River Government Water Scheme.

Figure 4.6: The Nandoni Dam over-spilling

(Source: Brits, 2008)

Construction of Nandoni Dam began in 1999 and was completed in 2005, taking seven years to complete; however, it was expected to be completed in four years (DWAF, 1998b). The purpose of Nandoni Dam is to supply water for domestic and irrigation uses in the surrounding areas. A summary of the main features of Nandoni Dam is shown in Table 4.6.

Table 4.6: Summary of the main features of Nandoni Dam

Date of construction:	
(a) Year of completion	2005
(b) Duration of construction (in years)	7
(c) Public or private design	DWA
(d) Public or private construction	DWA
Storage data and use	
Anticipated storage volume in m^3 (FSC)	166,881,600 (2010 hydro survey)
Live storage volume in m^3 (FSC)	166.2
Volume of sediment in reservoir	0.07%/a
Planned users	Irrigation / domestic
MAR	
(a) Natural catchment (m^3)	Not given
(b) Developed catchment (m^3)	130,000,000
Yield	
(a) When planned	93,400,000
(b) Revised	Not revised
Further data	
Pre-development approvals	White Paper
Current use	Primary water domestic
Catchment area (sq. km)	1,380
Wall type	Earthfill and concrete gravity
Wall height (m)	47
Spillway type	Ogee
Crest length (m)	2,215

(Source: Adapted from DWAF, 1998b)

In 1998, a White Paper (DWAF, 1998b) was issued by the Director General of the then Department of Water Affairs and Forestry, Mr AM Muller, on the "Proposed Luvuvhu River Government Water Scheme". In the preamble to the White Paper, it is stated:

> *To the Minister of Water Affairs and Forestry: I have the honour to present herewith my report on the proposed Luvuvhu River Government Water Scheme to augment the water supplies to the Thohoyandou, Malamulele and Louis Trichardt regions of the Northern Province in terms of Section 58 of the Water Act (Act 54 of 1956).*

The following costs, in Table 4.7, are detailed in the White Paper for the whole scheme, including the cost of the Nandoni Dam. The costs are shown in March 1997 prices, and then adjusted to December 2012 prices using the CPI inflation index (see section 3.4.4 and Appendix B).

Table 4.7: Breakdown of the estimated cost of Nandoni Dam

White Paper description	Costs at Mar 1997 (in rand values)	Adjusted for Dec 2012 (In rand values)
Nandoni Dam	222,000,000	540,145,985
Relocation/infrastructure	74,200,000	180,535,280
Development and training	3,000,000	7,299,270
Subtotal (excluding VAT)	299,200,000	727,980,535
VAT @ 14%	41,888,000	101,917,275
Total (March 1997 prices):	**341,088,000**	**829,897,810**

(Source: DWAF, 1998b)

From costs that were provided by Johannes van Zyl (from Mr Louis Cronje) of the DWS in 2013, Table 4.8 presents the actual costs (in November 2008 rand values , and adjusted to December 2012 using the CPI inflation index) for the Nandoni Dam (see section 3.4.4 and Appendix B):

Table 4.8: Breakdown of the actual cost of Nandoni Dam

Description	Costs at Nov 2008 (in rand values)	Adjusted to Dec 2012 (in rand values)
Administrative costs	94 931 500	115 770 122
Housing and works buildings	17 575 200	21 433 171
Roads and bridges	4 612 700	5 625 244
Plant and equipment installation	1 363 800	1 663 171
Maintenance and running costs	23 833 300	29 065 000
Delays and waste	13 645 200	16 640 488
Claims and servitudes	27 420 700	33 439 878
Training	3 367 000	4 106 098
Dam construction	233 107 500	284 277 439
Relocation AP work done by DWAF	31 416 500	38 312 805
Contracts	140 717 300	171 606 463
Flood damage repairs	385 100	469 634
Other costs	540 800	659 512
Total (including VAT @ 14%):	**592 916 600**	**723 069 024**
Additional costs (in September 2012 rands)	5 527 404	5 588 882
Final Total (including VAT @ 14%):	**598 444 004**	**728 657 906**

(Source: DWA, 2013)

While Tables 4.7 and 4.8 both have a breakdown of costs, the line items are not directly comparable because the costs are broken down to different levels. Nevertheless, it is apparent that the cost of the Nandoni Dam has decreased from an estimated R830 million to R729 million, or 88 per cent of the original estimated cost.

While the actual cost of construction was less than expected cost, the O&M costs still need to be taken into account. Despite repeated efforts to get the actual O&M costs from the DWS, the only figures received (shown in Appendix C) indicated expenditure of the actual O&M costs received from the DWS for between 2007 and 2013 are just 0.29 per cent per annum on average of the actual cost of the dam (R729 million in December 2012 rand values). This is way below the DWS guidelines of about 4.25 per cent per annum (DWAF, 1996b). Actual O&M costs using the DWS guidelines have also been calculated for comparison and are shown in Appendix C. There is no logical reason to suppose that the O&M costs for Nandoni Dam would be just seven per cent of the DWS guideline costs. No explanation of this was forthcoming from the DWS. The estimated O&M costs for Nandoni Dam calculated using the DWS guidelines are shown in Appendix C (DWAF, 199b).

It is not sufficient only to look at the cost comparison. When Minister Kader Asmal (the then Minister of Water Affairs and Forestry) gave the Director General his approval to go ahead with the Luvuvhu River Government Water Scheme in 1998, it was on the basis of a return on investment from R830 million (converted to December 2012 rand values). This cost was for the delivery of an annual yield of 93.4 million cubic metres of water to the Thohoyandou, Malamulele and Louis Trichardt (now Makhado) regions of the Northern Province (now Limpopo).

Efforts to ascertain what the yield has been for each of the years that the dam has been operative, and to whom the water has gone, have proven to be unsuccessful. As will be discussed later, the fact that it was not possible to get data on the actual yield of the dam and importantly to whom the water has gone, is cause for concern. It would be reasonable to expect that water resource decision-makers would want to know whether what was projected to be the benefits have been realised, acknowledging that there may well be valid reasons for the changes.

The equity and sustainability requirements in the National Water Act (RSA, 1998) have not been met in the Nandoni Dam case. The pipes delivering the water to the intended beneficiaries were defective, and ten years after the construction of the dam was completed, the beneficiaries still do not have the promised water for basic human needs from the dam. However, the problems around the bulk water supply pipelines could not have been anticipated at the time of the proposal to the Minister (Molewa, 2014).

The impact of the dam and scheme on the inflow stream requirements for the ecological Reserve was not estimated at the time of the decision being taken, but was later done (CSIR, 2001). The level of siltation in the dam has been recorded as a low 0.07 per cent per year (DWAF, 2008).

4.4.3 Berg River Dam

The Berg River Dam (which was formerly known as Skuifraam Dam) was constructed on the Berg River, near Franschoek in the Western Cape, as part of the Berg Water Project. The Berg River Dam, shown in Figure 4.7, was constructed between 2005 and 2010.

Figure 4.7: The Berg River Dam nearing full capacity

(Source: unknown)

The purpose of the Berg River Dam is to augment Cape Town's domestic and industrial water supply (as well as the surrounding agricultural area), to ensure that, in the short and medium term, a water deficit doesn't occur (DWAF, 1998c). A summary of the main features of the Berg River Dam is shown in Table 4.9.

Table 4.9: Summary of the main features of Berg River Dam

Date of Construction:	
(a) Year of completion	2008
(b) Duration of construction (in years)	4
(c) Public or private design	Berg River Consultants
(d) Public or private construction	BRP Joint Venture
Storage data and use	
Anticipated storage volume in m^3 (FSC)	126,400,000
Live storage volume in m^3 (FSC)	122,000,000
Volume of sediment in reservoir	0
Planned users	Municipality / industrial
MAR	
(a) Natural catchment (m^3)	139,000,000
(b) Developed catchment (m^3)	115,600,000
Yield	
(a) When planned	56,000,000 m3/a
(b) Revised	Not revised
Further data	
Pre-development approvals	Decision to proceed
Current use	Municipality / industrial
Catchment area (sq. km)	77.03
Wall type	Concrete face rockfall dam
Wall height (m)	65
Spillway type	Side channel spillway
Crest Length (m)	2,215

(Source: Researcher's own construction)

The site of the Berg River Dam (near Franschoek), was considered as a potential dam site as far back as 1904 (Legge, 2012). The site has been considered many times since then and was prominent in the 1996 Systems Analysis document, *Water of the Western Cape* (DWAF, 1996a), which listed all the potential alternatives to supply water to the City of Cape Town and the surrounding areas. The alternatives, shown in Table 4.2, were listed with their expected yield and costs compared to the cost of the Palmiet Phase 1 Scheme. The Berg River was listed as having an estimated yield of 56 million cubic metres and a cost of 2.4 times more than the Palmiet Phase 1 (which had an estimated yield of 31 million cubic metres). In 1996, the public, through a public participation process (DWAF, 1996a), helped to select the Berg River Dam as one of the preferred infrastructure development options to provide water to the Cape Town area.

In 1998, the Department of Water Affairs and Forestry released a document as part of the Skuifraam (now Berg River) Dam Feasibility Study, called *Guidelines for Implementation* (DWAF, 1998a). The report was originally drafted as a White Paper. However, when a White Paper was no longer required for dams due to a change in law brought about by the promulgation on the National Water Act (RSA, 1998), it became part of the Berg River Dam's Feasibility Study suite of papers.

The following costs, in Table 4.10, are detailed in the *Skuifraam Dam Feasibility Assessment: Guidelines for Implementation* (DWAF, 1998a). The costs are shown in June 1995 prices and then adjusted to December 2012 prices using the CPI inflation index (see section 3.4.4 and Appendix B). Text Box 4 refers to a possible error in Table 4.10.

Table 4.10: Breakdown of the estimated cost of the Berg River Dam

Record of implementation decisions - description	Costs at June 1995 (in rand values)	Adjusted for Dec 2012 (in rand values)
Planning design and supervision	29 488 000	82 139 276
Preliminary and general	66 918 000	186 401 114
Preliminary works, access	383 210	1 067 437
Accommodation	7 500 0000	20 891 365
Fencing	30 400	84 680
Excavation	15 313 000	42 654 596
Solum preparation	735 000	2 047 354
Drilling and grouting	1 837 000	5 116 992
Embankment fill	58 931 000	164 153 203
Concrete works	116 524 000	324 579 387
Robertsvlei – drilling and grouting	4 015 000	11 183 844
Mechanical items for dam	9 000 000	25 069 638
Landscaping	6 196 000	17 259 053
Miscellaneous items	10 237 000	28 515 320
Contingencies	29 786 000	82 969 359
Pump station 2m^3/s	17 500 000	48 746 518
Pipeline to Dasbos 2m^3/s	10 200 000	28 412 256
Increase to outlet works capacity	11 500 000	32 033 426
Subtotal (excluding VAT)	396 183 610	1 103 324 819
VAT @ 14%	50 000 000	139 275 766
Environmental programmes, land costs and compensation	23,500,000	65,459,610
Total:	**469,683,610**	**1,308,310,891**

(Source: DWAF, 1998a)

Text Box 4: Breakdown of estimated costs of the Berg River Dam

There may be an error in Table 4.10, regarding the White Paper costs of the Berg River Dam. In 1995 Rands, VAT at 14% is given as R50 million. However, R50 million is equal to the 14% (VAT) on an amount of R357 142 857 (R50 million/0.14), and not the R396 183 610 (the subtotal of all the line items added together). The R50 million is equal to a VAT rate of 12.623%. It is assumed that the VAT figure was not a mistake, and is correct, in that some of the line items did not incur VAT. It is not apparent from the figures, and would have to have related to sub-components in the figures shown.

From costs that were provided by the Chief Director for the Western Cape in the DWS, in 2013, the figures in Table 4.11, for the actual costs of the Berg River Dam are already in December 2012 rand values , and therefore there is no need for adjustment (Khan, 2013).

Table 4.11: Breakdown of the actual cost of the Berg River Dam

Description	Costs at Dec 2012 (in rand values)
Construction – dam	665 399 744
Construction – supplement C21-A	306 638 494
Construction – supplement C21-B	69 085 789
Construction – supplement C21-C	148 310 487
Construction – infrastructure	53 698 300
Engineering – BRC	164 129 661
Engineering – DWAF	3 508 961
Engineering – others	17 900 827
Administration – staff cost	53 144 888
Administration – governance	6 731 731
Administration – public relations	40 898 765
Administration – facilities	25 352 621
Administration – financial services	27 401 395
Total:	**1 582 201 661**

(Source: DWA, 2013)

The fact that there are no line items in the tables of expected and actual costs that are directly comparable, shows the difficulty of trying to compare dams on a financial basis. This also begs the question, why the people in charge of keeping track of the costs of the dam have shown the costs in ways that are inconsistent and difficult to compare Nevertheless, the increase in capital costs from the expected cost of R1.31 billion at the planning stage to the actual cost of R1.58 billion represents an increase in costs of 20.93

per cent. Although significant, it is certainly better than in the case of De Hoop Dam (73.69% increase), raising the question of why this should be so. Next, the O&M costs need to be added.

The Berg River Dam estimated O&M costs are calculated using the DWS guidelines and are shown in Appendix A (DWAF, 1996b). The actual O&M costs (shown in Appendix C) received from the DWS consist of two categories – the first is the compensation of employees, and the second is goods and services. Although these do not align with the guidelines for the costs (which breaks the O&M costs down into 'civil works' and 'mechanical and electrical' components and are also calculated in Appendix C), the total average actual costs per annum are 0.28 per cent of the cost of the dam in December 2012 rand values . This is, once again, way below the guidelines of 4.25 per cent for such costs anticipated by DWS (DWAF, 1996b and Appendix A). Once again, no explanation was forthcoming form the DWS.

As with the Nandoni Dam case, it is not enough to look only at the cost comparison. When Minister Ronnie Kasrils (of the then Water Affairs and Forestry) gave his approval for the Berg Water Project to go ahead in 2001, he did so on the basis that the return on investment (on the cost of R1.31 million in December 2012 rand values) would be an annual yield of 57 million cubic metres of water for the City of Cape Town and surrounding areas. However, this is uncertain; for example, Van Niekerk (2013) found that in other IBT schemes that he studied retrospectively, there was little correlation between the amount of water that was expected to be transferred in the planning phase, and that which was actually transferred.

It should be noted that the Berg River Dam project was the first dam project in South Africa where specific provision was made to clear IAPs in the catchment of the dam. A budget of R21 million has been spent on the catchment (0.13% of the actual costs of the dam), although the Working for Water Programme would have put in a budget itself over the years. Furthermore, the Berg River Dam project was possibly the first dam project in South Africa where the design of the dam was changed to accommodate environmental water flows for the ecological Reserve (Pienaar & King, 2011).

4.4.4 De Hoop Dam

De Hoop Dam, shown in Figure 4.8, is on the Steelpoort River in the south-eastern part of Limpopo Province. The construction is finished, but approximately R50 million will be spent for site rehabilitation, security fencing and dam monitoring instrumentation, and will be completed in 2015 (R. Martin, personal communication, 9 April 2014). The construction of De Hoop Dam is Phase 2A of the Olifants River Water Resources Development Project (ORWRDP). The purpose of De Hoop Dam is also to supply water for domestic and industrial (mining) uses in the surrounding areas.

In 2003, President Thabo Mbeki announced during his opening of Parliament address that there was to be a dam constructed in the Olifants River Catchment to ensure adequate water supply for anticipated developments in the area. As this was the first that the then Department of Water Affairs and Forestry had heard of a proposed dam in this area, the implementation of the ORWRDP was placed on the fast track by Cabinet (DWAF, 2006). A summary of the main features of De Hoop Dam is shown in Table 4.12.

Figure 4.8: The De Hoop Dam nearing completion

(Source: Labuschagne, 2013)

Table 4.12: Summary of the main features of De Hoop Dam

Date of Construction:	
(a) Year of completion	2014
(b) Duration of construction (in years)	8
(c) Public or private design	DWA
(d) Public or private construction	DWA
Storage Data and Use	
Anticipated storage volume in m^3 (FSC)	347,400,000 (ORWRDP HR)
Live storage volume in m^3 (FSC)	0
Volume of sediment in reservoir	0
Planned users	Domestic / industrial
Mean annual runoff (MAR)	
(a) Natural catchment (m^3)	134,000,000 (ORWRDP Hydro Report)
(b) Developed catchment (m^3)	116,000,000 (Info brochure)
Yield	
(a) When planned	80,000,000 m3/a (RID)
(b) Revised	64,000,000 revised
Further Data	
Pre-development approvals	Record of implementation decisions S110
Current use	None - pipelines are still being installed.
Catchment area (sq. km)	2,865
Wall type	RCC gravity
Wall height (m)	88
Spillway type	Uncontrolled stepped central ogee
Crest length (m)	1,015

(Source: Researcher's own construction)

The following costs, in Table 4.13, are found in the ORWRDP Phase 2A (Dam on the Steelpoort River at De Hoop): Record of Implementation Decisions (DWAF, 2006). The costs are shown in June 2005 prices and then adjusted to December 2012 prices (see section 3.3.4).

Table 4.13: Breakdown of the estimated cost of De Hoop Dam

Description	Costs at June 2005 (in rand values)	Adjusted for Dec 2012 (in rand values)
Net construction costs	632,800,000	1,002,852,615
Contingency provision	85,500,000	135,499,208
VAT (14%)	100,600,000	159,429,477
Subtotal	818,900,000	1,297,781,300
Other Costs:		
Graves & archaeological work	3,000,000	4,754,358
Valuator, survey & land acquisition	50,000,000	79,239,303
Public participation consultant	5,000,000	7,923,930
Relocation of utilities (Eskom & utilities)	10,000,000	15,847,861
Relocation of provincial road R555	96,000,000	152,139,461
Professional fees		
(a) Environmental Control Officer / EMC	3,000,000	4,754,358
(b) Site supervision including site transport	65,000,000	103,011,094
(c) Review panel	1,000,000	1,584,786
(d) Disputes Review Board	5,000,000	7,923,930
(e) Pre-qualification	300,000	475,436
(f) Implementation financing	1,500,000	2,377,179
(g) Consultant planning	300,000	475,436
(h) Road consultant (fees & disbursements)	6,300,000	9,984,152
Trial quarry	1,000,000	1,584,786
Subtotal (excluding VAT)	247,400,000	392,076,070
VAT @ 14%	34,600,000	54,833,597
Total other costs	**282,000,000**	**446,909,667**
Construction costs	**818,900,000**	**1,297,781,300**
Total costs	**1,100,900,000**	**1,744,960,967**

(Source: Researcher's own construction)

The De Hoop Dam is still under final construction. The actual cost of the dam has been extrapolated from the costs to date that were provided by the De Hoop Dam Project Manager in the DWS (Martin, 2014). The costs are shown in November 2014 prices and have been converted into December 2012 prices, so as to be comparable with the other dams. The actual cost of the De Hoop Dam is forecast to be R3.370 billion in November 2014 rand values , or R3.031 billion in December 2012 rand values . This is a 74 per cent increase, when compared to the expected costs of R1.745 billion (in December 2012 rand values).

In addition to the increase in the costs, a decrease in the benefits (estimated water yield) occurred. In the record of implementation decisions (RID) report for De Hoop Dam, the yield was originally said to be 80 million cubic metres per annum (DWAF, 2006b). In 2009 the DWS commissioned the Olifants Reconciliation Strategy to study the management and infrastructure options to meet the growing water demand in the catchment up to 2030, as well as to recalculate the yields of the De Hoop and Flag Boshielo Dams (DWA, 2010). The De Hoop Dam yield was recalculated as 64 million cubic metres per annum. This represents a twenty per cent decrease in the planned benefits. The reasons given for this significant change were new information, better water-use information (upstream irrigation use) and updated hydrology (DWA, 2010). In summary, DWS was anticipating getting an annual yield of 80 million cubic metres per annum for R1.745 billion, but now anticipate getting 64 million cubic metres per annum for R3.031 billion – in essence, a 217 per cent increase in the cost per volume.

From the interviews conducted with senior managers within the DWS (see Chapter 6), some of the reasons for the significant increases in the cost of the De Hoop Dam were the lack of infrastructure development capacity at the time (owing to competing demand for the 2010 World Cup infrastructure), the economic downturn of 2008 stifling the development of mining operations (which were meant to contribute towards the budget), the need for greater foundations than had been anticipated, a prolonged strike by construction workers, and an unanticipated level of rainfall. Another factor mentioned was the slow rate of work and pouring concrete, due partially to those people employed on contracts (under section 76 of the National Water Act) outside the provisions of the Public Service Act 103 of 1994. These employees are limited to actual work relating to construction of a DWS infrastructure project. There were times, however, when the speed of pouring concrete was exceptionally fast (Water and Sanitation Africa, 2012; Van Niekerk, 2012) and in the interviews it was questioned whether progress was deliberately slowed down to have work for those responsible for the construction.

For the URV calculations, the O&M costs need to be added to these construction costs. Since the De Hoop Dam has not started operating yet, there are no actual O&M costs, so the DWS O&M guidelines are used for both the estimated and actual O&M costs (DWAF, 1996b and Appendix A). The O&M costs for the De Hoop Dam are shown in Appendix C.

4.5 SUMMARY OF DATA

A summary of the data necessary to calculate the URVs of the four selected schemes (the Inyaka, Nandoni, Berg River and De Hoop dams) is shown in Table 4.15. The data shown in Table 4.15 includes the estimated and actual costs of construction of each dam, as well as the MAR and yield of each dam.

The estimated and actual costs are shown with a time dimension aspect, in two columns. The first shows the cost data in the year the costs were occurred. The second shows the costs when they have been brought to 2012 rand values to eliminate inflation bias so that the costs of the dams may be compared equally.

Inflationary differences are removed by converting the estimated costs (from a1 to a2, in Table 4.15) and actual costs (from b1 to b2, in Table 4.15) to December 2012 rand values. This is done using the CPI headline index (Statistics South Africa, 2015) as the guideline document on inflation in South Africa over the past 50 years (shown in Appendix B). The formula to convert a cost from its original time period to the chosen time period (in this case December 2012, which is the base year, in other words equal to 100) is: cost in year it occurred divided by the CPI of that year times the CPI of December 2012. This can also be written as: December 2012 Cost = Cost in year A / CPI in year A x December 2012 CPI.

An example of this is converting the estimated cost of the De Hoop Dam to December 2012 rand values: Cost is R 1 101 million in June 2005 rand values and the CPI for June 2005 is 63.1. CPI in December 2012 is 100. Therefore cost of the De Hoop dam in December 2012 rand values is: R 1 101/63.1*100 = R 1 745 million.

All the cost data in Table 4.15, except for the actual cost of the Berg River Dam, are from the records of the DWS. The actual cost of the Berg River Dam is from the record of the Trans Caledon Tunnel Authority (TCTA), which is a state-owned entity the DWS contracted to build the Berg River Dam. Part of the uncertainty of the costs is that there are other costs that may not be quantified, for example the cost to the DWS of supervising the TCTA.

Table 4.15: Summary of the data for the calculation of URVs

	Berg River Dam		De Hoop Dam		Inyaka Dam		Nandoni Dam	
Estimated Costs (in Million ZAR) and relevant dates								
(a) At planning stage	469.68	June 1995	1,100.90	June 2005	234.38	March 1994	341.09	March 1997
(a) Converted to 2012 rands	1,308.31	Dec 2012	1,744.69	Dec 2012	732.44	Dec 2012	829.90	Dec 2012
Actual Costs (in Million ZAR) and relevant dates								
(b) At the end of construction	1,582.20	Dec 2012	3,370.00	Nov 2014	305.00	June 2002	598.44	Nov 2008
(b) Converted to 2012 rands	1,582.20	Dec 2012	3,030.58	Dec 2012	536.97	Dec 2012	728.66	Dec 2012
MAR (Million m^3/a)	115.60		116.00		78.95		130.00	
Yield (Million m^3/a)	56.00		64.00		41.20		93.40	

(Source: Researcher's own construction)

To understand the data in Table 4.15, the quality of the sources of the data is relevant. In Table 4.16 the sources of the data are indicated, and whether or not a breakdown of the costs is available. A lack of official published documents as the source of data must diminish confidence in its integrity. Similarly, a lack of a breakdown of the costs would inhibit the confidence of the analysis. It has not been possible to clarify whether the data collected has been audited by the Auditor General.

Table 4.16: Integrity of data

Dam	Cost Data	Source	Breakdown of costs
Inyaka Dam	Estimated capital costs	DWS White Paper	Yes - Partial
	Actual capital costs	Single DWS total	No
	O&M costs	Incomplete DWS time series	No
Nandoni Dam	Estimated capital costs	DWS White Paper	No
	Actual capital costs	Detailed DWS breakdown	Yes
	O&M costs	DWS time series	No
Berg River Dam	Estimated capital costs	DWS RID report	Partial
	Actual capital costs	Long-term cost plan	Partial
	O&M costs	DWS time series	Partial
De Hoop Dam	Estimated capital costs	DWS RID report	Partial
	Actual capital costs	Single DWS total	No
	O&M costs	Not applicable	n/a

(Source: Researcher's own construction)

4.6 UNIT REFERENCE VALUE (URV) ANALYSIS OF SELECTED DAMS

As discussed under 3.4.4 in Chapter Three, URVs are a type of CBA used in water infrastructure decision-making. URVs show the infrastructure cost per cubic metre of water. For example, a URV of one indicates that the cost of delivering a cubic metre of water is one rand. While URVs can be calculated for an entire scheme, standard practice is to calculate the URV at the point where the water leaves the dam (abstraction point). The formula used for calculating URVs is shown in Figure 3.2 and the necessary assumptions for the calculations are listed under 3.4.4 in Chapter Three.

From these assumptions and using the yields, estimated and actual construction and O&M costs (in December 2012 rand values) and the DWS document, *Guidelines for the economic life, and annual operational and maintenance costs* (DWAF, 1996b & Appendix A), the expected and actual URVs for the four chosen dams can be calculated. These URVs are shown in Table 4.17. The Nandoni and Berg River Dam have two actual URV calculations each to shown the difference between the O&M costs from the available DWS data (Appendix C) and the DWS guidelines (DWAF, 1996b, Appendix A). The De Hoop Dam has two calculations to show the actual difference in the URV calculation that resulted from the estimated yield decreasing twenty per cent between planning (De Hoop Dam URV 2) and building the dam (De Hoop Dam URV 1).

The reason that the “difference as a %” calculations are the same for the different discount rates (six, eight and ten per cent in Table 4.17) for calculations using the DWS guidelines to calculate O&M costs, is because the change (the fixed discount rate) in the costs and yield is constant. What is important is the level of difference shown, for example, the De Hoop Dam has a difference of 73.71 per cent which is more than double that of any of the other dams.

Table 4.17: URVs of the estimated and actual costs of the selected dams

Summary of estimated and actual URV calculations				
	Discount rate	**6%**	**8%**	**10%**
			(in Rands/m³)	
Inyaka Dam	URV: estimated	1.43	1.54	1.64
	URV: actual	1.05	1.13	1.21
	Difference	-0.38	-0.41	-0.44
	Difference as a %		-26.69%	
Nandoni Dam	URV: estimated	0.71	0.77	0.82
	URV: actual 1 (based on guidelines)	0.63	0.67	0.72
	Difference	-0.09	-0.09	-0.10
	Difference as a %		-12.20%	
	URV: actual 2 (based on DWS data)	0.43	0.50	0.57
	Difference	-0.29	-0.27	-0.26
	Difference as a %	-40.35%	-35.23%	-31.22%
Berg River Dam	URV: estimated	2.11	2.34	2.56
	URV: actual 1 (based on guidelines)	2.55	2.82	3.10
	Difference	0.44	0.49	0.54
	Difference as a %		20.93%	
	URV: actual 2 (based on DWS data)	1.66	2.00	2.33
	Difference	-0.44	-0.33	-0.23
	Difference as a %	-21.05%	-14.30%	-8.97%
De Hoop Dam 1	URV: estimated*	2.04	2.18	2.32
	URV: actual	3.55	3.79	4.02
	Difference	1.51	1.61	1.71
	Difference as a %		73.71%	
De Hoop Dam 2	URV: estimated*	1.69	1.80	1.91
	URV: actual	2.93	3.13	3.32
	Difference	1.24	1.33	1.41
	Difference as a %		73.71%	

*De Hoop 1 is based on a yield of 66 million m^3 and De Hoop 2 on a yield of 80 million m^3

(Source: Researcher's own construction)

What Table 4.17 reveals is that there is a great deal of variation between and within the URVs of the four dams. The calculations of the URVs for both the Inyaka and Nandoni dams show that the actual URV was lower than the estimated URV. Inyaka has a difference between the estimated and actual URVs of negative 26.69 per cent. The Nandoni Dam, meanwhile, has a difference of negative 12.20 per cent if the DWS guidelines are followed for O&M costs, but a much larger difference (negative 35.23 per cent at an eight per cent discount rate) if the DWS O&M data is used. These variations occur because the DWS O&M data is not consistent from year to year and because the O&M costs from the DWS guidelines are significantly more than from the data. For the same reasons, the Berg River Dam also has large differences between the calculations using the guidelines (20.93 per cent) and the DWS data (negative 14.30 per cent at an eight per cent discount rate). The big difference between the actual URV calculations for the Berg River Dam (R0.82 per cubic metre) when compared to the Nandoni Dam (R0.17 per cubic metre), is possibly due to the Berg River Dam's O&M costs (from DWS) being higher compared to the capital cost, than the same comparison for the Nandoni Dam.

Furthermore, the De Hoop Dam calculations show, firstly, that the dam has the highest difference between estimated and actual URVs and secondly, that the twenty per cent decrease in estimated yield has increased the URV calculations in real terms by 28 cents a cubic metre at an eight per cent discount rate (from R1.33 to R1.61).

The URVs show that a cubic metre of water, in December 2012 rand values, using actual costs data and an eight per cent discount rate, is least expensive from the Nandoni Dam (between R0.50 and R0.67) and most expensive from the De Hoop Dam (initially R3.13 and then up to R3.79 when the yield was recalculated), even though it was the most recent of the dams to be built, showing the need for institutional learning in the DWS. Inyaka Dam (R1.12) and Berg River Dams (between R2.00 and R2.82) were between the extremes. In the Nandoni and Berg River Dam cases the ranges are due to the differences between DWS data and guideline based O&M costs.

4.7 FURTHER ISSUES RELATING TO THE SELECTED DAMS AND THEIR URVS

In terms of the broader purpose of this study – water supply development decision-making in South Africa, and specifically the comparison of between the costs and benefits of dams and catchment management options – the pertinent comparison would not just be the cost of the dam, per se, but the cost of the full scheme. It would appear that here the costs may be more difficult to predict, and in fact the accuracy of the opportunity costs may be different than those just for the dam. For example, the Nandoni White Paper (DWAF, 1998b) put the estimate of the cost of development and training at R3 million (adjusted to R7.3 million in December 2012 rand values), whereas the actual expenditure for this has been R4.1 million – 56.2 per cent of the expected cost. An additional complication, for example, in the Nandoni Dam case is that other parts of the scheme, such as the pipelines, have not yet been completed nearly ten years after the dam was built – and thus the full benefits have not yet materialised (Molewa, 2014).

The creation of jobs in the construction and maintenance of dams is an important consideration that did not feature in the Nandoni White Paper or official policies of the then Department of Water Affairs and Forestry, but have nevertheless been extremely valuable in a country with such high unemployment and poverty. It is now a major focus in the National Development Plan (2012), and can be expected to be monitored and reported upon by the Department.

Furthermore, it does not appear that there were there any real trade-offs offered to the Minister in the White Paper of the Nandoni Dam, as alternatives to building the dam. The Luvuvhu River Dam Feasibility Study (DWAF, 1997) resulted in a systems analysis of the Luvuvhu River that showed a number of alternative dam sites and their suitability; however, the feasibility study did not look at other non-dam alternatives. It is not clear if there were viable non-dam options in the area, which could have met the supply and demand needs of those being served (including options for DSM and unaccounted-for water). It was also not clear if there were any other existing dams on the Luvuvhu River that could absorb additional water flow, especially during low-flow periods. The DWS Dam Safety Office's List of registered Dams (DWA, 2011) shows that there are four other dams on the Luvuvhu River, all of which were built before the Nandoni Dam and one of them, the Albasini Dam, is a Category Three dam.

In the case of Nandoni Dam, it is therefore not possible to look at the costs of the full scheme, and the projected benefits, and to make a comparison with catchment management options that might have been considered at the time. However, in terms of the costs of the dam itself, it would appear that the costs that the then Director General presented to the then Minister were a significant underestimation, and did not afford the Minister the opportunity to make a sufficiently informed decision.

The wisdom of delaying the building of dams is not only the deferring of costs, but the fact that one might be able to remove the last dam(s) from the proposed development list in a catchment entirely, through investing in catchment management and other interventions (for example, DSM). The potential savings of not having to build those final dams are substantial – more so because inevitably they are the most expensive, and least favourable, dam options.

The knock-on costs of a dam should be part of the decision-making for comparison purposes. For example, the building of the Berg River Dam did lead to a need for a further water-purification plant, which cost a further R1 billion. If IAPs had been cleared in catchments and riparian zones, it is not clear whether further purification would have been necessary, although it possibly would have been. However, for DSM and unaccounted-for water, there would not have been a need for water purification, making the comparison so much more favourable for that option.

Lastly, it is apparent from the calculations that a limitation of URVs is that they do not adequately take the long-term costs and benefits of different options into consideration, primarily because water supply does not grow with interest and therefore, in reality, cannot be discounted to a present value (Mullins et al., 2007).

4.8 DISCUSSION OF RESULTS

The point must be raised that decision-makers act on the basis of available information, and it is disconcerting to discover that a retrospective analysis of these costs and benefits is so difficult to uncover. It would be logical to think that the DWS, the National Treasury and the Auditor General would want well-documented analyses of decisions to build dams, and auditing of the cost-effectiveness of these decisions. Relevant to this is that political decision-makers are asked for a decision on a dam or scheme, based on plans that may later change (and where decision-making is delegated to officials).

Furthermore, it is difficult to access cost data for dams in South Africa (estimated cost data is easier to find than actual cost data). This is especially so for estimated cost data for dams planned during the 1990s (such as Inyaka Dam and Nandoni Dam), when plans known as White Papers were required and published by the Government before permission to construct the dam was granted. Since after the Nandoni White Paper was published in 1998, the National Water Act (36 of 1998) was promulgated, and White Papers have been replaced by RID reports. Even the new RID reports are not readily accessible. The RID report for the Berg River Dam (that was originally drafted as a White Paper) and called the '*Guidelines for Implementation*' was not held by the DWS or the TCTA (the state-opened entity that built the dam), but rather it was found in the archives of an engineering firm that was involved in the project (E. Van Der Berg, personal communication, 22 August 2013). The difficulty in securing data, despite the willingness of officials in DWS to assist, is a problem that will continue to compromise the assessments of decisions made in the public's interests. This underlines a lack of acceptable archiving and curation within the DWS.

Another issue is that there is no consistent way of displaying costs (even for White Papers), and this makes it harder to know if the same costs are being shown when comparing the estimated and actual costs of a dam. This then makes the comparison of estimated and actual costs more complicated and uncertain. Added to this is the inconsistent availability of O&M cost data, especially considering how difficult this data was to get hold of. Obtaining O&M data for the three dams (not including De Hoop Dam as it has not yet incurred these costs) took nearly two years of repeatedly contacting the DWS head and regional offices. Considering that O&M costs are yearly governmental expenditures that are ratified by National Treasury, they should be readily available.

Added to the inconsistent availability of O&M cost data, there is a lack of information regarding the actual annual yield (the benefits) from dams in South Africa. Although the assurance of supply (having the water available) is a key consideration, dams are built on the promise of yield. While weekly reporting of the water levels in large dams across the country does occur, there is little evidence of actual yield justifying decisions.

4.9 CONCLUSIONS

The first objective of this study is to calculate and evaluate the variation between estimated and actual URVs for a selection of water supply infrastructure schemes. To achieve this objective an understanding of cost-benefits analyses within a water supply development context was presented. Then the estimated and actual URVs for four case study dams (the Inyaka, Nandoni, Berg River and De Hoop dams) were analysed and discussed.

A first important conclusion from this chapter is the difficulty that was experienced in obtaining water resources data from the DWS. Obtaining expected and actual construction costs as well as O&M costs for the four cases from the DWS turned out to be time-consuming and challenging as data was often not readily available, or, in the case of the Inyaka Dam's O&M costs, incomplete. Furthermore, there is uncertainty that not all incurred costs were reflected in the actual costs. Whether this is true, and whether it would have further increased the actual costs, can only be speculated upon.

A second important conclusion is that there is considerable variation between the estimated costs (at the time that the decision to build the dams was taken) and the actual costs of building the dams. In addition to the capital costs the URV analysis used DWS O&M guidelines costs in all four cases and additional DWS O&M cost data in the Nandoni and Berg cases. The unit reference value (URV) analyses, using an eight per cent discount rate, revealed that both Inyaka (27 per cent less expensive than planned) and Nandoni (twelve per cent less expensive when O&M guideline costs were used; or 35 per cent less expensive when available O&M data costs were used) cases the actual cost was less than expected. In the Berg River case, the actual cost was 21 per cent more than expected when O&M guideline costs were used; but fourteen per cent less than expected when available O&M data costs were used. This was possibly due to big difference between the O&M costs from the guidelines and the data. The De Hoop Dam URV calculation was the highest by a long way (74 per cent more expensive than estimated); however this was further exacerbated in real terms by an eighteen per cent decrease in estimated yield.

A third conclusion is that the URV analysis is a limited tool in that it does not adequately take the long-term costs and benefits of different options into consideration. The clearest example of this limitation is that yield does not grow with interest and therefore, in reality, cannot be discounted to a present value. Nevertheless it was found that, at an eight per cent discount rate, and in December 2012 rand values, the actual cost of water is getting more expensive in real terms. Unit reference values estimated that water cost per cubic metre is: R1.13 from Inyaka Dam, R0.50 to R0.67 from Nandoni Dam, R2.00 to R2.82 from Berg River Dam and R3.79 from the De Hoop Dam.

The final conclusion of this chapter is that externalities were, at best, a limited consideration in the costs of the four cases. Other than for the Berg River Dam, none of the estimates included an analysis of the catchment management alternatives (or supplementary action). None of the proposals to the relevant Minister included a budget for a concurrent DSM intervention, although this was mentioned in the case of the Berg River Dam. None of the proposals looked at the conservation of supply in terms of aspects such as leaks, aging distribution infrastructure and other aspects of unaccounted-for water.

In the following chapter (Chapter Five), an analysis of the costs and effect of IAP management, in the catchments of the dams analysed in this chapter, is presented.

CHAPTER FIVE

AN ANALYSIS OF INVASIVE ALIEN PLANT (IAP) MANAGEMENT AS A WATER SUPPLY OPTION IN SELECTED CATCHMENTS

5.1 INTRODUCTION

The second objective of this study is to analyse the costs and benefits of IAP management as a water supply option. The costs and water benefits of IAP management, as a component of water conservation and enhancement of existing supplies of water, are analysed in this chapter. Although only IAP management is considered, other options are mentioned so as to provide a broader context for the multiple approaches needed in water supply optimisation. The catchments of the four dams analysed in Chapter Four are the case studies for the analysis.

Systematic review of past decisions (and decision-making processes) and their associated actual costs and benefits can assist future decision-making and reduce cost escalation by building institutional knowledge. Opportunity costs associated with the estimated and actual costs of building a dam and other infrastructure projects should be included in such reviews. Opportunity costs estimate the costs of alternatives that were forgone in the decision to build infrastructure, in other words, other potential interventions that could have been considered by the decision-makers at the time of the decision.

The Minister of Water and Sanitation is identified in the National Water Act 36 of 1998 as the principal water resource decision-maker. The Minister is supported in decision-making by officials in the DWS. The National Treasury, Department of Environmental Affairs, Department of Economic Development and the relevant provincial government(s) also contribute to decision-making processes. Although the Minister of Water and Sanitation has to submit the recommendations to the Cabinet for final approval, the principal decision will have been taken by the Minister. This would include opportunity cost considerations.

Decisions about water supply systems are complex and are best approached by evaluating multiple options rather than just a single option. If infrastructure development is implemented alongside other options, it could increase and optimise the water-mix (a combination of demand and supply options) to meet the national requirements for water.

The second *National Water Resources Strategy* (DWA, 2013b) states that the water-mix needs to be diversified, and lists a number of possible additional options, such as desalination and water re-use. A further additional option is IAP clearing (Le Maitre *et al.,* 2009). It is possible for infrastructure decisions to include a directive for associated IAP clearing as was tested when the Berg River Dam was built (Geland *et al.,* 2008). Inclusion of water-mix options can contribute to the vision of equity and sustainability that the National Water Act (36 of 1998) is based upon, by ensuring that any gaps between the demand and supply of water are managed and ultimately reduced to ensure a healthy water balance while also creating job opportunities (DWA, 2013b). A benefit from diversifying the water-mix may be creating jobs, which is imperative in South Africa, with its high unemployment and low skill levels (Statistics South Africa, 2014).

In South Africa, there are chronic imbalances in terms of poverty, unemployment and inequity (National Development Plan, 2013). The relative benefits for the poor, particularly in terms of temporary and long-term employment opportunities, would have been a factor when the then Minister (of Water Affairs and Forestry) and the senior departmental officials weighed up alternatives for water supply enhancement options. It is argued here that decision-makers considering a proposal for the augmentation of water supply through infrastructure development (for example, dams and/or inter-basin transfers), should consider other options as well. These other options are, according to the second *National Water Resources Strategy* (DWA, 2013b), part of a water-mix designed to meet the increasing water needs in a sustainable and cost-effective manner. Maintaining this diversity of options for securing the limited, remaining supply is a necessity, as surface water infrastructure development will be insufficient to meet the growing water needs in South Africa (DWA, 2013b).

A number of other water-mix options to enhance supply, for example groundwater management, desalination and IAP management, are presented in the National Water Resources Strategy 2 (DWA, 2013b) and in the *Water for Growth and Development Framework: Volume 7* and its appendices (DWAF, 2009a; Le Maitre *et al.,* 2009). These water supply enhancement options are discussed under 5.3 to give a broader context to IAP management, which is the focus of this chapter. A discussion of IAP management is presented under Section 5.2.

5.2 INVASIVE ALIEN PLANT (IAP) MANAGEMENT IN CATCHMENTS

In this chapter, a specific catchment management-based alternative, namely the control of IAPs, is considered for the catchments of the four dams that were analysed in Chapter Four. The impact of IAPs on water availability in South Africa is an important consideration for any catchment with water infrastructure development plans because IAP management is a relatively inexpensive option to ensure that low flows in rivers are sustained (Le Maitre *et al.,* 2002; Van Wilgen *et al.,* 1997); it can lessen the impacts of soil erosion and fires (Le Maitre *et al.,* 2002; Euston-Brown, 2000, Le Maitre *et al.,* 1996); it increases yield (Marais & Wannenburgh, 2008; Le Maitre & Gorgens, 2003); the potential costs of not clearing IAPs are extremely high (Marais & Wannenburgh, 2008; Le Maitre *et al.,* 2002); and it derives social benefits from creating jobs (Le Maitre *et al.,* 2002).

The Jan Dissels River in Clanwilliam (in the Western Cape), shown before and after the clearing of black wattles (*Acacia mearnsii*) and other invasive species by the Working for Water programme (WfW) in Figure 5.1, is an example of these benefits. Although no actual measurements were done, WfW estimates suggest that MAR would have been increased by at least 3 000 cubic metres per hectare per annum (C. Marais, personal communication, 3 April 2015), from this clearing. Furthermore, in-stream flow requirements in terms of the National Water Act (RSA, 1998) would have been enhanced and jobs created. To better understand the benefits of IAP management, the impact of IAPs and the use of IAP management as a catchment-based addition to the water-mix are now discussed.

Figure 5.1: The Jan Dissels River in a) 2000 (left) and b) 2013 (right)

(Source: a & b - Zimmermann, 2014)

5.2.1 The impact of IAPs on water in South Africa

Besides their impacts on agriculture, forestry and human health, biological invasions are also widely recognised as the second-largest global threat (after direct habitat destruction) to biodiversity (Van Wilgen *et al.,* 2008.)

IAPs are plants that have been introduced into the country from other parts of the world, and have been able to outcompete and displace indigenous plants (IUCN, 2000). Technically, they can be plants introduced from one part of a country into another part in which they do not occur. Some of these plants use more water than the plants they displace, and can have other impacts. These could include accelerating runoff and erosion, which affect water security (Van Wilgen *et al.,* 2008; Le Maitre, 2004). Many of these IAPs are introduced accidentally, but most of those that reduce runoff have been deliberately introduced, particularly by the forestry and nursery industries (Van Wilgen *et al.,* 2008). Some of these IAPs have been deliberately introduced by the state or by forestry companies, as commercial plantations (for timber), and by the nursery industry for domestic garden use (such as ornamental plants like *Lantana* hybrids). For example, *Acacia saligna*, *A. longifolia, A. mearnsii* and *A. cyclops* were all introduced between 1827 and 1858 for horticultural and botanic garden purposes and then disseminated for sand-stabilisation, tannin and timber uses by the state; *Pinus pinaster*, *P. radiata* and *P. halepensis* were introduced by the state for timber during 1680s, 1865 and 1830 respectively (Richardson *et al.,* 1992).

IAPs reduce the flow in all watercourses (Le Maitre *et al.,* 2009; Görgens & Van Wilgen, 2004; Le Maitre et al., 2002). Upstream, IAPs affect the quantity, quality and timing of water flows into a dam. Invasions downstream of dams influence releases needed from the dams, as well as for run-of-river abstractions. Furthermore, the water for the ecological Reserve (Rowlston, 2011) and supply to downstream users can be compromised by the water use of IAPs. This is especially important because riparian invasions, for example black wattles (*Acacia mearnsii*), use much more water than non-riparian invasions through higher rates of evapo-transpiration (Le Maitre *et al.,* 2015; Van Wilgen & Richardson, 2014; Dye & Jarmain, 2004).

The impact of IAPs on evapo-transpiration and runoff has been the subject of intense research (see Chamier *et al.,* 2012; Milton & Dean, 2010; Le Maitre *et al.,* 2009; Everson, *et al.,* 2007; Görgens & Van Wilgen, 2004; Richardson & Van Wilgen, 2004). That there is an effect is beyond dispute. However, it is a more complex matter to model the effects of different types of IAPs at different stages of their growth, in different terrains (such as aspect, slope, availability of water, soil type) in order to understand them.

The WfW programme has worked on an estimate that IAPs are currently using approximately seven per cent of South Africa's MAR annually (Van Wilgen *et al.,* 2008; Le Maitre *et al.,* 2000; Versfeld, *et al.,* 1998). A more recent estimate has reduced this figure to about five per cent of MAR (Le Maitre *et al.,* 2013). The DWS estimates that IAPs reduce yield by 695 million cubic metres per annum (DWA, 2013b). The reduction of available water by IAPs is particularly severe in the dry seasons, typically where the roots of the IAPs are able to access deeper water. When high evapo-transpiration rates occur, the IAPs affect the low-flows, which are particularly important for water security (Van Wilgen & Richardson, 2014; Dye & Jarmain, 2004; Görgens & Van Wilgen, 2004).

IAPs do not only reduce the quantity of water. They also have been shown to affect water quality, wildfires, soil erosion, flooding, siltation, the productive use of land, the ecological functioning of natural systems, diseases, biological diversity, human wellbeing (for example, tourism, aesthetics, safety, property values), and more (Euston-Brown, 2000). Certain of these effects are most pertinent in water management decision-making, such as the reduction in water quality (see Chamier *et al.,* 2012; Van Wilgen & De Lange, 2011; Richardson & Van Wilgen, 2004).

Wildfires are particularly important, as the seeds of the invasive species are usually better able to withstand the intensity of the fires than the indigenous species they displace (Van Wilgen, 2009; Euston-Brown, 2000), and they use fire for germination. This means that each wildfire in an invaded area will lead to greater invasions, and worse fires in years to come (Chamier *et al.*, 2012, Le Maitre *et al.,* 2009; Van Wilgen, 2009). Longer periods without ground cover lead to acceleration of the rates of soil erosion. It has also been shown that the intensity of alien-fuelled fires can lead to changes in the chemical composition of soils, making them more water-repellent (Chamier *et al.,* 2012; Le Maitre *et al.,* 2009; Euston-Brown, 2000), leading to further erosion. An example of IAPs dominating a landscape can be seen in Figure 5.2, which shows pine trees invading the landscape (with gum and wattle trees in the foreground).

Figure 5.2: An example of IAPs dominating a landscape

(Source: Marais, 2013)

These additional impacts, such as water quality, wildfires, soil erosion and siltation, have not been the focus of this study, but are acknowledged as factors that should be considered by decision-makers when comparing alternative water supply options.

5.2.2 IAP management as an addition to water-mix

To enable the decision-makers to make informed decisions concerning water supply, they need to understand the impacts of IAPs may have on yield and in-stream flow requirements. The following are some questions that should be considered. To what extent can the management of IAPs in the catchments of existing dams improve water security? What are the long-term implications of not doing this clearing, given the propensity of invasive plants to spread and grow? What happens when the indigenous plants grow back (increasing transpiration of water), or when wildfires occur in the area? How do these cyclical events of fires and re-growth affect planning for water security? (Meijninger & Jarmain, 2014; Marais & Wannenburgh, 2008; Cullis *et al.,* 2007; Blignaut *et al.,* 2007; Görgens & Van Wilgen, 2004; Brooks *et al.,* 2004; Le Maitre *et al.,* 1996). It is thus critical to consider the implications of not clearing IAPs.

The implications of not clearing IAPs include their spread, growth and reproduction, and the consequent effects on water quantity, quality and security (Chamier *et al.,* 2012; Van

Wilgen *et al.,* 2008; Le Maitre & Görgens, 2004; Richardson & Van Wilgen, 2004; Le Maitre *et al.,* 2000). Modelling suggests that climate change will exacerbate the spread of many invasive species, but may decrease the invasiveness of other species and could perhaps lead to species that are currently not invasive becoming invasive (Schulze, 2012; McNeely *et al*., 2001). Moreover, the levels of evapo-transpiration by invasive plants may increase as a result of climate change, thereby further threatening the long-term security of dams (Kgope *et al.,* 2010). There was, however, insufficient IAP data available to analyse IAP spread in the dam catchments before the case study dams were built. Furthermore, in-depth analysis of larger areas according to these questions is beyond the scope of this thesis, although clearly relevant for decision-making.

Water resource planners need to understand the dynamics of IAP invasions. Clearing IAPs is not a once-off cost. The WfW programme takes an estimate that the follow-up clearing costs will be as much again as the initial clearing costs (C. Marais, personal communication, 3 April 2015). The seed banks of many invasive species are long-lasting (Van Wilgen, 2009) and once an area has been invaded, it will require almost permanent follow-up clearing. Furthermore, a wildfire can lead to a massive germination of invasive seeds, requiring an almost immediate clearing response if the gains are to be maintained. Timing of the clearing is particularly important. For example, it can be between three and twenty times less expensive to clear a light invasion than a heavy invasion (Marais & Wannenburgh, 2008). It has been shown that, as plants continue to invade watersheds, the costs to clear them increase disproportionately (Cullis *et al.,* 2007; Larsen *et al.,* 2001).

The disproportionate increase in costs is influenced by a number of other factors including: growth of the invasion; the type of plant being cleared such as tree, creeper, shrub, and their related clearing methods; the location and ease of access to the invasion (for example, mountainous versus flat areas); density of the invasion; herbicide requirements; options for biological control; the number of follow-up clearings required; and secondary invasions by other species (Marais & Wannenburgh, 2008; Van Wilgen *et al.,* 2008; Marais, *et al.,* 2004; Richardson & Van Wilgen, 2004; Le Maitre *et al.,* 2002).

Other consequences of not clearing timeously have long-term costs, such as greater follow-up costs. For example, the seed banks of IAPs can be established in areas they might not otherwise have reached had clearing been done when the plants were establishing themselves. They are difficult and expensive to clear, can last for decades, are germinated by fires (for example, *Pinus* and *Hakea* species), and may have allelopathic properties (for example, *Eucalyptus* species) that inhibit the growth of other species. Furthermore, an immediate response to control the spread of seedlings after a wildfire is difficult (Van Wilgen, 2009). Soil erosion will also worsen as the result of fires and poor land management with scouring of rivers, siltation, slippage and flooding as the consequences (Richardson & Van Wilgen, 2004; Euston-Brown, 2000; Richardson *et al.,* 1986). Soil erosion and the resulting siltation of downstream dams quickly becomes more expensive to manage. For example, Mount Fletcher Dam on the Thina River in the Eastern Cape, which was finished in 2008, lost 70 per cent of its full supply capacity by 2012 due to siltation from over-grazing, wildfires and IAPs (CSIR, 2013; Gordon & Muller, 2010).

It is possible that a threshold will be reached where it is no longer feasible or affordable to clear the mountains of the IAPs (Richardson & Van Wilgen, 2004). If this threshold was reached, biological control would remain an opportunity, and would have to be considered along with possible consequences for the plantation industry (Van Wilgen & De Lange, 2011; De Lange & Van Wilgen, 2010). It would be an ironic reminder of the consequences of not dealing with invasions timeously – namely that the forestry industry may be at risk for failing to take responsibility for invasions from their plantations.

5.2.3 Criticisms of the theory and practice of IAP management

There had been some scepticism regarding both the theory and the practice of the management of IAPs for water security benefits, particularly driven by researchers in the employ of the forestry industry (Grafton, 1997). The past practice of siting plantations around dams was an indication that there was a belief that “trees bring rain” (Van Wilgen, 2012). Precipitation recycling may be true in some localised ecosystems such as the Amazon, where evaporated water falls as rain (Eltahir & Bras, 1994). However, as early as 1945, Professor Wicht had reported that plantations reduce stream flow (Van Wilgen, 2012). With the advent of the WfW programme in South Africa in 1995, research was done demonstrating that plantations do impair water security (Scott *et al.,* 2000; Van Wilgen *et al.,* 1997), leading to a change in the payment for water for stream-flow reduction activities in the late 1990s (DWAF, 2002; Grafton, 1999).

Research results did not fully stop the questioning of the value of clearing of invasive alien species for water benefits, as was debated at the United States–South Africa Binational Commission meeting on IAPs in 2000, where all the evidence that was put forward indicated that IAPs do reduce water security (see Muller & Le Maitre, 2000).

The challenge for scientists is that there are so many variables to consider, and testing for each is difficult and expensive. For example, one can do a paired-catchment study to compare invasions in one catchment to a lack of invasions in the other. But that can change from species to species of IAPs, and the situation is affected by other variables such as slope, soil, wetlands, age of the IAPs, the species they displace.

Specialists in the DWS are now incorporating the management of IAPs into their considerations (DWA, 2013b). It would thus appear that it is no longer officially contested that IAPs impair water security.

Hosking *et al.* (2002) analysed the water benefits of several WfW projects in the Eastern Cape, and concluded that they were not cost-effective. However, they used a discount rate of 10.1 per cent in their CBA calculations. The theoretical underpinning of their analysis is in stark contrast with the approaches advocated by Blignaut and Aronson (2008), quoting many other economists. Blignaut and Aronson (2008) postulate that a negative discount rate is appropriate in evaluating natural capital and the long-term implications of maintaining ecosystem services from the catchments (the opportunity costs of not restoring). While Hosking *et al.* (2002) acknowledge that their discount rate might not have been appropriate for such analysis, what may be an uncontrolled variable is the efficacy of the work that was done by WfW in these projects in the Eastern Cape.

What appears to be of more substance is the criticism of the practices of the management of IAPs. It is clear that prioritisation is challenging for WfW (Van Wilgen *et al.,* 2012), partially because of the multiple benefits from the work (employment, social development, fire management, biological diversity and other factors, rather than just water security).

Follow-up clearing has been a problem in many areas for WfW, and “lost hectares” have been reported, these being areas that revert to requiring initial clearing, owing to a failure to follow up timeously (C. Marais, personal communication, 3 April 2015). Although landowner agreements have been put in place to ensure follow-up clearing by the landowners, this has not been monitored as carefully as it should have been (Marais, 2015), and has been hampered by a lack of legislative powers until the recent publication of the Alien and Invasive Species Regulations (DEA, 2014b; DEA, 2014c). Careful and continuous monitoring, as can be seen from the clearing work done in the Bains' Kloof area (Figure 5.3), is necessary to avert such problems. The Bains' Kloof area, in the Western Cape, is shown in Figure 5.3 in July 2004 (left), when invaded by black wattle (*Acacia mearnsii*), and after clearing in April 2010 (right). The blue boundary lines indicate different land ownership (and responsibility for maintaining cleared areas, through landowner agreements).

Figure 5.3: Bain's Kloof before and after IAP clearing

(Source: WfW programme, 2014)

There have been many other areas of concern regarding best practices for the management of invasive alien species, including biosecurity (preventing the introduction of invasive alien species into the country), early detection of and rapid response to emerging species, failure to prioritise difficult-to-access areas (for example, mountains), failure to prioritise lightly infested areas, failure to always clear from high in a catchment downwards (to limit seed pollution), sub-optimal use of biological control, management of and response to wildfires, and, in particular, the failure to impose appropriate laws on the management of invasive alien species (DEA, 2014a; Preston, *et al.,* 2000). These concerns also relate to the inadequacy of the budget for what needs to be done (C.Marais, personal communication, 3 April 2015).

Another criticism of the theory and practice of the management of IAPs has been the importance of the utilisation of IAPs, notwithstanding any water impacts. This ranges from the need for plantations – although they are meant to be permitted and managed within demarcated areas, so the criticism appears to be unfounded – to the need for shade and aesthetic benefits (but there are always non-invasive alternative species), to the need for utilisation especially by poor, rural communities. The last-mentioned criticism has had to be addressed by WfW. De Neergaard, *et al,* (2005) concluded that black wattle (*Acacia mearnsii*) is an important resource to poor, rural communities. Virtually all households in two rural communities in the Drakensberg used the black wattle as their primary heat source and for building materials. It also raised the concern that, without access to this biomass, the communities would resort to utilising indigenous species or even using cattle dung (with nutrient depletion impacts on the soil) (De Neergaard *et al.,* 2005). However, the WfW programme has a policy that it does not clear IAPs being used by poor, rural communities, but rather maintains this source of materials in contained areas. This has been more formally developed in woodlot management through its emerging Working for Forests programme (C.Marais, personal communication, 3 April 2015).

These performance-related challenges will always exist, for no operation can run without mistakes. It is therefore reasonable for decision-makers to question what the actual benefits will be from the management of IAPs, rather than the scientific projections of potential benefits. The WfW programme has a detailed information management system (Marais & Wannenburgh, 2008), and quantification of the outcomes of the work is possible. It is thought that, with the passing of the Alien and Invasive Species Regulations (DEA, 2014b; DEA 2014c), there will be an improvement in the efficacy of the work. Already the laws have begun to be applied, with landowners in Grahamstown, Cape Town and George being served Directives to clear their land (Sishuba, 2015).

Fundamental to this thesis is the concern that clearing of IAPs, even if well done, will not yield sufficient water to meet projected demands in many catchments. Part of this will relate to the water benefits from over 2.6 million hectares of land that has been cleared by WfW since 1995 (Khan, 2015). The premise for clearing obviously has more to do with what will be lost in future than with what will be gained right now. However, there are exceptions to this perspective, as is shown in the subsequent sections of this chapter.

5.3 OTHER WATER-MIX OPTIONS

In addition to the infrastructure development options (such as the construction of dams and inter-basin transfers) and IAP management, there are a number of other options in the water-mix that are available to decision-makers. These options as listed in Table 5.1 include groundwater management, re-allocation of water rights, water re-use, water harvesting, demand-side management, wetland management, desalination and soil erosion/siltation management. All the options in Table 5.1 have been listed as water-mix options in the second *National Water Resources Strategy* (DWA, 2013b) and the *Water for Growth and Development Framework: Volume 7 and its appendices* (DWAF, 2009a; Le Maitre *et al.,* 2009).

Table 5.1: Additional water-mix options available to decision-makers

Option	Description
Groundwater management	This important water-mix option has been discussed under 2.3.3 and is not repeated here.
Reallocation of water rights	Reallocation of water-use rights occurs when water-use rights (the legal option to use a set quantity of water at a set quality level) are transferred from one use to another without changing the quantity of water demanded from the catchment. The only change is in how it is used. Usually water-use rights are transferred from a low-value use such as agriculture, to a higher-value use such as industrial or mining use. Water-use rights transfer from agriculture to mining was an option in the Olifants River Catchment feasibility study that was undertaken in 2003 (DWAF, 2006). Potential negative considerations of the reallocation of water-use rights include the social impacts such as a loss of jobs, and the environmental impacts (for example, a possible increase in water pollution). Another potential negative consideration could be the additional conveyance costs to get the water to its new destination.
Water re-use	The first *National Water Resources Strategy* (NWRS – DWAF, 2004) identified water re-use as an important part of the water-mix. In terms of return flows, water re-use now accounts for about fourteen per cent of South Africa's water supply and its extent is expected to increase considerably over time (DWA, 2013b). As part of the second *National Water Resources Strategy* (DWA, 2013b), the DWS developed a national water re-use strategy because of its importance. Water re-use entails using water of varying quality, which may have been treated for a purpose other than the one it was used for in the first place, for example, re-using domestic water in mining processes (DWA, 2013b). Furthermore, water re-use can be planned or unplanned, can be directly or indirectly used, and can occur anywhere from local to national scale for a multitude of purposes, such as irrigation, mining and/or industrial use (DWA, 2013b).

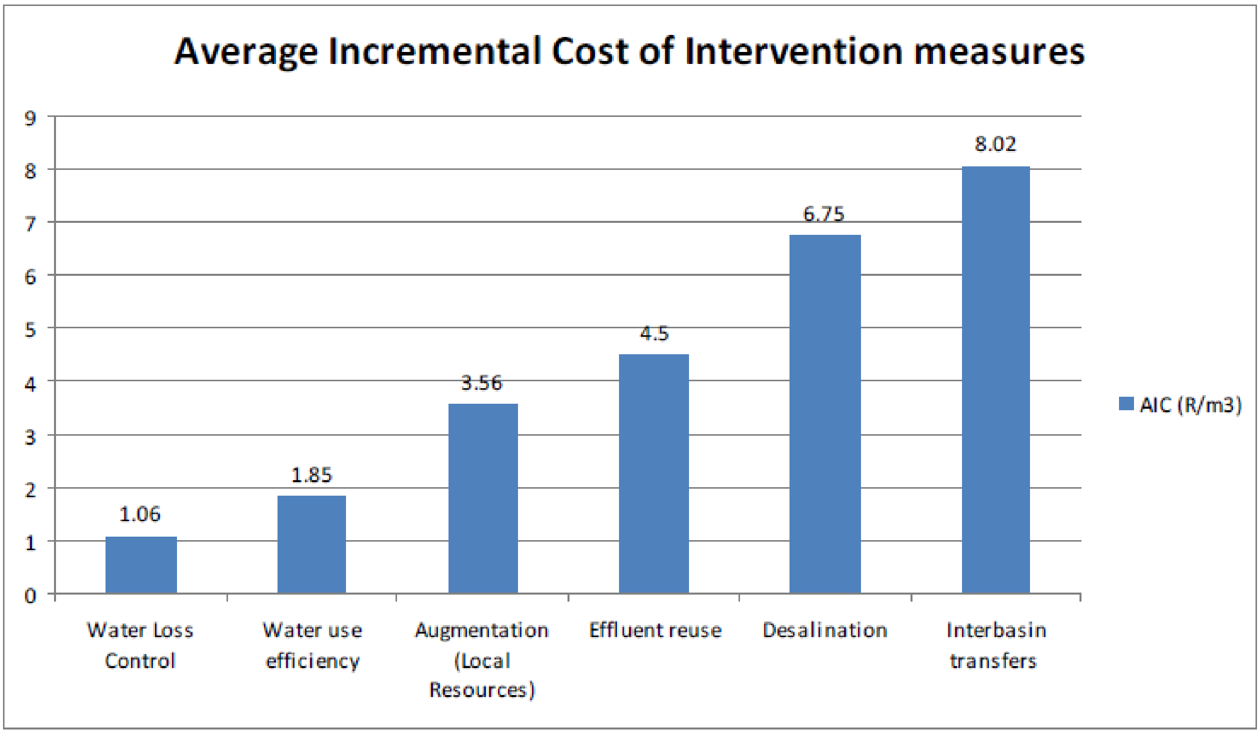
Option	Description
Demand-side management	This important water-mix option has been discussed in Textbox 3.1 and is not repeated here.
Wetland management	Wetlands are an important part of riverine systems as they provide many ecosystem services (MEA, 2005). Wetlands absorb and slow down high flows of water; they are biologically diverse and they improve the water quality (for ecosystem functioning and for downstream users' benefits) through water filtering, the settling of sediments and the absorption of pollution (Le Maitre *et al.,* 2009; MEA, 2005). Wetlands are also more resilient than many other types of ecosystems and so long as they have not been permanently changed, they can be rehabilitated to a basic level of functioning (Driver *et al.,* 2012). Unfortunately wetlands are the most threatened ecosystem in South Africa, with only eleven per cent of all wetlands being well protected and 71 per cent having no protection at all (Driver *et al.,* 2012). The impacts of IAPs, deliberate drainage for agricultural purposes, over-pollution, flood damage in degraded catchments and through hardened surfaces, or desiccation through over-abstraction, are among the reasons for the decline in health of South African wetlands (Le Maitre *et al.,* 2009). This degradation of wetlands has resulted in a substantial loss in biological diversity and ecosystem services (Palmer *et al.,* 2002) and these ecosystem services (such as pollution assimilation) are extremely expensive to substitute with technology (Constanza *et al.,* 2007). Similar to the destruction by IAPs, the degradation or destruction of wetlands is another major consideration in catchment management. Historically, it is estimated that more than half of all wetlands have been lost (Driver *et al.,* 2012). Of the roughly 300 000 that remain, Sixty-five per cent are classified as threatened, of which 48 per cent are critically endangered (DWA, 2013b). Rivers and wetlands are classified as endangered when hardly any of the river is still in good health (Driver *et al.,* 2011). The Government, through the Department of Environmental Affairs' Working for Wetlands Programme, has invested in wetland management, albeit at a far more modest level (currently R80 million per annum) than IAP management (Le Maitre *et al.,* 2009). It seems inappropriate that the management of wetlands could be such an important consideration in long-term water management, and yet we have so little documented research to guide decision-making on the relevant merits of investing in wetland management.

Option	Description
Water harvesting	Similar to groundwater management, there are gaps in knowledge about water harvesting. These gaps mean that the full costs and benefits of water harvesting, at both local and national levels, are relatively unknown (Le Maitre *et al.,* 2009). What is known is that water harvesting has had limited application at a national level (as it has little impact on total water resources), but that it does have important benefits at a local level (for example, rainwater tanks that harvest rooftop water runoff, and field water-harvesting). These benefits include fast-tracked and practical water access especially for the poor (and reduced vulnerability to the failure of, or lack of access to, large supply systems); storm-water control and harvesting (thereby reducing local erosion, flooding and downstream sedimentation impacts); and, cost-effectiveness at a local level (Le Maitre *et al.,* 2009). The issues with water-harvesting include possible impacts on groundwater recharge and in-stream flow requirements (the level of impacts is uncertain due to gaps in the knowledge); the unclear impacts of climate change; how it can be implemented at a larger scale, and its impact on water quality (Le Maitre *et al.,* 2009).
Desalination	Desalination consists of the treatment of seawater, brackish groundwater and water from acid mine drainage, to make it usable for industrial and domestic needs (DWA, 2013b; DWAF, 2009a). Desalination has a host of benefits including being close to the demand, having relatively short lead times (both for construction and expansion when compared to dams), it can be operated only when it is needed, and it has an almost unlimited supply (DWAF, 2009a). As the costs to supply water continue to rise and desalination technologies continue to improve, the relative cost of desalination improves. Desalination does however, also have drawbacks: it is one of the more expensive water supply options (largely because of high energy costs), it uses high levels of energy – which is a concern in South Africa's current (2014) lack of sufficient base-load energy supplies, and the highly saline waste water is difficult and costly to dispose of and can be harmful to the surrounding ecosystems. Furthermore, desalination is also only an option for limited, high-value or high assurance-of-supply use (domestic use, energy generation, industrial use), and it is far too expensive to distribute it to where it may be needed for agricultural purposes. As such, it is not an alternative to productive catchment supply.
Erosion/siltation management	This important water-mix option has been discussed in Section 2.2.2 and is not repeated here.

(Researcher's own construction from DWA, 2013b; DWAF, 2009a; Le Maitre *et al.,* 2009)

The water-mix options presented in Table 5.1 vary geographically in effectiveness and cost due to climate, topography, land use and population density. An example, from *Water for Growth and Development in South Africa: Version 6*, (DWAF, 2007a), of the difference in marginal costs (per cubic metre, in 2007 rand values) for different options for the Inkomati Water Management Area (WMA) is shown in Figure 5.4.

Figure 5.4: Marginal costs of alternative water-mix options for the Inkomati WMA



(Source: DWAF, 2007a)

In Figure 5.4, it is shown that for the Inkomati WMA, water loss control option has the lowest marginal cost, while inter-basin transfer option has the highest. (Note that there are additional costs that are seldom taken into consideration, such as the risk of the introduction of invasive fish and aquatic plants, from one system to another.)

The rest of the water-mix options increase in cost, from efficient use of available supply to building additional infrastructure in the case of desalination. It is generally found that water conservation and water demand-management have the lowest marginal costs (DWAF, 2007a). Note that the marginal costs shown in Figure 5.4 would differ in other water management areas and that the national marginal costs of different water source options could vary considerably (DWAF, 2007a). Water loss control, which differs by use, location and ability to apply controls, would be an example. What the above discussion shows is that uncertainty is an important (and difficult) factor in water-mix choices and decision-making.

5.4 UNCERTAINTY

There are many risks and uncertainties in the decision-making concerning water resource planning and management (DWA, 2013b; Loucks, 2011; Shamir, 2002). These risks and uncertainties accumulate during the process of bringing water to where it is needed, on time, at a reasonable cost and at a preferred quality and quantity (Loucks, 2011). Water is needed for multiple uses, some of which may compete with each other, and at the same time satisfy social and environmental requirements (for example, the Reserve). Added to this, water supply and demand are uncertain and variable; both depend on multiple factors such as the season, the climate, the weather, the population size, the water quality and the transport and purification costs. Furthermore, the social, environmental, ecological and economic impacts of a decision or series of decisions cannot be predicted with certainty (Loucks, 2011).

The consequences of a decision or series of decisions can change quickly; they are complex and outcomes are often difficult to predict. A further issue with the impacts of water resource decision-making is that their effects are often long-lasting and extensive. Even the decisions made to meet the various demands and needs for water are themselves uncertain, given changes over time (Loucks, 2011). Uncertainty not only arises regarding natural sources but can also arise from lack of knowledge and/or understanding. It can thus be suggested that uncertainty is entrenched in the planning, management and decision-making of water resources, and explains a tendency of water engineers to err on the side of caution when selecting and implementing water-mix options.

As previously discussed, one of the aspects of water resource planning and management where uncertainty occurs, is the management of IAPs. This uncertainty is based on all the factors listed above as well as on economic reasons such as estimations and predictions over time. IAPs are dynamic; they do not stand still. They may invade at varying rates depending on a number of factors, including the quantity of water available, climatic conditions, natural enemies, fires, the introduction of new species, climate change and other factors. They invade until they reach a maximum possible coverage, which in turn has a peak impact upon MAR. This severity of the impact varies by species and circumstance.

Le Maitre *et al.* (2013) have revised downwards the estimated current losses due to IAPs, to approximately 2.4 billion cubic metres (of which about one billion cubic metres is in riparian areas). Based on the estimated MAR for South Africa of 49.2 billion cubic metres (Middleton & Bailey, 2011), this represents a 4.9 per cent loss of MAR due to IAPs, which is down from the previous estimates of seven per cent (Versveld *et al.,* 1998). What is pertinent is what can happen if nothing is done to control the invasions. Cullis *et al.* (2007) work on an estimate of sixteen per cent loss to IAPs, should clearing not be done. However, in specific catchments, it is possible for up to a 100 per cent loss of MAR to occur (D. Le Maitre, personal communication, 13 April 2015; Scott *et al.,* 2000).

The rate at which IAPs spread and densify is also uncertain. This is because IAPs have variable rates of spread. The variability depends on which species is invading, the condition of the land cover, the climate, the topography and the proximity to a permanent water source (riparian or non-riparian invasion) to name a few variables. In the absence of efforts to prevent invasions, it is a question of when, rather than if, an area will become fully invaded. The estimate of the average rate of spread is now double what was taken before (ten per cent versus five per cent), but within that there are highly variable rates by species and circumstance (Van Wilgen & Le Maitre, 2013).

It would appear that any tendency to err on the side of caution in the provision of water from dams has, until recently, not been mirrored in any similar tendency to be precautionary about the impact of catchment degradation. This is perhaps also reflected in the Government's recent focus on Strategic Infrastructure Programmes (SIPs), where SIP 18 is merely focused on water and sanitation infrastructure, but pays no attention to ensuring the supply of water, including through catchment management (Parliamentary Monitoring Group, 2013).

5.5 RESEARCH METHODS

The cases presented in this chapter are the quaternary catchments of the four dams that are studied in Chapter Four. The four dams are the Inyaka, Nandoni, Berg River and De Hoop dams. Each case is analysed initially in terms of an extrapolation of the 2008 levels of IAP growth and the level of clearing done until 2013, and secondly, in terms of the hypothetical impacts over 45 years of not clearing the IAPs. The IAPs are considered in terms of their impact on MAR and their cost to clear. The cost to clear includes both initial and follow-up clearing. All the clearing costs are shown in 2013 rand values, so that inflation is a controlled variable (Statistics South Africa, 2014).

The data collection methods used in this chapter include documentation (see 3.4.1) and archival records (see 3.4.2). The core documents upon which this analysis is built, are: *National Invasive Alien Plant Survey* (Kotzé *et al.,* 2010), *Rates of spread in invasive alien plants in South Africa* (Van Wilgen & Le Maitre, 2013) for the estimated rate of spread of various IAPs; *Estimates of the impacts of invasive alien plants on water flows in South Africa* (Le Maitre *et al.,* 2013) for the estimated reduction in MAR by various IAPs; *Water Resources of South Africa: 2005 Study* (Middleton & Bailey, 2011) for the MAR estimates for the case studies and *Forestry and streamflow reductions in South Africa: A reference system for assessing extent and distribution* (Scott *et al*., 1998).

The data analysis methods for this chapter are inter- and intra-case analysis (see 3.4.5) in which the differences and similarities between cases are analysed in order to find patterns in the costs and benefits of clearing IAPs (Collis & Hussey, 2009). The methodology and methods have been explained in more detail in Chapter Three.

5.6 FINDINGS AND DISCUSSION

In reaching an informed decision on the importance of clearing IAPs in a catchment, especially the riparian area, the current level of IAP invasion is important in understanding what additional water (and other benefits) may ensue from bringing them under control and at what cost. More important, however, is understanding what will happen in terms of their spread and growth, and their impact on water security (and other impacts) in the long-term if nothing is done to control them. The current impacts as well as hypothetical potential impacts of not clearing IAPs in the case study catchments based on data from the *National Invasive Alien Plant Survey* (Kotzé *et al.,* 2010) are presented and discussed.

The *National Invasive Alien Plant Survey* (NIAPS) was undertaken in 2007 and 2008 (Kotzé *et al.,* 2010). This survey looked at the levels of invasion in all of the water management areas in South Africa. An acknowledged limitation of the NIAPS study is that it was designed principally at a tertiary catchment level and not at the more detailed quaternary level (Kotzé *et al.,* 2010), while the focus in this chapter is on the quaternary level. The NIAPS also excluded all areas with a transformed land cover (for example, cultivated land, urban areas and commercial forest plantations), as these were assumed to be unlikely to become densely invaded. This is a pragmatic assumption; although it is well known that all such areas can indeed be invaded (noting, too, that the focus of the NIAPS was not just on the impact of IAPs on water). Examples of transformed land presented in Figure 5.5 show invasions by species such as famine weed (*Parthenium hysterophorus*, a species that is not known not diminish water quantity) and triffid weed (*Chromolaena odorata*, which has been found to have a substantial impact on water quantity).

Figure 5.5: Famine weed (left) and triffid weed (right) invading transformed land

(Source: Unknown)

It should be noted that the Kotzé *et al.* (2010) study surveyed 215 species and groups of species, including the 28 most common and distinctive species and groups of species of IAPs in South Africa. Although this is only a proportion of the 2014 list of IAPs which has 379 plant species (DEA, 2014b; DEA 2014c), it includes all the main high water-using species. Invasive aquatic plants such as water hyacinth (*Eichhornia crassipes*), which are known to have an impact on water quantity (Hill & Coetzee, 2008), were also not mapped (I. Kotzé, personal communication, 22 September 2014).

In the hypothetical examples in this study, the 2008 levels of IAPs in the dam catchments were projected for 15, 30 and 45 years into the future (the planned lifespan of a dam), assuming that no control operations are carried out, to show the changes in MAR and cost to clear the IAPs. The level of invasions were extrapolated into the future with the help of Dr David Le Maitre (personal communication, 13 April 2015), as well as with guidance from Mr Ian Kotzé (personal communication, 22 September 2014), Dr Christo Marais (personal communication, 3 April 2015) and Mr Andrew Wannenburgh (personal communication, 17 October 2014), and using data and assumptions from Le Maitre *et al.* (2013), Van Wilgen and Le Maitre (2013), Kotzé *et al.* (2010) and Middleton & Bailey (2008). The projections and calculations are shown in Appendix D.

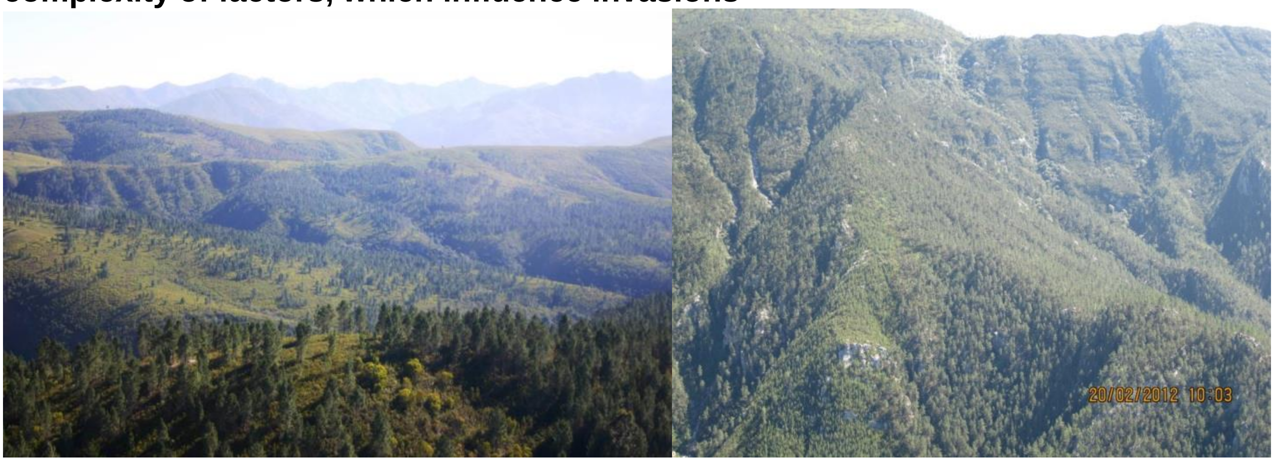
The assumption that no control measures will be taken to limit invasions is based on the fact that the clearing of IAPs is currently being done through WfW, by land-owners, and – very recently – through the application of the Alien and Invasive Species Regulations (DEA, 2014a). These actions provide no guarantee that a specific catchment will be cleared. The policy of WfW is that the budgets necessary to clear IAPs in such catchments, including invasive aquatic plants, ultimately should come from the Trading Accounts from the price of water. However, the present funding from this source is almost exclusively for invasive aquatic plants (C. Marais, personal communication, 3 April 2015) and there is no guarantee that it will be increased to cover other species.

The estimates require projections of the current invasions, based on the NIAPS survey estimates of the initial densities and extent, which necessarily involves some errors and uncertainty and these will affect the projected invasions. (The errors will increase in magnitude, but they will not change as a proportion of the area, and thus offer no systematic bias.) They thus illustrate a potential magnitude of the negative impacts of allowing IAPs to spread and grow unhindered. These projections have to take two processes into account: firstly, the expansion of the invasion into new areas, and secondly, the increases in density in areas already occupied through ongoing invasion and fore-prone IAP seedling recruitment from seed banks, especially following fires.

This study assumed certain rates of spread and applied them uniformly. In reality, the situation is more complex. Certain areas, such as riparian areas, are more susceptible to invasions than others (Richardson *et al.,* 2007; Decamps *et al.,* 1995). Furthermore, the rate of spread will vary and be limited, in specific areas, by space and growth requirements of specific species (I. Kotzé, personal communication, 22 September 2014). For example, the black wattle (*Acacia mearnsii*) can invade almost anywhere in the terrestrial landscape, while the weeping willow (*Salix babylonica* – which may or may not be considered to be re-listed as an invasive species) is strongly linked with water and will not spread naturally in most non-riparian areas, thus limiting its potential rate of spread. What further complicates rates of spread is that the amount of water lost through invasions in riparian areas is estimated to be two to three times as high as the same species in non-riparian areas (Le Maitre *et al.,* 2015; Everson *et al.,* 2007; Dye & Jarmain, 2004; Görgens & Van Wilgen, 2004).

There are further factors that can influence the growth and rate of spread of IAPs, including susceptibility to invasion of the natural vegetation, the frequency and season of wildfires, climate and other environmental or habitat factors such as soil types. These factors range from extremely difficult to nearly impossible to quantify and doing so is beyond the scope of this study. They are likely also too complicated for the planning processes that should inform decision-making by a Minister. They are also unlikely to influence the fact that invasions and their impacts will inevitably increase to occupy the available areas. Following consultation with specialists advising on the methodology, they are assumed, therefore, to be constant for the purposes of this study (D. Le Maitre, personal communication, 13 April 2015; C. Marais, personal communication, 3 April 2015). The complexity of the factors discussed above is illustrated in Figure 5.6, which shows *Pinus* invasions in the Southern Cape Mountains, by demonstrating the spread of pine trees (left) and how mountainous areas can become densely invaded by pines (right), notwithstanding factors such as rainfall, slope, aspect and soils.

Figure 5.6: *Pinus* invasions in the Southern Cape Mountains showing the complexity of factors, which influence invasions



(Source: Van Wilgen, n.d.; Pretorious, 2012)

In all four case studies, WfW has done varying degrees of IAP clearing. This clearing has included initial clearing as well as years of follow-up clearing, as is necessary because of the long lasting seed banks (see 5.2.2). The size, cost to clear and the impact on MAR of the clearing is shown in Table 5.2.

The cost of the clearing in the dam catchments by WfW, was calculated from the number of person-days (an ideal day's clearing work, done by one person) that have been worked in the specific catchment multiplied by the cost per person-day (R350 in 2013 rand values) (Table 5.2). This cost would be considerably higher for inaccessible areas such as the mountains where high-altitude teams need to abseil down to the invasive plants (C. Marais, personal communication, 3 April 2015). Although high-altitude teams are certainly needed in parts of the catchments of the four dams, estimating how this affects the costs was considered too difficult given the scope of this study. Therefore, this analysis used the average WfW cost of R350 per person-day in 2013 rand values (A. Wannenburgh personal communication, 17 October 2014).

Normally an area that is invaded by alien plants will only be partially invaded (therefore having variable densities) and this is measured in total invaded ("uncondensed") hectares. The density of the invasion can range from one specimen per hectare to thousands of specimens of different species per hectare. For this reason, the total invaded area is not a useful measure of the long-term full invasion of the area. In order to simplify the calculations of invaded areas for modelling purposes, the invaded area is expressed as condensed hectares (the mathematically equivalent hectares with the density scaled to 100 per cent canopy cover by IAPs). Using condensed hectares facilitates comparisons by standardizing the different densities of invasions in a given area (such as a catchment).

In each case, the initial invaded area is what was estimated in 2008 by Kotzé *et al.* (2010). As shown in Table 5.2, the invasions are then projected forwards as if no further clearing had been done and expressed in condensed hectares and as a percentage reduction of MAR. It should be noted that only in the Berg River Dam proposal was there any provision made for the clearing of IAPs in the catchment. It is therefore reasonable to assume that the Minister did not factor in any clearing of IAPs (or any other catchment-management interventions) in the decision-making process. Thus it is reasonable to project future invasions as if no further clearing had been done.

The reduction in MAR by IAPs in 2013, together with an estimate of the total reduction by IAPs if the clearing work is not continued, are given as volumes and as percentage reductions of the MAR. The future level of impact is based on estimates of the current reductions for each of the quaternary catchments as calculated by the researcher and Dr Le Maitre, and based on data from Le Maitre *et al.* (2013). The reductions in the MAR could become exceedingly large as illustrated by the two catchments (Berg, De Hoop) that initially had relatively high levels of invasion. For the other two catchments the impacts are lower, but they too have the potential to reach similar levels of MAR reduction, given sufficient time.

Table 5.2: Data on the catchments, current and potential invasions, reductions in flows and the costs of IAP management for the selected cases.

		Inyaka Dam Catchments	Nandoni Dam Catchments	Berg River Dam Catchments	De Hoop Dam Catchments
a.	Number of quaternary catchments associated with the dam	1	6	1	6
b.	Total size of the dam catchment area (ha)	21 385	141 759	17 185	286 489
c.	Size of area with natural / semi-natural land cover (ha)	7 671	67 792	13 570	233 875
d.	Percentage of total area with natural / semi-natural land cover (ha)	35.87%	47.82%	78.96%	81.63%
e.	Total MAR for the dam catchments (million m3/annu	80.32	199.66	136.34	134.33
f.	2013 hectares cleared to date (condensed hectares)	1 466	1 979	3 607	180
g.	Clearing & follow-up costs up to 2013, in 2013 rands (Million ZAR)	R 64.73	R 68.58	R 72.58	R 23.61
h.	2008 levels of invasion by IAPs (uncondensed hectares)	0	11 038	1 175	173 638
i	2008 levels of invasion by IAPs (condensed hectares)	0	621	370	17 295
j.	Cost to clear 2008 invasions by IAPs in 2013 rands (Million ZAR)	R 0.00	R 10.76	R 4.13	R 286.85
k.	Cost-per-condensed-hectare to clear 2008 IAPs (in 2013 rands)	R 0	R 17 338	R 11 162	R 16 586
l.	The 2008 impact of IAPs on MAR for dam catchments (Million m3/yr)	-	0.27	1.90	8
m.	The 2008 impact on MAR of these IAPs (as a % of MAR)	0.00%	0.14%	1.39%	5.94%
n.	Estimated area of invasion by IAPs after 45 years (uncondensed hectares)	6 547	64 302	12 279	233 146
o.	Estimated area of invasion by IAPs after 45 years (condensed hectares)	2 946	32 551	12 279	128 138
p.	Estimated cost to clear catchments after 45 years in 2013 rands (Million ZAR)	R 38.75	R 564.56	R 136.99	R 2 125.25
q.	Estimated reduction in MAR after 45 years of invasion (Million m3/yr)	13	14	63	59
r.	Maximum percentage of total MAR that might be lost	31.93%	42.56%	70.28%	72.66%
s.	Estimated percentage of MAR lost after 45 years of invasion	16.12%	7.03%	46.22%	44.01%

(Source: Author's construction from: D. Le Maitre, personal communication, 13 April 2015; A. Wannenburgh, personal communication, 17 October 2014; Kotzé *et al.,* 2010; and, Middleton and Bailey, 2008. Calculations are shown in Appendix D.)

It should be noted that, given that IAP seed banks persist for many years, the Inyaka Dam's 2013 level of invasion is most certainly greater than zero. The estimate from the NIAPS survey, which was conducted to be used at a tertiary level, may not be representative of the true state of invasions in this particular catchment. For this study an initial invaded area and density was assumed and this data was used for estimating the future cost to clear IAPs for the Inyaka Dam.

It is apparent from Table 5.2 that WfW has already spent a total of approximately R208 million on clearing IAPs in the four catchment areas. Without these expenditures, the initial invasions would have been far greater. The differences in invasions per catchment are due to the differences in terrain, species, amount of initial and follow-up clearing done (including the number of times), and variation in the efficacy of the clearing (Mugido *et al.,* 2014; Marias & Wannenburgh, 2008). Other factors include the proportion of the catchment that can be invaded (namely the proportion of natural or semi-natural land), the occurrence, severity and frequency of wild fires, and possible climate change impacts.

A key consideration is the cost of clearing IAPs after 45 years of invasion (Table 5.2, p). These estimates are calculated using condensed hectares and are based on the WfW clearing rates per hectare in 2013 rand values. The variation in the costs depends largely upon the type of species present, for example, sprouting tree species cost R17 344 per hectare to clear, while non-sprouting tree species cost R11 156 per hectare – see Appendix D for the full list (Wannenburgh, 2014). In practice, the costs will also vary according to the location of the trees. Trees that are on steep slopes, or that need to be extracted from riparian areas, or that can cause damage when they are felled, or that are very large, or that must be removed or burnt owing to a fire risk, together with the number of follow-up clearings that are necessary, all increase the costs. Costs also reflect on the efficacy of the work. In a similar project run in the Eastern Cape, the efficacy of clearing teams was measured, and significant differences were found (Mugido *et al.,* 2014).

An additional key consideration is what proportion of the catchments of these dams could be invaded by alien plants, and what the consequent reduction in MAR would be. This study follows the assumption (Kotzé *et al.* 2010; Van Wilgen *et al*., 2008) that only areas with natural/semi-natural land cover can be invaded. Additionally different IAPs have different rates at which they will invade (see Appendix D), and areas in which they invade (for example, riparian versus dry land). But they also have different impacts in terms of the MAR. The variation in the potential impacts of different taxa can be seen from this quotation from Le Maitre *et al.* (2013, p. 72):

> *The taxa with the most extensive invasions and the greatest impacts on water resources are* Acacia mearnsii *(474 489 condensed ha, 34% of the total flow reduction),* Pinus *species (132 937 ha, 19%) and* Eucalyptus *species (273 573 ha, 16%).* Chromolaena odorata *(101 992 ha, 7%),* Hakea *species (36 344 ha, 5%) and* Solanum mauritianum *(40 413 ha, 4%) also have important impacts on runoff. Together these taxa account for 85% of the total impacts on runoff.*

While focus may be centred more on the catchment areas above the dam, water needs below the dam must also be considered, especially in the riparian areas. More water may have to be released from the dam to compensate for the water lost to evapo-transpiration by the IAPs as well as to maintain the commitments to the ecological Reserve and to run-of-river water users, such as rural communities and irrigated agriculture.

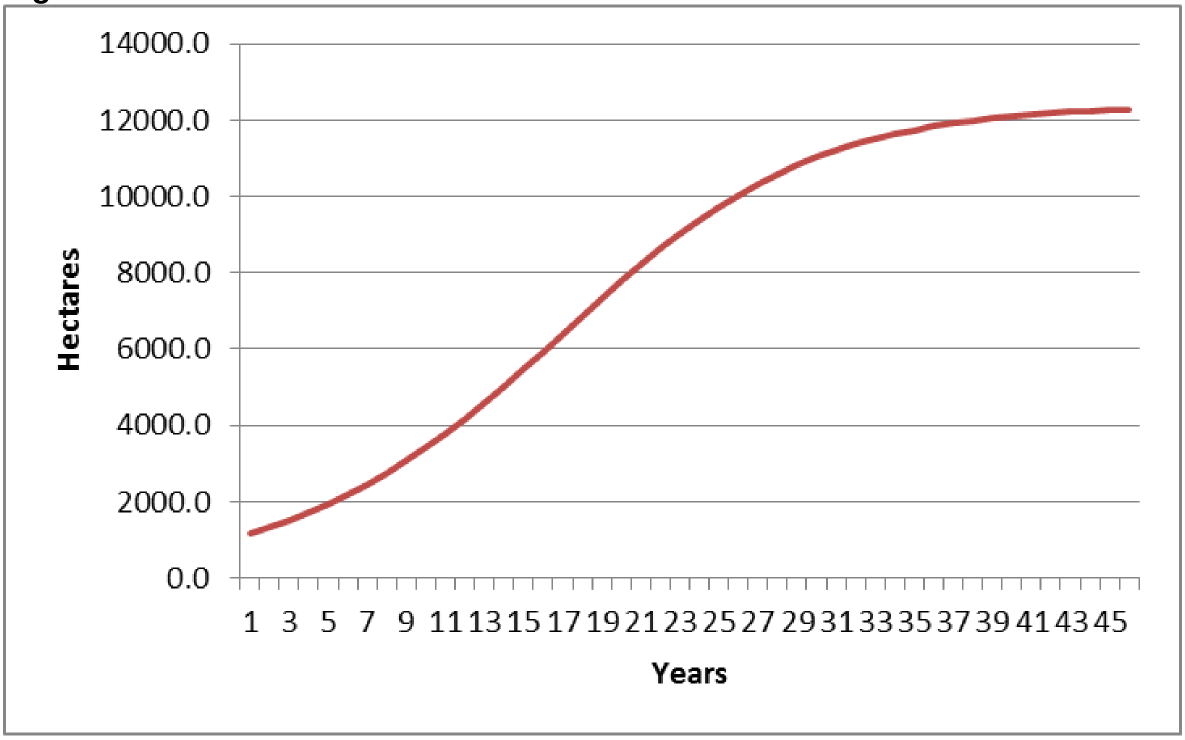
If nothing is done to clear the IAPs, then theoretically, almost all the natural and semi-natural areas can be invaded. Not only will this then mean that the initial clearing costs will have to be borne, but there will also be ongoing follow-up costs, possibly into perpetuity. These long-term costs could be massive, given that the seeds would have been spread, and (in many cases) germinated, by periodic fires. In mountainous areas, these follow-up costs would be financially crippling, which emphasises the necessity of decision-makers taking timeous steps to prevent the invasions in the first place.

If areas are then fully invaded, this poses the question of what impact the invasion would have on the MAR. Plantations are meant to be kept out of riparian areas, off steep slopes, and out of wetlands and inappropriate soils (RSA, 1998), because of the reduction in MAR and other negative effects associated with planting these areas. Scott *et al.* (1998) analysed the impact of plantations on MAR in various catchments. They found that the extreme was planting 100% of the Mokobulaan catchment, on the Mpumalanga Province escarpment, with *Eucalyptus* (gum) species. This resulted in a 100 per cent reduction in the runoff and the river drying up. It also took five years for the river to start running again after felling owing to deep soil moisture and ground-water depletion.

To take the De Hoop Dam as an example, currently there are IAPs recorded on 173 638 hectares (74 per cent) of the 233 875 hectares of natural and semi-natural land cover that can be invaded (Kotzé *et al.*, 2010). If nothing is done to clear these IAPs, then in theory the entire natural and semi-natural land cover areas could be fully invaded. The relatively low densities of invasion in the catchment have caused a 5.84 per cent decrease in MAR. After 45 years of no IAP management, the reduction in MAR would increase to 44 per cent (Table 5.2, s). A further example taken from Scott *et al.* (1998) is that of rivers which have dried up completely as a result of evapo-transpiration losses caused by invasive species. This will vary from catchment to catchment, depending upon natural flows, as well as the total invadable area and factors such as topography, soil depths and fertility, ground-water recharge and rainfall intensity. For these reasons, it is important to examine each dam catchment in detail.

The calculations for the hypothetical scenarios project the effect of IAPs on MAR 45 years into the future from the 2008 invasion levels as estimated by Kotzé *et al.* (2010). In the calculations, the rate of spread into uninvaded areas for the summer rainfall catchments uses an annual rate of spread for IAPs of ten per cent per year. The rate of spread for the Berg River Dam catchment (G10A), which is predominately invaded by *Pinus* species, has been calculated as fifteen per cent per year based on data from Van Wilgen and Le Maitre (2013). The rate of spread is modelled, in Figure 5.7, to decline from this percentage as the catchment becomes increasingly occupied – a trend that is found in many other studies of the spread of invaders (Le Maitre et al., 2002).

Figure 5.7: Increase in total area invaded in G10A

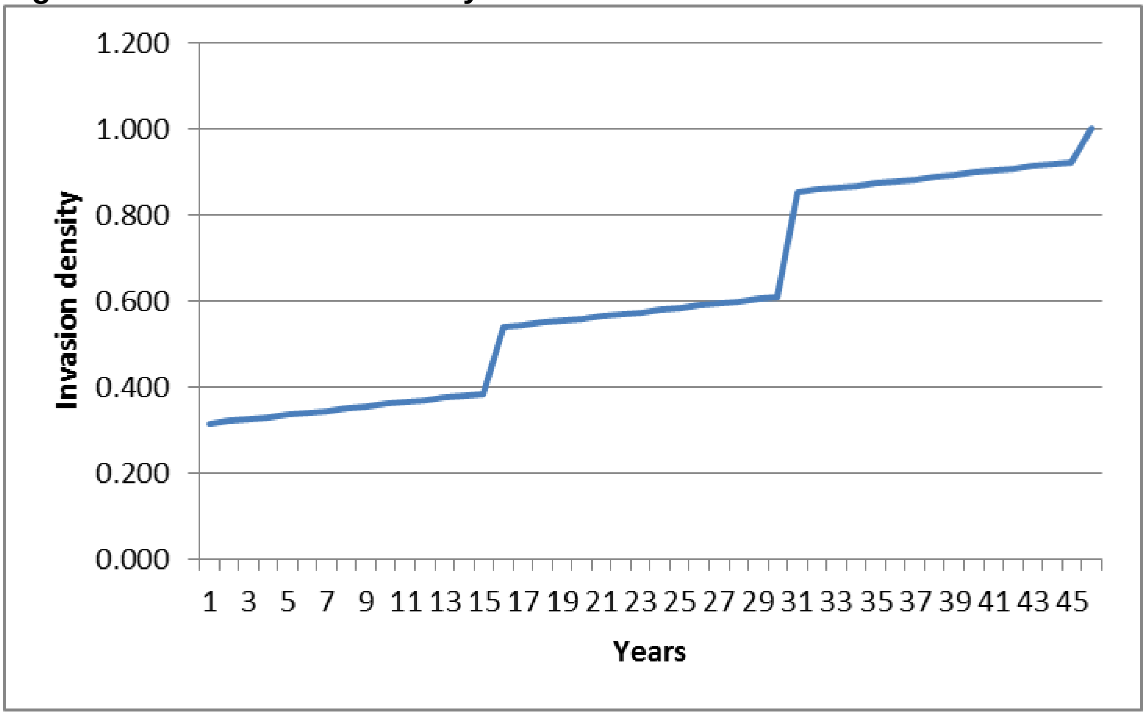


(Source: Modelling by author and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé *et al.,* 2010))

In the calculations, the single variation is the densification rate. In the summer rainfall case studies (the Inyaka, Nandoni and De Hoop Dam catchments), densification rates are modelled to increase by one per cent and five per cent year. A conservative estimate has been deliberately taken, as advised by Dr le Maitre (D. Le Maitre, personal communication, 13 April 2015), because even such conservative estimates show how it is imperative that decision-makers to take invasions in catchments into consideration when considering augmentation of water supply through a dam or other similar options. More research is needed to understand the appropriate rates of densification (D. Le Maitre, personal communication, 13 April 2015) but these estimates are sufficient to show conclusively the wisdom of taking invasions of catchments into account when approving the building of dams.

The densification in the Berg River Dam catchment (G10A) has been modelled to increase by one per cent per year, and by 40 per cent every fifteen years. These densification rates are used to simulate the rapid increase in density because of seedling recruitment after wildfires (Figure 5.8) (D. Le Maitre, personal communication, 13 April 2015; Le Maitre *et al.,* 1996). What has been modelled is a conservative fire regime (every fifteen years) based on Le Maitre *et al.* (1996). The rates of spread and densification are derived from the research conducted by Brown and Richardson (1986) and Rouget *et al.* (2001), together with assessments by Dr David Le Maitre (D. Le Maitre, personal communication, 13 April 2015).

Figure 5.8: Increases in density of invasion in G10A



(Source: Modelling by author and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé *et al.,* 2010))

The decrease in MAR caused by the IAPs is calculated for the whole catchment, not just the section with natural/semi-natural land cover, because the impact on the water affects the runoff of the whole catchment.

In the cases of the Inyaka Dam and De Hoop Dam, the calculations were split into riparian and dryland zones before being combined for catchment totals. This split was necessary because the reduction in MAR caused by IAPs in summer rainfall areas doubles for riparian zones compared to dryland zones (Le Maitre *et al.,* 2013; Scott *et al.,* 1998). To calculate the impact of IAPs on MAR, catchments are split between the riparian and dryland zones using a general rule from Scott *et al.* (1998) which states that the riparian zone covers about ten per cent of a catchment on average, and thus the dryland zone covers the remaining 90 per cent. The invasion in the Berg River Dam catchment does not occur in the riparian zone; therefore splitting the calculation becomes unnecessary.

While a rigorous analysis of the relationship between the spread and density of IAPs would be instructive, the actual values used in this modelling are intended to be conservative and illustrative, rather than precise. The purpose is to demonstrate the inevitable outcome of the rapid spread and densification of invasions in areas of natural/semi-natural land cover if no management is applied. Whether this happens sooner than 45 years or later, ought to be less important to a decision-maker than the fact that it will inevitably occur and that the long-term reduction in MAR would cancel out any action to augment water supplies with dams. Note that, in the view of experienced managers of invasive species, catchments exist where invasives have spread beyond the threshold of being able to be controlled through conventional management practices, and where only biological control may offer any hope for their long-term control (C. Marais, personal communication, 3 April 2015). Given the differences between the findings for the different catchments (Table 5.2) and the above discussion, it becomes important to look at each dam catchment in detail.

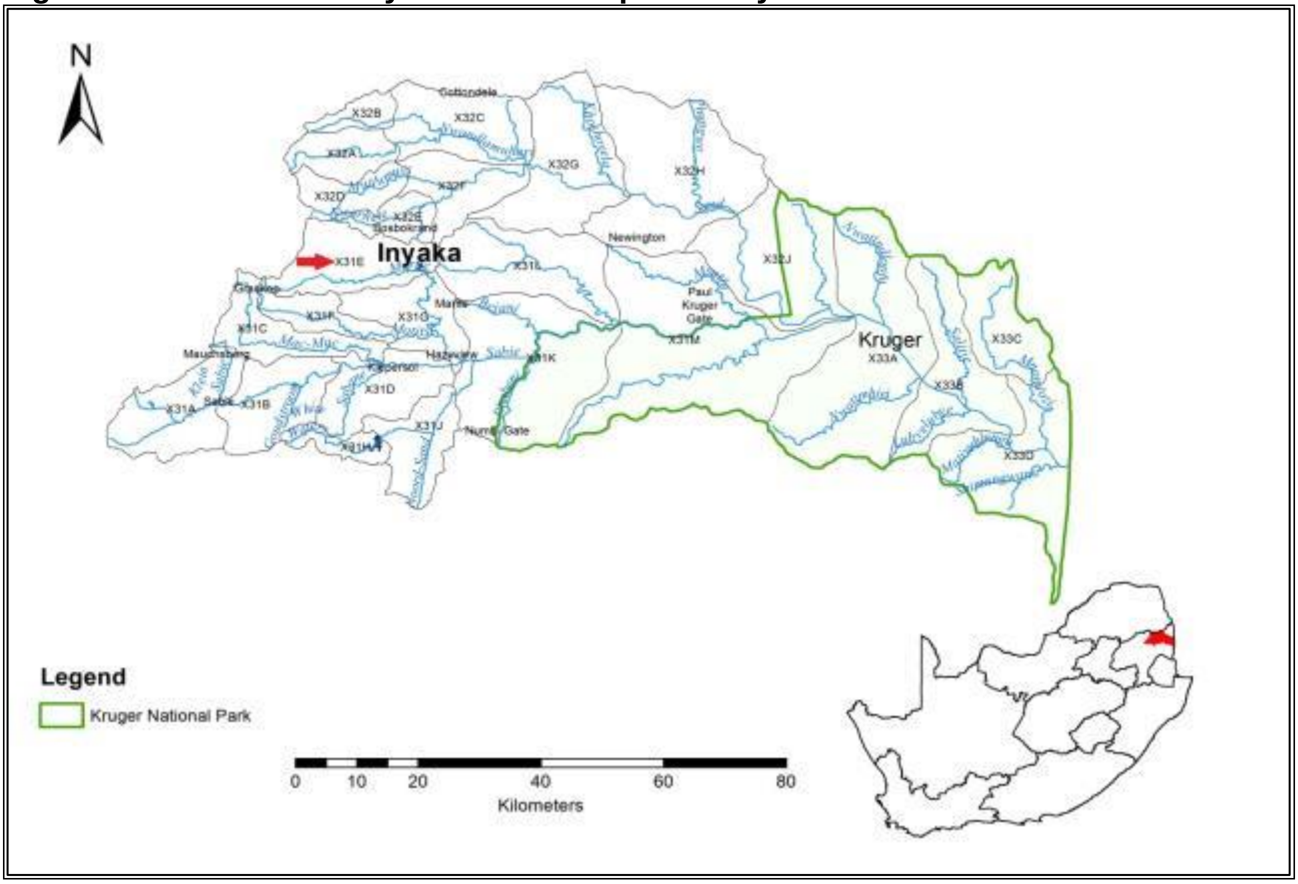
Detailed discussions of the findings pertaining to the 2008 levels of IAPs, the IAP clearing that has already occurred and the estimated impacts of not managing IAPs for a 45-year period (the planning lifespan of a dam) are presented according to each dam catchment. The catchments are presented in chronological order of the construction of the dams to show what, if any, progress in the inclusion of IAP management as a condition of the decision to build the dam, has been made.

5.6.1 Case 1: Inyaka Dam catchment

The Inyaka Dam is found in the Marite River (in Mpumalanga) at the downstream end of the quaternary catchment X31E. The Marite River is one of the main tributaries of the Sabie River. Thus, X31E is located in the Sabie River catchment, which is part of the Inkomati-Usuthu Water management area (WMA).

There are no other quaternary catchments upstream of X31E as it is located within the upper section of the Sabie River catchment, next to the border with the Olifants River catchment. Thus all the water that flows into the Inyaka Dam is from a single quaternary catchment. A map of the locations of the Inyaka Dam and quaternary catchment X31E are shown in Figure 5.9.

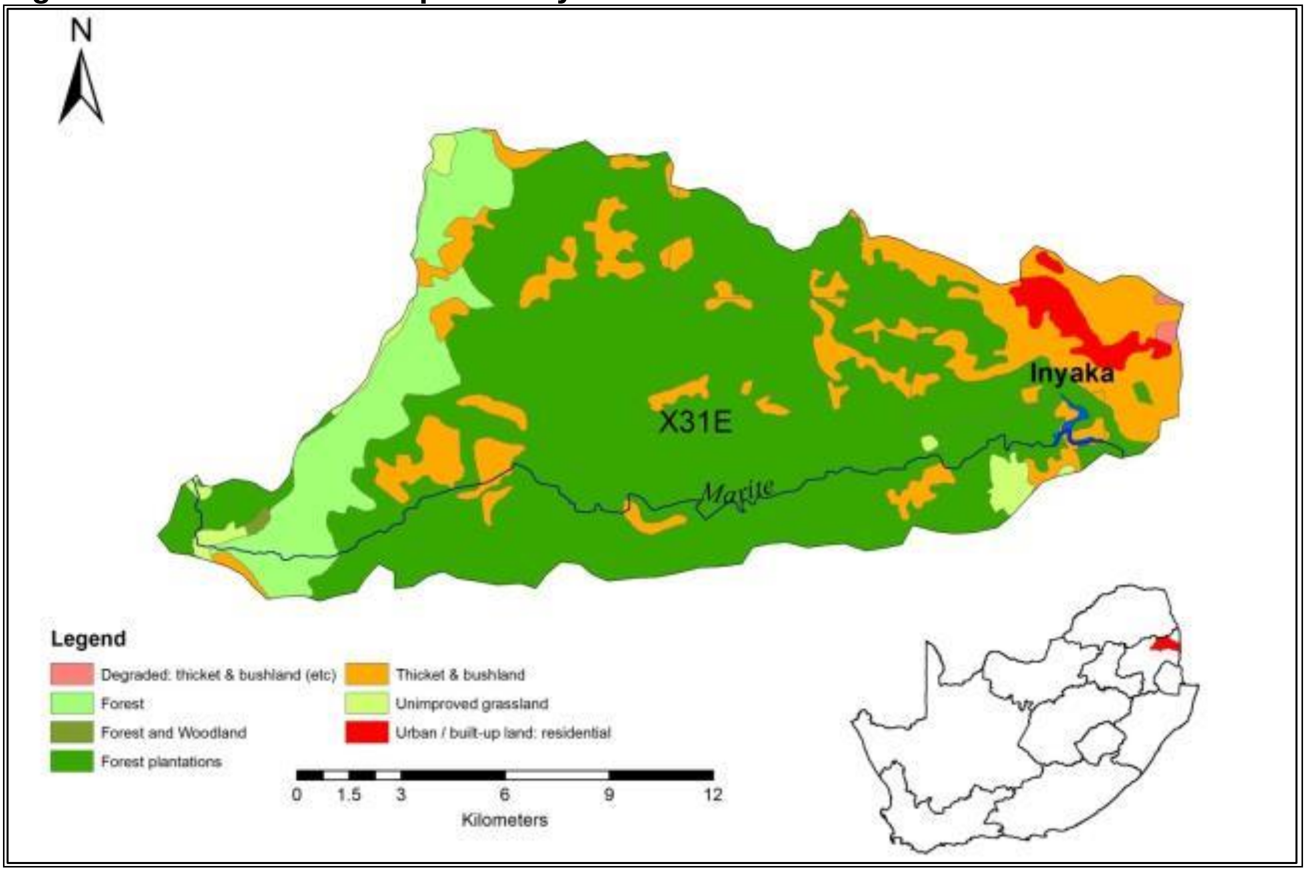
Figure 5.9: Location of Inyaka Dam and quaternary catchment X31E



(Source: Van Den Berg *et al., 2008*)

Quaternary catchment X31E falls predominantly into the north-eastern highlands ecoregion with the most western section covered by the northern escarpment mountains (Kleynhans *et al.,* 2005). The settlement of Bushbuck Ridge is on the eastern edge, just north of Inyaka Dam. The catchment, shown in Figure 5.10, is largely covered by plantations intermingled with patches of degraded thicket and bushland. Small areas of grassland and woodland are also present.

Figure 5.10: Land cover in quaternary catchment X31E

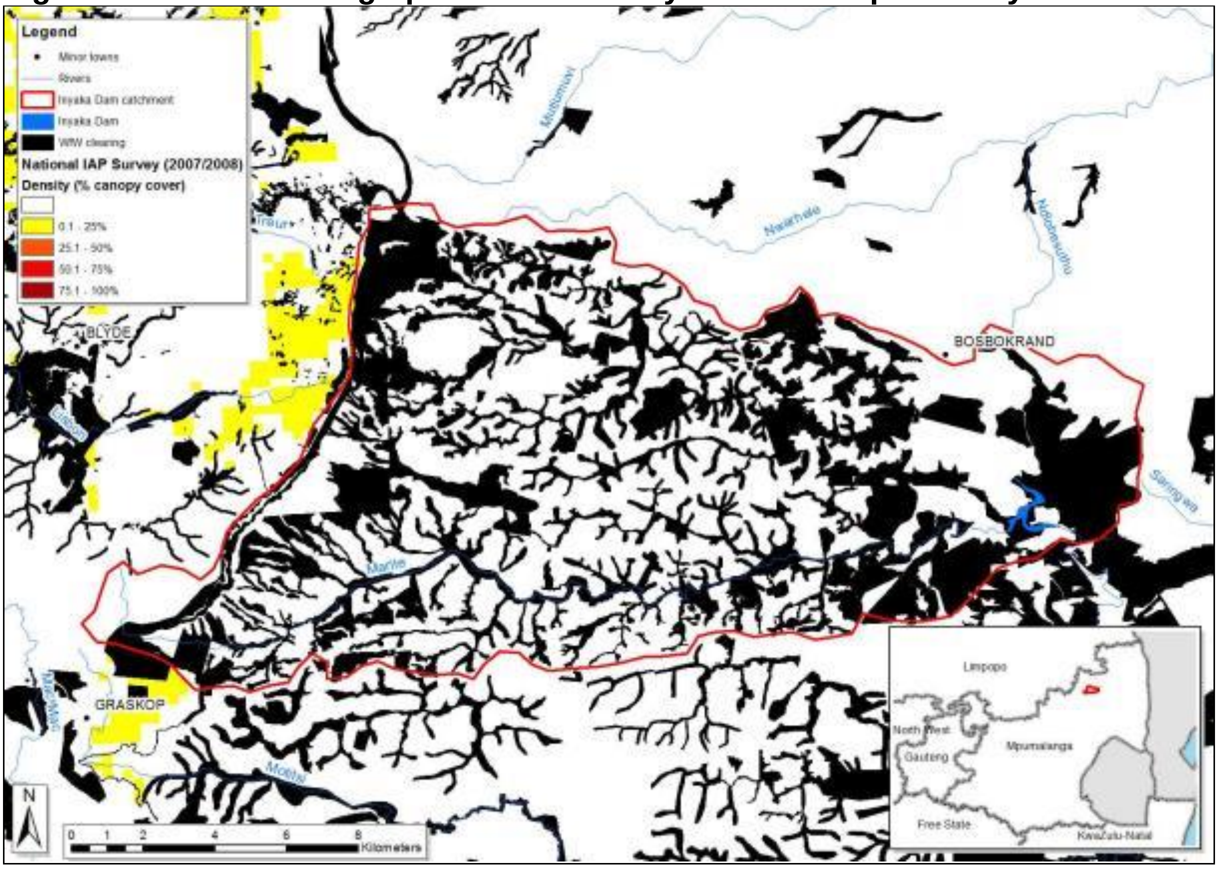


(Source: Van Den Berg *et al., 2008*)

The plantations in Figure 5.10 consist of predominantly *Pinus* and *Eucalyptus* species and cover approximately 60 per cent of the catchment. They are not regarded as being 'invading' alien plants, despite being IAPs, as they are seen as a managed resource (Scott *et al.,* 1998). In the *National Alien Invasive Plant Survey* (Kotzé *et al.,* 2010), the plantations were classified as transformed land cover (along with other land cover such as built-up and agriculture areas) and are excluded from subsequent IAP calculations.

Although X31E is largely covered by plantations, WfW has done significant clearing of IAPs. This clearing (as is shown in black in Figure 5.11) has occurred largely along the riparian areas of the catchment as well as in a few larger areas. WfW has spent R64.7 million (in 2013 rand values) on clearing 1 466 (condensed) hectares of IAPs in the catchment. It would appear from the DWS data (in Table 5.2) that the threat of IAPs in the catchment of the Inyaka Dam is now negligible in theory, as a result of the clearing that WfW has done.

Figure 5.11: IAP clearing upstream of the Inyaka Dam in quaternary catchment X31E



(Source: A. Wannenburgh personal communication, 17 October 2014)

However, IAPs always require follow-up clearing. Responses to enquiries made to WfW did not indicate that measures were in place to ensure maintenance of follow-up clearing. The Alien and Invasive Species Regulations could be invoked for this purpose, however, since much of the land is under the control of Government authorities. The fact that the NIAPS did not record invasions at in 2007/8 (Table 5.2), is patently a temporary situation (Kotzé *et al.,* 2010). It is highly likely that there are still large seed banks of IAP species in the area, and there will be an inevitable germination of these seeds, especially after fires in this fire-prone area. The existing plantations are also an important seed source.

The calculations for the hypothetical scenarios for Inyaka Dam, looking 45 years into the future from 2008, were split into riparian and dryland zone calculations before being combined for the catchment total. The calculations are summarised using conservative densification rates of one per cent in Table 5.3 and five per cent in Table 5.4. It is assumed that the seeds from the seed bank will germinate quickly in the first year with no follow-up clearing taking place.

Table 5.3: Combined calculations using the 6 761 m^3/ha/yr optimal *Eucalyptus* reduction (riparian) and the 3 268/m^3/ha/yr optimal pine reduction (Dryland) at Inyaka. Densification rate = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0	0	0%	0	-
2023	2,652	442	5.77%	2.43	3.02%	6.67	3,084%
2038	4,624	1,479	19.29%	7.05	8.77%	20.42	9,442%
2053	6,547	2,946	38.42%	12.95	16.12%	38.75	17,919%

(Source: Modelling by researcher and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

It is estimated that the area invaded will increase from zero to 2 946 condensed hectares in 45 years, representing 38 per cent of the catchment (Table 5.3). Natural MAR would be reduced by sixteen per cent and the cost to clear would increase to nearly R39 million, an increase of 17 919 per cent, based on the cost to clear in 2009 (R 216 261), as the cost to clear in 2008 is officially zero. The higher densification rate in Table 5.4, results in these estimated reductions more than doubling.

Table 5.4: Combined calculations using the 6 761 m^3/ha/yr optimal *Eucalyptus* reduction (riparian) and the 3 268/m^3/ha/yr optimal pine reduction (Dryland) at Inyaka. Densification rate = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0	0	0%	0	-
2023	2,652	2,100	27.39%	11.52	14.34%	31.68	14,650%
2038	4,624	4,771	62.22%	22.73	28.30%	65.87	30,457%
2053	6,547	6,547	85.38%	28.78	35.83%	86.11	39,819%

(Source: Modelling by researcher and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

The fundamental objective posed in this chapter is, however, to analyse the costs and benefits of IAP control in the context of the catchments for the water supply infrastructure schemes. In determining this objective, it could further be asked whether clearing IAPs to supply water as an additional option to the Inyaka Dam or as a concurrent option, would have been viable. Unfortunately, the level of IAPs, when the decision to build Inyaka Dam was made, is unknown as no data exists for that period.

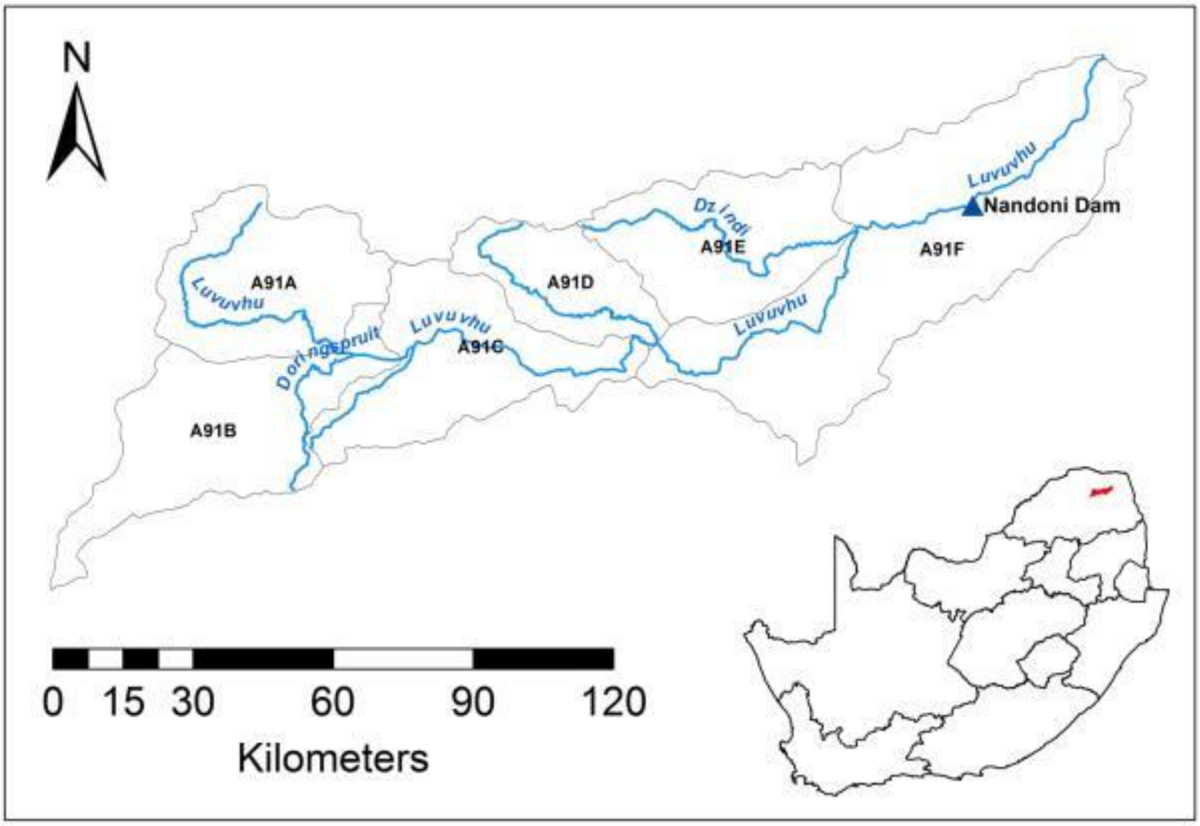
The data in Table 5.3 and Table 5.4 indicates that clearing the IAPs in the catchment would not have compensated for the potential yields and water security provided by the construction of the dam. However, if follow-up clearing is not continued, the estimations show that IAPs will reduce the security of the water supply.

The IAP consideration did not feature in the planning documents for the building of the dam. The Minister could not, therefore, have considered this alternative when making the necessary decisions. It can, however, be argued that, because WfW was established in the Department of Water Affairs and Forestry of that time, the establishment of WfW contributed towards compensating for the lack of IAP consideration in the dam planning documents. As has been indicated, the seed banks of IAPs mean that there are future costs in keeping the land clear, and that a failure to do so will affect runoff and thus dam yields. Estimates for the 45-year scenario are between a sixteen per cent and a 36 per cent reduction in MAR. This figure will reach the 36 per cent level and go substantially higher in the long-term, if nothing is done. This cannot be afforded by those needing the future yields from this dam. The analysis suggests that long-term management of IAPs ought to have been built into a strategy that included building the dam, at the time when this decision was made. Although it may be important to establish whether the effect will be noticeable within more or less than 45 years, the most important consideration is the necessity of managing invasions to prevent them reaching levels where the costs to clear become exceedingly high, and where the seed banks then impose similarly high long-term follow-up costs. "*A stitch in time saves nine*", as the old adage goes, is patently appropriate.

5.6.2 Case 2: Nandoni Dam catchment

The Nandoni Dam is located in Limpopo Province, on the Luvuvhu River. It is located in quaternary catchment A91F and has five further quaternary catchments upstream: A91A to A91E (Figure 5.12).

Figure 5.12: Location of the Nandoni Dam and the upstream quaternary catchments,

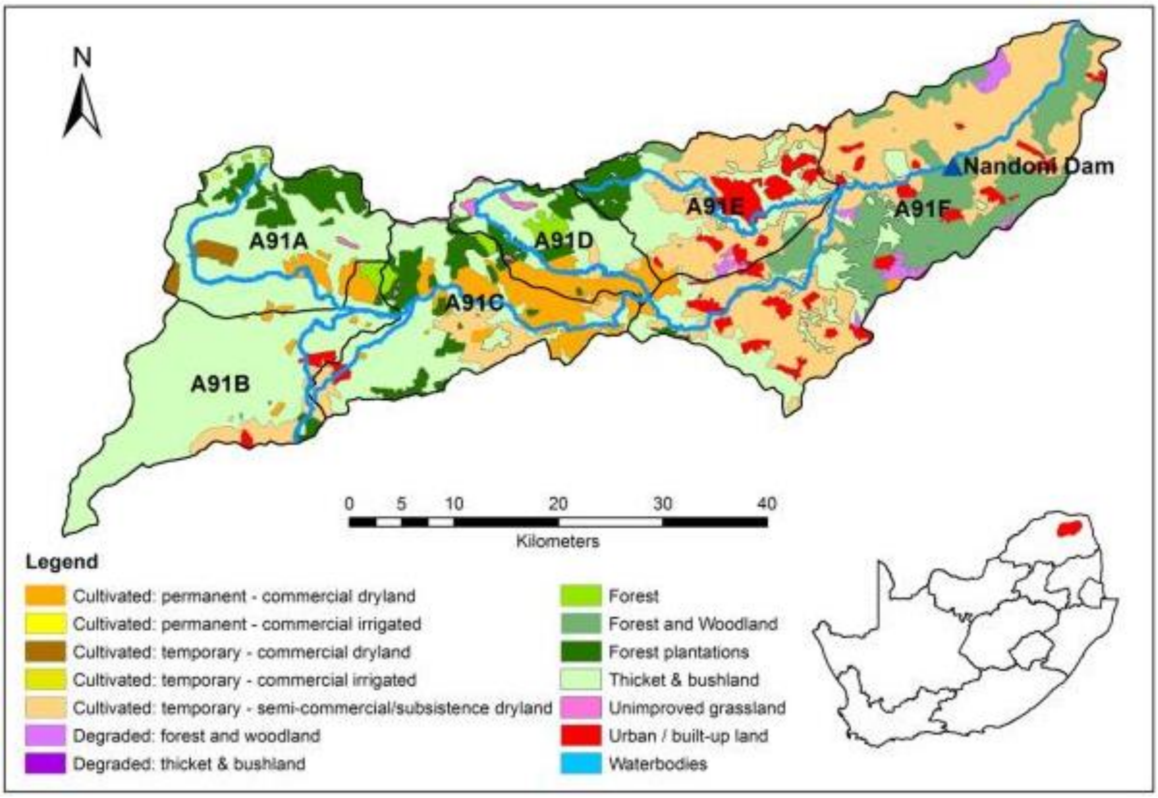


(Source: Van Den Berg *et al., 2008*)

As shown in Figure 5.12, the six quaternary catchments are all located in the Limpopo WMA. While the total catchment area of Nandoni Dam (169 233 hectares) is many times bigger than the Inyaka Dam (21 386 hectares) or Berg River Dam (17 185 hectares) catchments, it is still much smaller than the De Hoop Dam catchment (286 489 hectares).

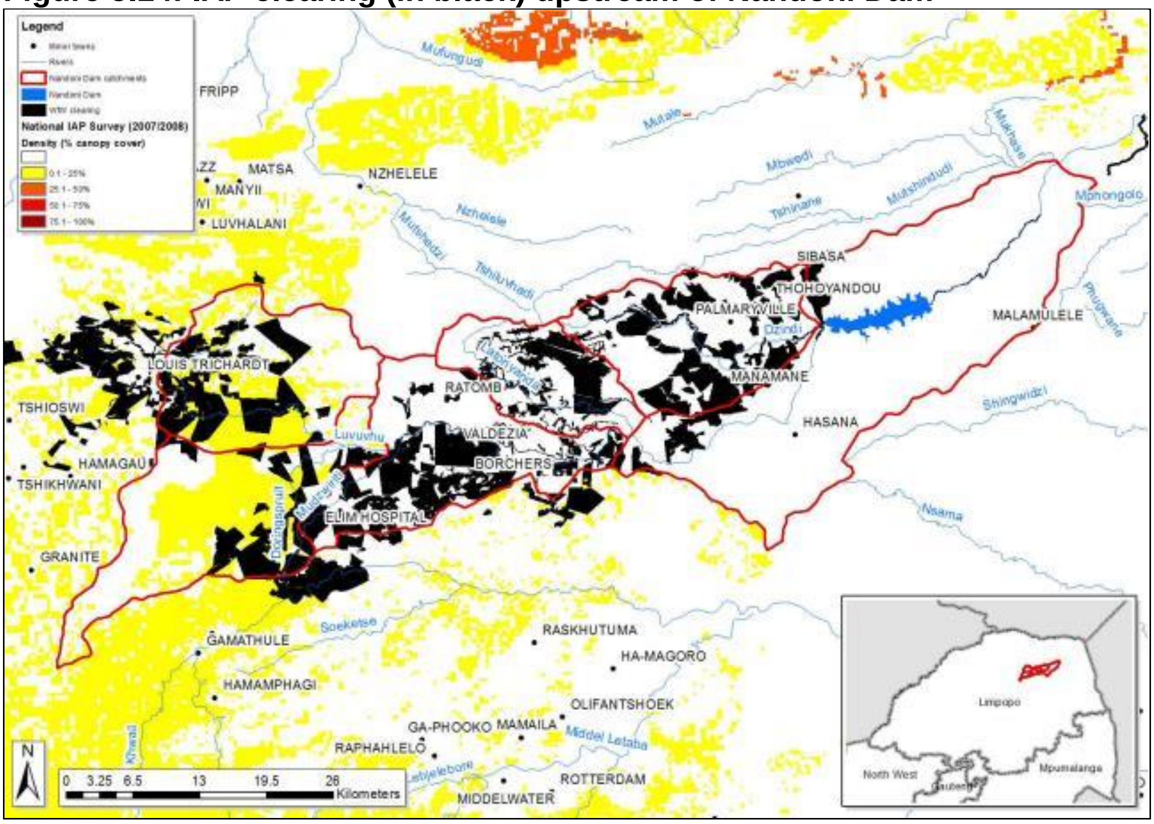
The land cover in the six quaternary catchments, as shown in Figure 5.13, is varied, with only 48 per cent of the catchment considered to have natural/semi-natural land cover and thus to be invadable (Table 5.2). The limited area of natural (untransformed) vegetation may account, along with the clearing that has been done in the catchment, for the failure to record invasions in the lower Nandoni Dam catchments (A91D to F) in Figure 5.14. Much of the invasion in A91A and B (shown in yellow, in Figure 5.14) corresponds with the thicket and bushland land cover (in Figure 5.13) and consists principally of *Eucalyptus, Jacaranda, Opuntia and Cereus* species. Only the *Eucalyptus* and *Jacaranda* species are considered to reduce the MAR in the catchment.

Figure 5.13: Land cover in the quaternary catchment upstream of the Nandoni Dam



(Source: Van Den Berg *et al., 2008*)

Figure 5.14: IAP clearing (in black) upstream of Nandoni Dam



(Source: Wannenburgh, 2014)

WfW has cleared IAPs in all six quaternary catchments (shown in black in Figure 5.14). In total, WfW has spent R69 million (in 2013 rand values) clearing 1 979 condensed hectares of IAPs. As a result, the equivalent of 621 condensed hectares of IAPs remains, with an estimated clearing cost of eleven million rand and reduce MAR by 0.13 per cent (Table 5.5). The calculations for the hypothetical scenarios for Nandoni Dam, looking 45 years into the future from 2008, are summarised using conservative densification rates of one per cent in Table 5.5 and five per cent in Table 5.6.

Table 5.5: Using the 431 m^3/ha/yr estimated for optimal *Eucalyptus* at Nandoni. Densification rate =1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	11,038	621	0.92%	0.27	0.13%	10.76	-
2023	31,061	6,406	9.45%	2.76	1.38%	111.10	1,032%
2038	53,868	19,189	28.31%	8.27	4.14%	332.81	3,092%
2053	64,302	32,551	48.02%	14.03	7.03%	564.56	5,245%

(Source: Modelling by researcher and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

It is estimated, in Table 5.5, that the area invaded will increase to 32 551 condensed hectares in 45 years, representing 48 per cent of the catchment and the cost to clear would increase to nearly R565 million, a cost increase of over 5 000 per cent. Natural MAR would, however, only be reduced by seven per cent because firstly 52 per cent of the catchment is considered transformed land and is not invadable; and secondly, the relatively low estimated flow reduction caused by the IAPs, which reflects the relatively dry conditions in the catchment (Table 5.2; Kotzé et al., 2010). The higher densification rate in Table 5.4 results in these estimated reductions nearly doubling. Given a longer time period, these estimates would be closer to those of the Inyaka Dam and other catchments.

Table 5.6: Using the 431 m^3/ha/yr estimated for optimal *Eucalyptus* at Nandoni. Densification rate =5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	11,038	621	0.92%	0.27	0.13%	10.76	-
2023	31,061	25,042	36.94%	10.79	5.41%	434.32	4,035%
2038	53,868	53,868	79.46%	23.22	11.63%	934.26	8,680%
2053	64,302	64,302	94.85%	27.71	13.88%	1,115.23	10,362%

(Source: Modelling by researcher and Dr Le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

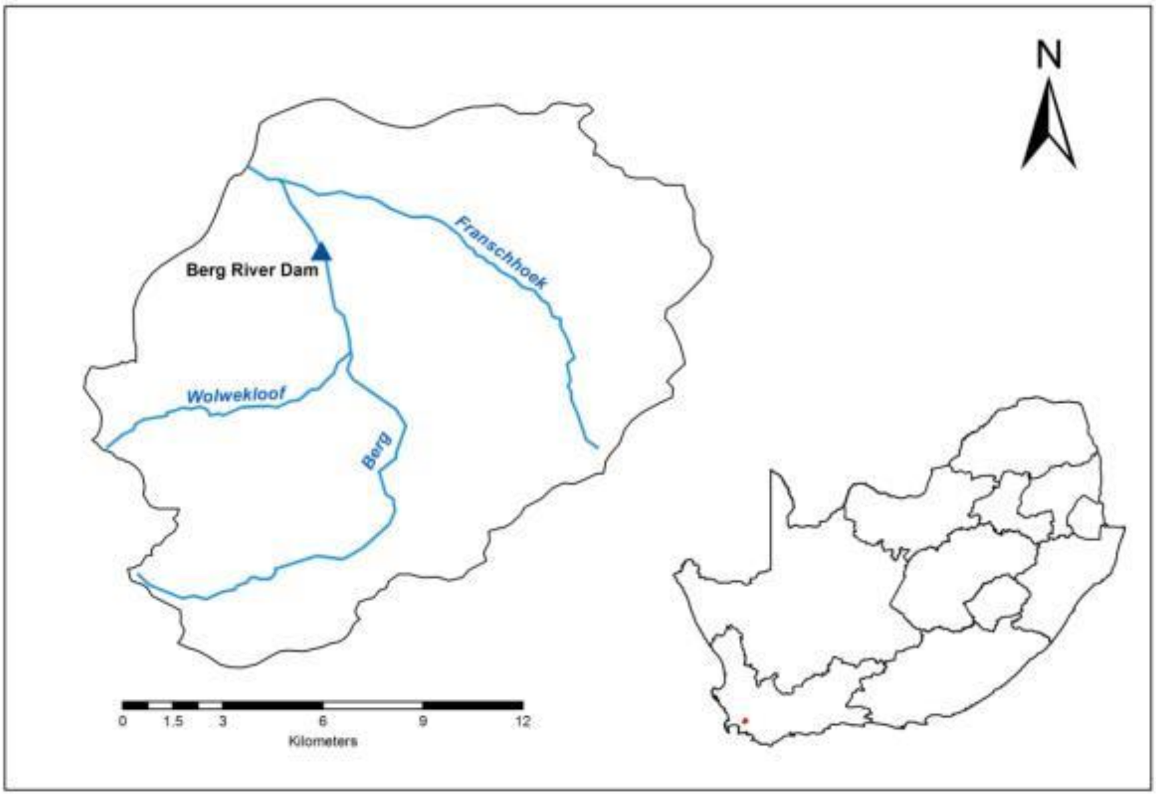
Similar to the Inyaka Dam catchment, Table 5.5 and Table 5.6 show that clearing IAPs in the catchment would not have compensated for the potential yields and water security provided by constructing the dam. However, if follow-up clearing is not continued, the estimated negative effects of IAPs will again be a major water security problem. The projected loss of 13.88 per cent of MAR to invasions – and an even higher level when fully invaded, whatever the time period – is an important loss to be borne in a dry area, and one that may exacerbate any decrease in water security from climate change (Kgope et al., 2010). By making the right choice, decision makers can avoid the cost-to-clear escalating from an estimated R11 million to R1.1 billion.

Like the Inyaka Dam case, the IAP considerations did not feature in the planning documents for the building of the Nandoni Dam and the Minister could not, therefore, have considered this alternative when making the necessary decisions. As with the Inyaka Dam, this analysis suggests that IAP control should have featured in the planning considerations and in the overall system strategy of which the building of the Nandoni Dam was a part. This would be even more justified as an argument, if the other catchment management impacts were to be factored into the planning considerations, as they should have been. Proposing to build a dam – with minimal consideration of measures for its long-term optimal viability – does not put a Minister in a position to make a fully informed decision.

5.6.3 Case 3: Berg River Dam catchment

The Berg River Dam is found on the Berg River in the Western Cape, in the middle of a single quaternary catchment, G10A (Figure 5.15). G10A is located in the Berg River catchment which is part of the Berg-Olifants WMA. The Berg River is one of the main sources of water for the City of Cape Town and the surrounding areas.

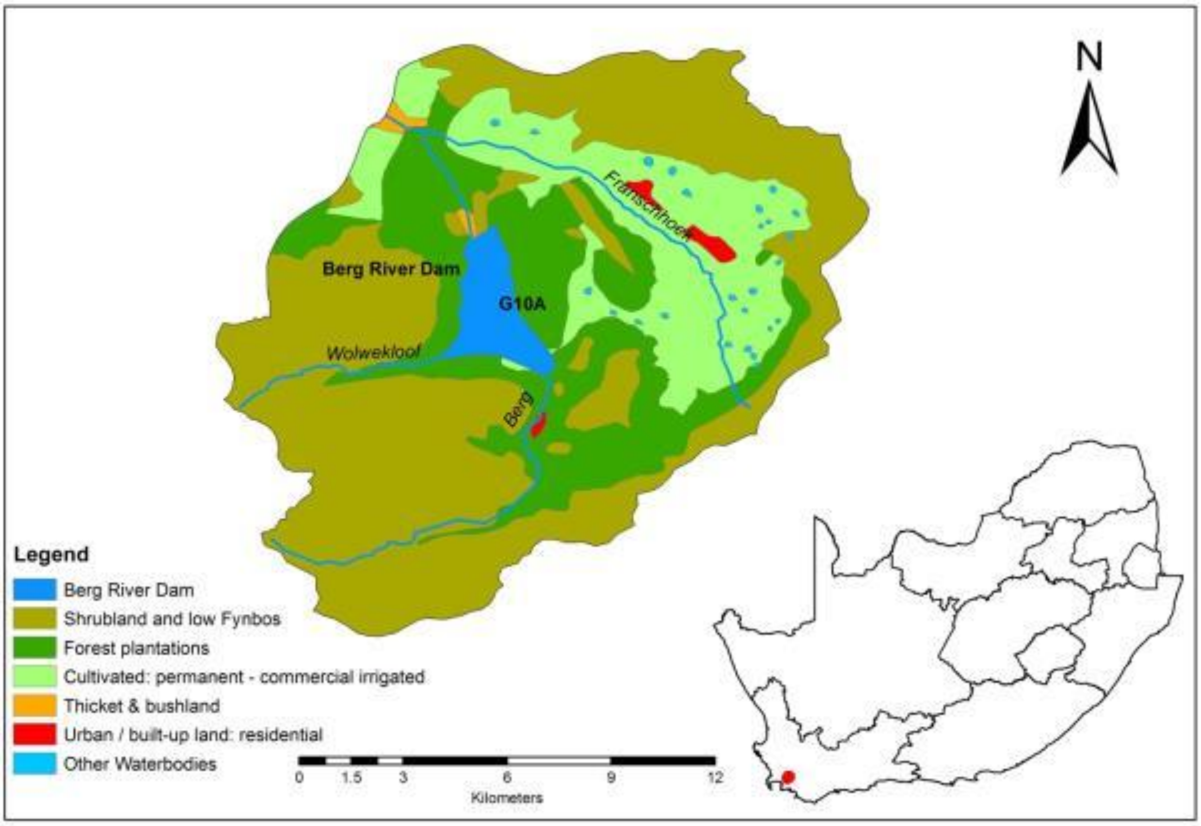
Figure 5.15: Location of the Berg River Dam within quaternary catchment G10A



(Source: Van Den Berg *et al., 2008*)

G10A is largely covered by a mix of low fynbos and shrub land, as well as cultivated land and plantations. A small amount of thicket, bushland and urban land cover are also present, as shown in Figure 5.16. Since the land cover data were collected in 2000 (Van Den Berg *et al., 2008*), much of the plantation areas has been cleared, as a condition of building the Berg River Dam (C. Marais, personal communication, 3 April 2015).

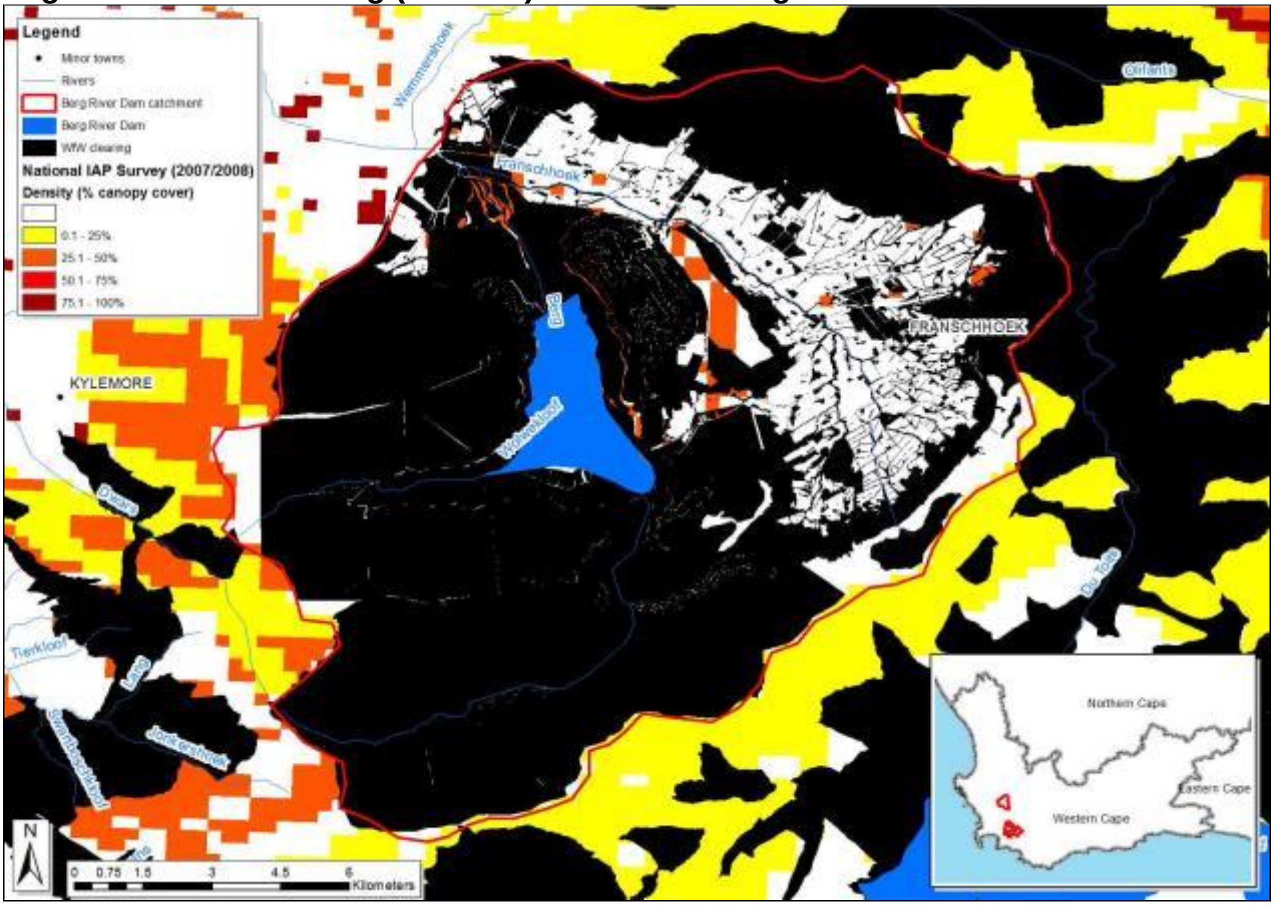
Figure 5.16: Land cover in the quaternary catchment G10A



(Source: Van Den Berg *et al., 2008*)

WfW has extensively cleared IAPs in G10A, having spent R72.6 million (in 2013 rand values), clearing the equivalent of 3 607 condensed hectares (shown in black in Figure 5.17). An estimated 370 condensed hectares of IAPs remain in G10A and are predominantly *Pinus* species, although the seed banks of other IAPs remain in the soils. The remaining invasion is estimated to cause a 1.4 per cent reduction in MAR and cost R4.1 million to clear. The densification in the Berg River Dam catchment has been modelled to increase by one per cent per year, but by 40 per cent every fifteenth year, to simulate the rapid increase in density because of seedling recruitment after wildfires (D. Le Maitre, personal communication, 13 April 2015; Le Maitre *et al.,* 1996). As a result of the use of episodic densification, a five per cent densification rate per year is considered to be too high and therefore has not been modelled.

Figure 5.17: IAP clearing (in black) around the Berg River Dam



(Source: Wannenburgh, 2014)

The reduction of MAR by *Pinus* species in G10A is estimated to be about 5 132 cubic metres per condensed hectare per annum (D. Le Maitre, personal communication, 13 April 2015, based on Le Maitre et al., 2013). This is relatively high because of the exceptionally high rainfall that is experienced in the mountains of this catchment (more than 2 500 millimetres per year).

Table 5.7: Using the optimal pine reduction of 5 132 m^3/ha/yr at Berg. Densification rate = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	1,175	370	2.99%	1.90	1.39%	4.13	-
2023	5,929	3,777	30.47%	19.38	14.22%	42.13	1,020%
2038	11,204	11,204	90.40%	57.50	42.17%	124.99	3,027%
2053	12,279	12,279	99.07%	63.01	46.22%	136.99	3,318%

(Source: Modelling by researcher and Dr le Maitre using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

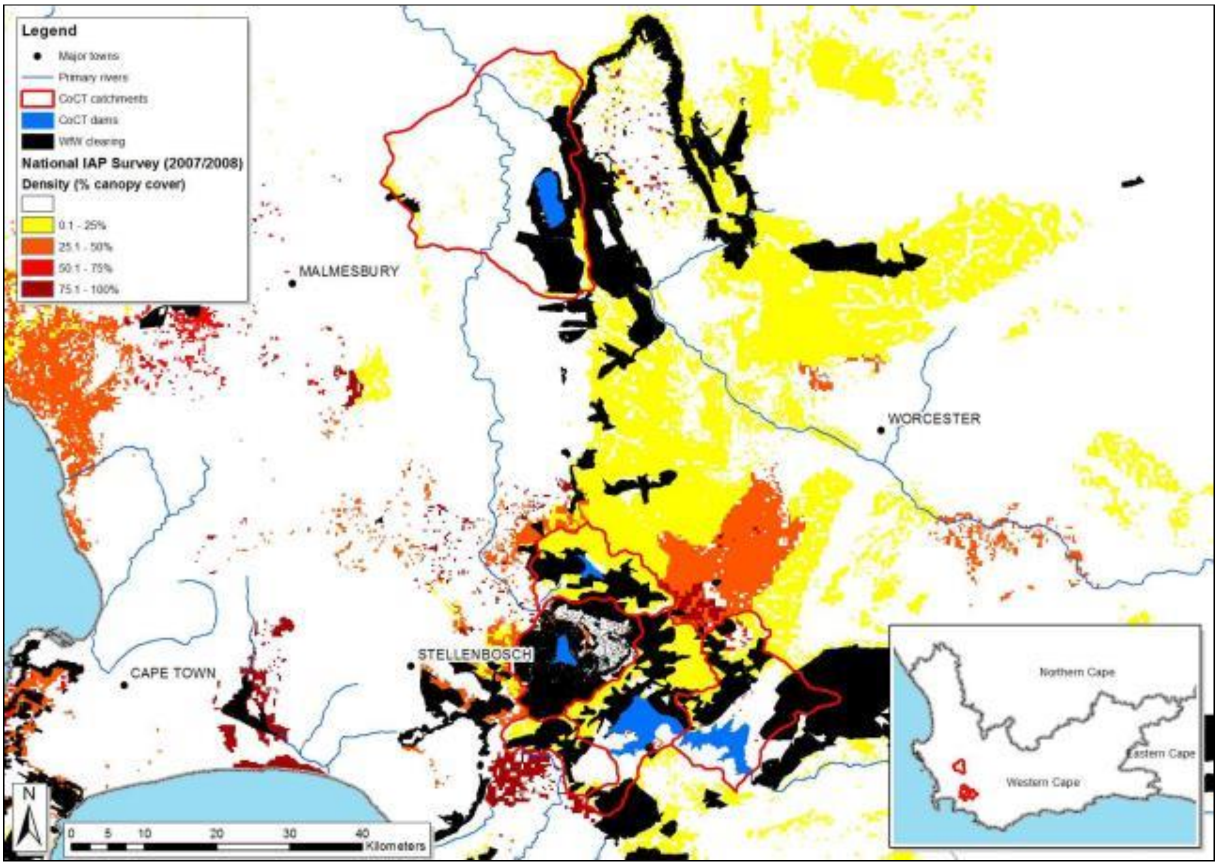
It is estimated in Table 5.8, that the area invaded will increase to 12 279 condensed hectares in forty five years, representing 99 per cent of the invadable area. The cost to clear would increase to R137 million, a cost increase of over 3 300 per cent, and natural MAR would be reduced by 46 per cent. The cost to clear increases from low amounts – where land is not invaded and only requires periodic maintenance treatments for new invaders – to extremely high amounts when the land is densely invaded, given the inevitability of wildfires that will lead to massive seed germination periodically. Quite clearly, decision-makers need to ensure that everything possible is done to stop catchments from being invaded in the first place.

From a decision-making perspective, the Minister would need to be informed of the immediate and long-term clearing costs and water benefits from the clearing (especially in areas where additional yield is needed), in order to best decide on what combination of water-mix options to use. This is especially so when longer-term considerations may be factored into the decision-making, when both dam construction and IAP clearing are given the go-ahead. This was the case in Berg River project and to a lesser extent in Phase 2A of the Olifants River Catchment Resources Development Plan (when De Hoop Dam was built), where partial clearing was required (DWAF, 2005).

An important difference in the case of the Berg River Dam is that the DWS and its implementing agent (the Trans-Caledon Tunnel Authority (TCTA)) committed themselves to ensuring that the catchment around the dam was cleared at the time of the decision by the then Minister of Water Affairs and Forestry, Mr Ronnie Kasrils, to go ahead with the dam. They have largely kept their word, with R15 million (paid over five years) of the agreed R21.35 million (to have been paid over eight years) having been paid over to WfW to implement the work, run the necessary training, and perform the initial and the follow-up clearing (N. Oliver, personal communication, 23 October 2014). The planned clearing and follow-up work was completed at a cost lower than what was originally budgeted.

However, those who were promoting conservation alternatives were seeking more than just the clearing of the catchment of the Berg River Dam (C. Marais, personal communication, 3 April 201). They were arguing for the clearing of all catchments for all existing dams supplying the City of Cape Town. Their logic was that all options affecting overall security of supply should be addressed, rather than looking at just one catchment in isolation. The IAP clearing that has been done in these catchments is shown in black in Figure 5.18. The main argument was that the long-term implications of not clearing catchments would be that invasions would spread, and the long-term clearing costs would be significantly higher. The existing IAP seed bank ensures that long-term follow-up work will be required.

Figure 5.18: IAP clearing in the catchments of dams that supply Cape Town with water



(Source: Wannenburgh, 2014)

The estimates provided by this study (Table 5.8) demonstrate that the authorities have no option but to control IAPs in the catchments. These are the “water factories” (Nel *et al.,* 2013) that will determine whether existing agriculture and other users will have enough water, let alone any new developments requiring water. Thus, the analysis in this case appears different from the other three dams selected, in that the Berg River Dam was primarily an augmentation of supply of water to the City of Cape Town, which was already served by other dams that themselves had IAPs in their catchments.

Looking at the catchments of the dams supplying Cape Town, the key questions would be whether the water released by the clearing of the catchments of these dams would exceed the quantity yielded through the Berg River Dam, and what proportion of the water released by the clearing of the catchments would be able to be stored in the dry months. Another factor would be the higher evaporation rates in the dry summer months, and what influence that might have on actual yield. In summary, the question to ask is: would it make more sense to clear the existing catchments of dams, from a yield perspective as a result of the enhanced runoff (especially in low-flow periods), than to build a dam at the cost and capacity of the Berg River Dam.

Those arguing for clearing the catchments maintain that clearing IAPs is not a direct comparison with the volume of water at the time of the decision (to build the dam), but that it must also take into consideration future invasions and their long-term effects on water supply security as well as on water quality (Marais & Wannenburgh, 2008; Larsen *et al.,* 2001; Le Maitre *et al.,* 2000; Van Wilgen *et al.,* 1997).

What complicates the Berg River Dam situation, unlike for example the Inyaka Dam, is that the catchments are largely the responsibility of the authorities. State money is going to have to be found to do this clearing work, and these costs will escalate significantly if IAPs are allowed to spread, grow and dominate in an area. Any delays in clearing in the mountainous areas potentially result in exponential increases in the long-term costs, given the difficulties in clearing high-altitude areas.

When water is stored in dams, it is for the use of downstream or water transfer beneficiaries. Although the bulk of the water from the Berg River Dam is for the City of Cape Town (which has a higher assurance of supply than for agricultural use), part of the storage is for the water-users situated down-river. The dam releases water to meet the needs of the Ecological Reserve, as well as for farmers and others utilising run-of-river abstraction downstream. However, these needs could have been met, and exceeded, by clearing IAPs in the riparian areas of the river (and indeed elsewhere in the catchments flowing in to the river below the dam), especially since at a national level there is little difference between reliable yield and demand for water. Nationally, reliable yield is estimated to be 13 227 million cubic metres per annum and demand is estimated to be 12 871 million cubic metres per annum (DWA, 2013b).

In this scenario, the authorities could then either build a dam and release amounts of water needed by downstream farmers and other run-of-river users - or they could achieve a similar result by clearing the IAPs from the riparian areas downstream of the dam. Marais and Wannenburgh (2007) calculated that the volume of water (yield) secured through the clearing of IAPs would be 34.4 million cubic metres (61% of the yield of Berg River Dam), at a cost of R 116 million including follow-up costs, or just over seven per cent of the total cost of R1.6 billion for the Berg River Dam). There is corroboration of significant impacts on yield from the work done by Van Wilgen *et al.* (1997) in the Theewaterskloof Dam catchment and Larson *et al.* (2001) in the George catchments.

The yield from clearing of IAPs is less certain than from building a dam and it would take longer to implement – but it would then create more and longer-lasting jobs (given the need for follow-up clearing). Furthermore, the cost of the impact of not clearing increases rapidly. As an example, photographs taken in a small area of the Outeniqua Mountains (Figure 5.19), show how *Pinus* species can dominate catchments. Once established to these levels, the initial and especially the follow-up clearing costs are extremely high (given the need to abseil to get to the plants, and the transport costs), and fire becomes a major factor in the costs to address the invasions. A fire in the Soetkraal area, to the south of the area photographed in Figure 5.19, was estimated to cost WfW about R10 million in follow-up costs, as their capacity to respond to IAP regrowth following unexpected fires is limited (Marais, 2015).

Figure 5.19: Pines dominating catchments in a small area of the Outeniqua Mountains in the southern Cape

(Source: Pretorius, 2012)

There would also be considerations for the water that would flow out to sea (and then the ecological benefits of estuarine requirements for fresh water). While these considerations are complex, they do suggest that the real trade-offs between the provision of water through the Berg River Dam and the conservation benefits of the control of IAPs for the benefits of the users, were not fully thought through.

To these costs and considerations must be added the additional costs and benefits of the different options. The clearing of IAPs can have significant conservation and biodiversity benefits. Many jobs would be created that target the National Development Plan goals of combatting inequity, poverty and unemployment (National Planning Commission, 2012). Further benefits include: fewer wildfires, a reduction in erosion, siltation and flooding, and an improvement in water quality (Le Maitre *et al*., 2002). Additionally, there are tourism and recreational benefits of control of IAPs; canoeists have lost their lives on the Berg River by being trapped under IAPs and drowning. If one option has many more positive externalities than another, these should surely feature in the decision-making of the authorities.

A strong likelihood exists of finding a biological control agent against pine trees (Figure 5.20), and indeed, two inadvertently introduced species are already affecting pines, namely the sirex wasp (Hurley, 2010) and the pitch canker fungus disease (Wingfield *et al*., 2008). However, the implications for the forestry industry of releasing these agents would be significant. As the availability of fresh water will inevitably override the benefits of the forestry industry, it may be surmised that this option will have to be faced by the authorities in years to come. Given that the forestry industry is worth billions of rand and provides many sustainable jobs, this is not a decision that can be lightly taken. Management of IAPs remains, however, as one of the externalities which should have featured in the decision-making regarding the building of the Berg River Dam, as this consideration could have helped to place a figure on the opportunity cost of first building the dam before securing the catchments in terms of IAPs.

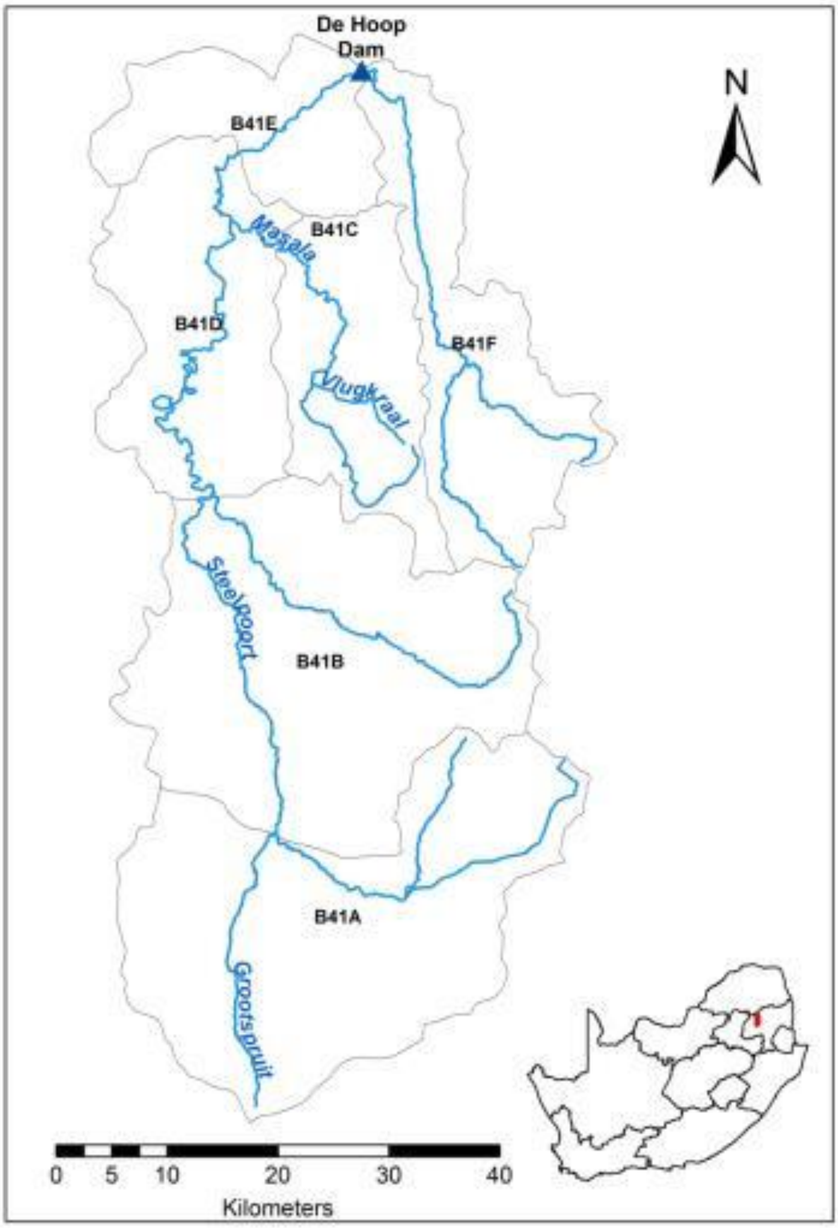
Figure 5.20: Dense invasions of *Hakea sericea* and *Pine trees*

(Source: Van Wilgen, 2014)

5.6.4 Case 4: De Hoop Dam catchment

The De Hoop Dam is located on the Steelpoort River in Limpopo Province. It is located at the northern edge of quaternary catchments B41E and B41F, as shown in Figure 5.21. Added to these are a further four quaternary catchments spread over both Limpopo and Mpumalanga Provinces – B41A to B41D – that feed into the dam. The six quaternary catchments are all located in the Olifants WMA. The De Hoop Dam catchment is the biggest case study in terms of total catchment area.

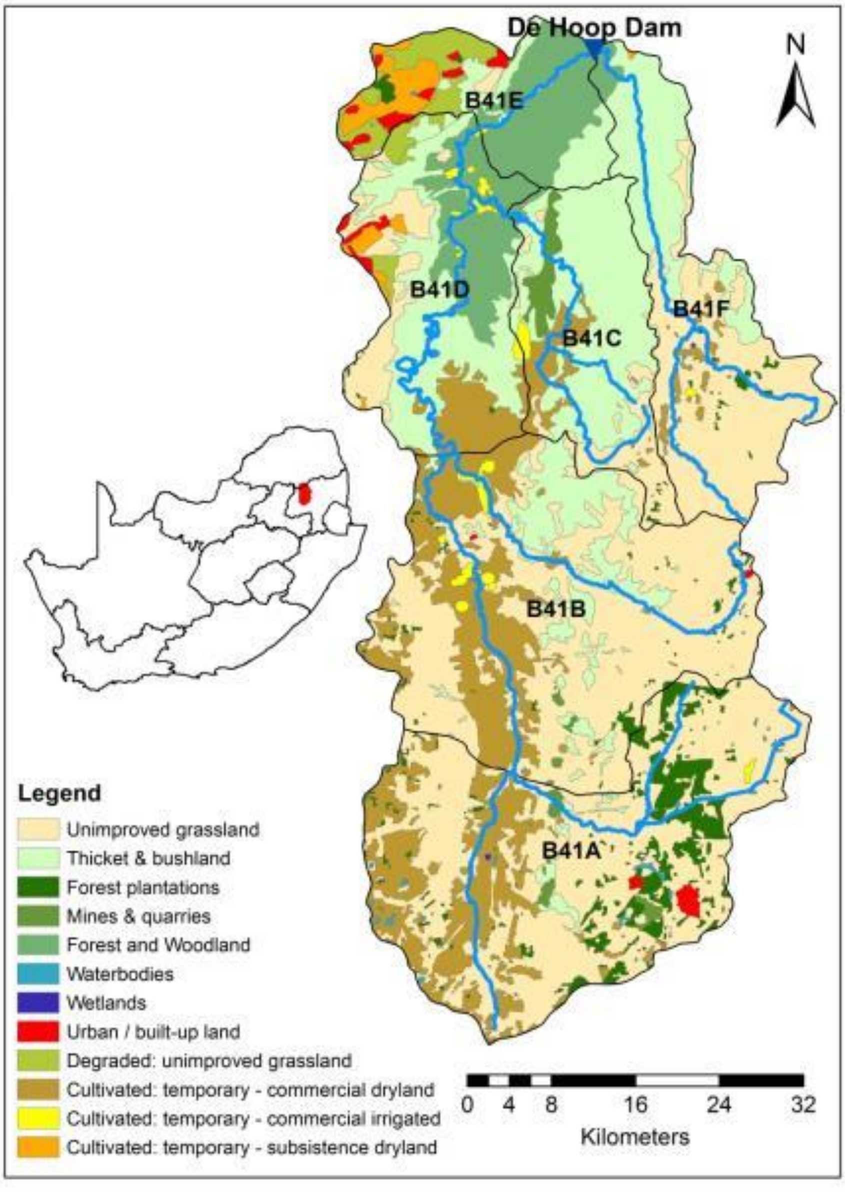
Figure 5.21: Location of the De Hoop Dam and the upstream quaternary catchments



(Source: Van Den Berg *et al., 2008*)

The De Hoop Dam catchment has a variety of land cover types, the most abundant of which is natural (unimproved) grassland, seen in beige, in Figure 5.22. Upstream of the dam (B41C, B41E and the lower half of B41F) the natural vegetation is largely thicket, bushland, and forests and woodland – all of which can be invaded. Further upstream from the dam (B41A, B41B and the upper half of B41F), the land cover is largely made up of natural grassland (able to be invaded) and cultivated land (assumed to be transformed and thus not invadable). Quaternary catchments B41A, B41D and B41E contain some urban land cover, while B41A also contains the majority of the forest plantations in the De Hoop catchment, which are largely *Eucalyptus* and *Pinus* species (Kotzé et al., 2010).

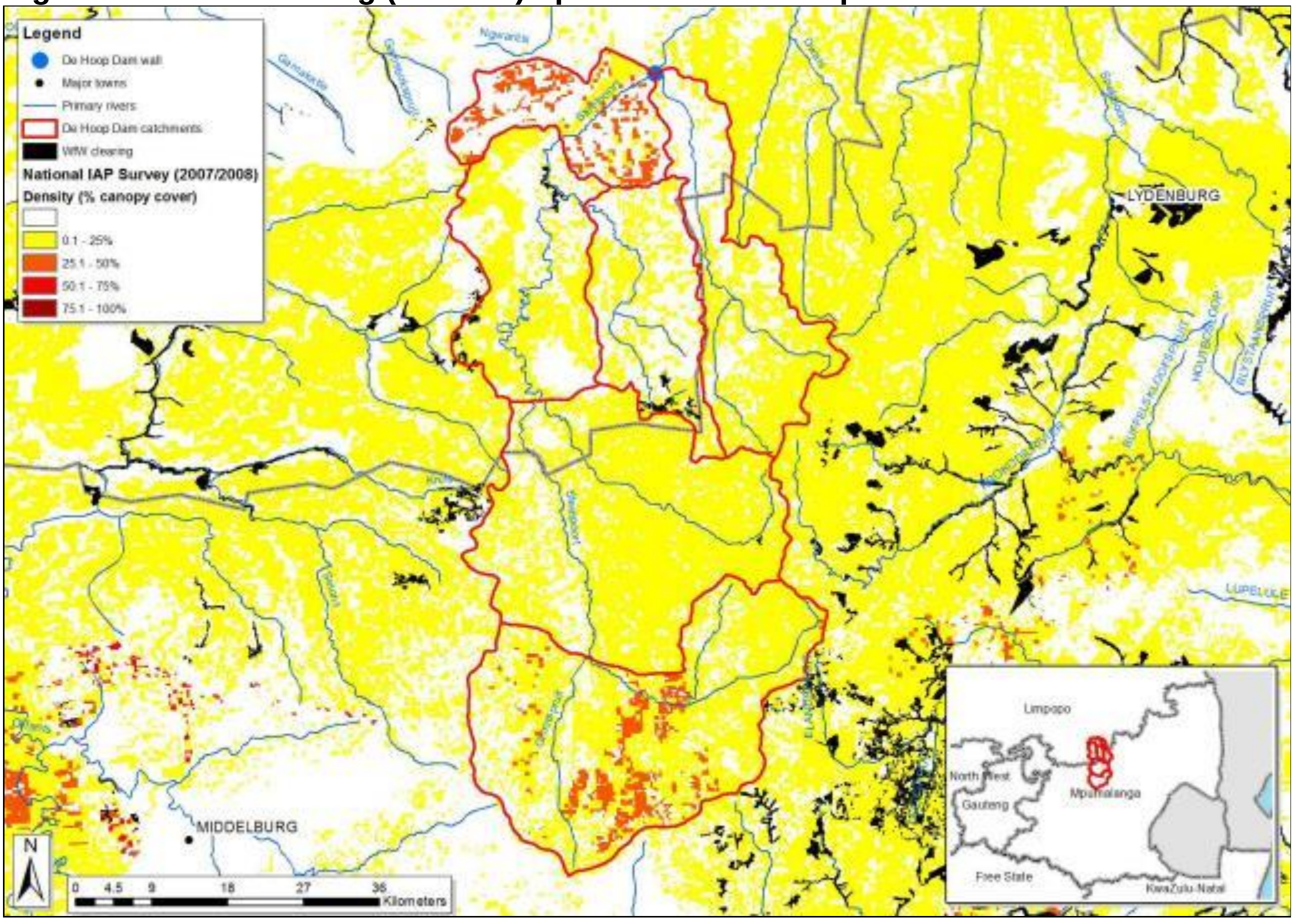
Figure 5.22: Land cover in the quaternary catchment upstream of the De Hoop Dam



(Source: Van Den Berg *et al., 2008*)

Of the four cases in this research, the De Hoop catchment has the highest proportion of invadable land, as 82 per cent is classified to be natural/semi-natural land cover. De Hoop catchment is invaded predominantly by *Eucalyptus* and Wattle in the riparian zones and *Pinus* and *Wattle* in the dryland zones. De Hoop catchment has by far the most extensive invasions (17 295 condensed hectares) and the highest cost to clear (R 287 million) and the least amount of IAP clearing (Figure 5.23).

Figure 5.23: IAP clearing (in black) upstream of De Hoop Dam



(Source: Wannenburgh, 2014)

In total, WfW has spent R2.4 million (in 2013 rand values) clearing the equivalent of 180 condensed hectares of IAPs. This is a surprisingly small amount to have spent on such an important catchment, given the water quality problems in the Olifants catchment (Ashton and Dabrowski, 2011).

Like the Inyaka catchment case, the calculations for the hypothetical scenarios, looking 45 years into the future from 2008, were split into riparian and dryland zone calculations before being combined for the catchment total. The calculations are summarised using conservative densification rates of one per cent in Table 5.8 and five per cent in Table 5.9.

Table 5.8: Combined calculation using the 844/m^3/ha/yr optimal *Eucalyptus* reduction (riparian) and the 408/m^3/ha/yr optimal pine reduction (Dryland). Densification rate = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	173,638	17,295	7.39%	7.98	5.94%	206.06	-
2023	217,916	54,393	23.26%	25.10	18.68%	648.04	314%
2038	230,380	92,061	39.36%	42.48	31.62%	1,096.83	532%
2053	233,146	128,138	54.79%	59.12	44.01%	1,526.66	741%

(Source: Modelling by researcher and Dr David Le Maitre, using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

It is estimated, in Table 5.9, that the area invaded will increase to 128 138 condensed hectares in 45 years, representing 55 per cent of the catchment. Natural MAR would be reduced by 44 per cent and the cost to clear would increase to R1.53 billion, a cost increase of 741 per cent. The higher densification rate used in Table 5.10, results in these estimated impacts nearly doubling.

Table 5.9: Combined calculation using the 844/m^3/ha/yr optimal *Eucalyptus* reduction (riparian) and the 408/m^3/ha/yr optimal pine reduction (Dryland). Densification rate = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	173,638	17,295	7.39%	7.98	5.94%	206.06	-
2023	217,916	54,393	23.26%	85.43	63.59%	2,205.82	1070%
2038	230,380	92,061	39.36%	106.30	79.13%	2,744.77	1332%
2053	233,146	233,146	99.69%	107.58	80.08%	2,777.74	1348%

(Source: Modelling by researcher and Dr David Le Maitre, using unpublished data from (D. Le Maitre, personal communication, 13 April 2015 and Kotzé et al., 2010))

Like the Inyaka and Nandoni cases, clearing the IAPs in the catchment would not have compensated for the potential yields and water security that were provided by the construction of the dam. However, if follow-up clearing is not continued, estimates suggest that IAPs will cause a major water security problem. Unlike the Inyaka and Nandoni cases, however, IAP management has appeared in the De Hoop Dam planning documents, albeit briefly, as no evidence of a deep, analytical consideration of non-infrastructure-based options could be found.

It is clear from the above analysis that the authorities cannot allow IAPs to spread, densify and grow as is projected. The water losses are not affordable, and the cost-to-clear budgets – increasing to over R2.8 billion in time (whether or not over 45 years) – are prohibitive. It patently makes sense to have a strategy for clearing and maintaining the catchment in a cleared state, at the time of commissioning the dam. Not to do so makes as little sense as not budgeting for operational and maintenance costs for the dam itself. Once again, then, it can be concluded from this analysis that the Minister at the time was not put in a position to make an informed decision, and to ensure that a comprehensive strategy for long-term water security in the area was sought, rather than a simple plan to build a dam.

5.7 CONCLUSIONS

The second objective of this research project is to analyse the costs and benefits of IAP management as a water supply option. To achieve this objective IAP management was discussed as a general concept, within the context of a range of water-mix options. Then the current and potential future costs and effects of IAP management were analysed within the context of the four case study catchments.

As a first and very clear finding, the results show that the clearing of IAPs in these catchments would not have provided anywhere near the amount of water that has been secured through the building of each of the dams. Even the Berg River Dam case, where other catchments could be cleared, would not provide the yields that the planners had deemed necessary. From this respect, the Ministers could be said to have made informed decisions to go ahead with the dam, albeit only based on this one alternative, the clearing of the IAPs in the catchments of the dams. It can also be argued that, without a dam to catch the enhanced MAR from clearing the IAPs, the benefits of clearing would be diluted further. Nevertheless a comparison of the management of IAPs in all four cases ought to have been provided to the Minister at the time, to enable him to have made a fully informed decision. There is no evidence, however, that this was done. Notwithstanding this fact, the pivotal argument needs to relate to what will happen to yield in the future, if clearing is not done.

A second, and more relevant finding, is that if the clearing of IAPs is not done, and they are allowed to spread to their full potential, the IAPs can reduce the MAR and yield substantially in the long-term (46 per cent of MAR in the Berg River Dam case). Areas that are not currently invaded will become invaded, demanding extreme long-term management. Wildfires, which are natural and necessary for ecosystem functioning in fire-adapted systems at certain times, will exacerbate the spread of IAPs. Moreover, the cost of controlling the IAPs grows exponentially, and can reach a threshold where it is no longer affordable to control them (given their copious and long-lived seed banks). The evidence suggests that clearing of IAPs from catchments (especially riparian areas) is essential for long-term assurance of water supply and the need for this clearing should have been factored into water supply decision-making from the outset.

A major conclusion of this chapter is that water resource planning is not just for immediate needs, but for long-term, sustainable supply. That being the case, the management of IAPs ought to have been a critical consideration by the Ministers when taking decisions regarding all four of the case-study dams. The estimated long-term reduction in MAR by IAPs, if they are not controlled, far outweighs the increase in MAR and the yield from constructing a dam. What is more, climate change effects, while difficult to quantify, are likely to exacerbate the situation (Midgley *et al.,* 2005).

In the case of the Berg River Dam, a specific budget to clear IAPs in the catchment was agreed to, after representation by WfW. This was not done in the subsequent decision to build the De Hoop Dam, and nor was it done in the two prior decisions, for the Nandoni and Inyaka dams. These four cases demonstrate the need to secure budgets for the long-term conservation of the supply of water through IAP management and other water-mix options. Furthermore, the cases demonstrate the need for legal enforcement of IAP management.

Options to regulate IAPs have been possible through the Conservation of Agricultural Resources Act (Act No. 43 of 1983), the National Water Act (Act No. 36 of 1998), the Mountain Catchment Areas Act (Act No. 63 of 1970) and the recent Alien and Invasive Species Regulations (DEA, 2014a), in terms of the National Environmental Management: Biodiversity Act (No. 10 of 2004). It would also make sense for decision-makers to require a legal enforcement of the control of IAPs, to protect the catchments from the water loss and many other negative impacts of IAPs. Yet this, too, has never been done.

What becomes increasingly obvious is that the potential of using catchment management options to improve water resources management has not been effectively realised within the decision-making mechanisms regarding water supply in South Africa. Nor is there any comprehensive retrospective analysis that has been done in South Africa on the efficacy of the management of catchments for water security, notwithstanding a slew of work related to organisations like the Working for Water programme in particular (for example, Meijninger & Jarmain, 2014; Le Maitre et al., 2013; Marais & Wannenburgh, 2008, Blignaut et al., 2007; Everson et al., 2007; Görgens & Van Wilgen, 2004; Marais et al., 2004; Le Maitre & Görgens, 2003; Le Maitre et al., 2000 Van Wilgen et al., 1997). Ministers have clearly not been put in a position to make informed decisions regarding dams in South Africa, in comparison to investments in alternatives, including with respect to catchment management.

It is finally concluded that the various Ministers were not put in a position to make fully informed decisions for optimal water security in the long-term, when approving each of the four dams that form the case studies for this research.

In the following chapter, (Chapter Six) the decision to build De Hoop Dam is considered. The decision to build is examined through an analysis of the decision-making that took place, using the rational decision-making model (Zindiye, 2012) as a framework.

CHAPTER SIX
EVALUATING THE DECISION TO BUILD THE DE HOOP DAM

6.1 INTRODUCTION

In Chapters Four and Five, four dams (Inyaka, Berg River, Nandoni and De Hoop) together with their catchments were discussed and analysed in terms of the costs and benefits of constructing the dams, and of clearing the IAPs from the dam catchments (linking to the first two objectives of this study). In Chapter Six, the third objective – evaluating the quality of the decision-making process in which the decision to build De Hoop Dam was made using a decision-making model – is discussed.

As discussed in Chapters Four and Five (under 4.4. and 5.6.4), the De Hoop Dam is located on the Steelpoort River as Phase 2A of the Olifants River Water Resources Development Project (hereafter referred to as ORWRDP Phase 2A). The De Hoop Dam was planned, designed and built by the DWS to supply water for domestic and industrial (mining) purposes. At the end of 2014, the construction of De Hoop Dam was 99 per cent complete. The De Hoop Dam was expected to cost R1.744 billion (in December 2012 rand values); by December 2014 it had cost R3.1 billion (in December 2012 rand values). Some of the reasons for the cost (and time) overruns include: the economic recession of 2008/2009 which stifled the development of mines (which were supposed to pay half the De Hoop Dam costs); the demand for infrastructure development capacity leading up to the 2010 Soccer World Cup; unanticipated rainfall impacts that delayed construction; construction labour force strikes; foundation excavations needing to be much greater than anticipated (and subsequently concrete usage nearly doubling); and conservative design decisions (for example, using roller compacted concrete rather than rock fill in the left embankment) (Cloete, 2014).

In addition to the cost increases, the estimated yield for the De Hoop Dam was re-evaluated. When the building of this dam was authorised (in the record of implementation decisions report (DEAT, 2005)) the estimated yield was stated as 80 million cubic metres per annum (DWAF, 2006b). The estimated yield was recalculated (on new information, including better water use information), as part of the Olifants Reconciliation Strategy, as 66 million cubic metres per annum (DWA, 2010). This represents a 17.5 per cent decrease in the estimated yield of De Hoop Dam. The decrease in estimated yield and the near doubling of costs indicate a large gap between the original estimates and the actual outcomes. These gaps suggest that making a retrospective analysis of the decision-making process related to the building of the De Hoop Dam (Figure 6.1) is worthwhile.

Figure 6.1: Releasing of water from the De Hoop Dam.

(Source: GCIS, 2014)

In the decision to build the De Hoop Dam, the DWS (as well as other sections of the South African Government, notably Cabinet) had to make many decisions of varying magnitude, importance and consequence. Chapter Six focuses on evaluating the decision to build De Hoop Dam by firstly considering the ORWRDP Phase 2A decision-making documents (DWAF, 2006a; 2006b; DEAT, 2005; 2006) and associated documents, and secondly, by analysing the views and opinions of ten key people involved in managing different aspects of the planning and construction of the De Hoop Dam. Decision-making models and other components of the decision-making process (Zindiye, 2012) are discussed in the following section.

6.2 DECISION-MAKING MODELS

One of the fundamental aspects of all levels of management is decision-making. Decision-making ranges from routine (of little consequence, for example, ordering office supplies), to key decisions with importance and major consequences (for example, what type of dam wall to build and where to build it). Decision-making is the outcome of a process which is essential in all stages of the lifecycle of any project. The decision-making process essentially includes: understanding and explaining a problem, collecting information, determining alternative solutions and selecting a response and reviewing the decision-making (Zindiye, 2012, Turpin & Marais, 2004). However, decision-making is rarely a straightforward process because of the uncertainty embedded in decisions made in the present, with assumptions about the future. Impacts envisaged and assumptions made are affected by multiple internal and external forces which the decision-makers may have little or no control over. In attempting to account for this uncertainty, decision-making is often supported by a decision-making model (or models). There are many different models of decision-making, some of which are listed in Table 6.1.

Table 6.1: A selection of decision-making models

Decision-making model	References
The rational model	Zindiye, 2012; Turpin & Marais, 2004
The bounded rationality model	Zindiye, 2012; Turpin & Marais, 2004
The political model	Zindiye, 2012; Turpin & Marais, 2004
Simon's sequential model	Paul *et al.,* 2015
Mintzberg, Raisinghani & Theroret's iterative model	Paul *et al.,* 2015
March and colleagues' anarchical model	Paul *et al.,* 2015
Single objective management model (with bee algorithm)	Paul *et al.,* 2015
The multiple perspectives model	Turpin & Marais, 2004
The garbage can model	Turpin & Marais, 2004

(Source: Researcher's own construction)

All the models listed in Table 6.1 have limitations. For example, the single objective management model (Paul *et al.,* 2015) cannot deal with more than one objective, and in the garbage can model (Turpin & Marais, 2004), any decision that is made, is completely dependent on the people who make up the decision-making group. Furthermore, some of the models, such as the single objective management model, are not commonly used. Zindiye (2012) presents the rational, bounded rationality and political models in relation to management in South Africa.

In the context of this study, solutions to the problem of water scarcity are actively searched for, to accomplish the goal of maintaining a positive water balance (i.e. ensuring, as far as possible, that water supply is greater than demand). For these reasons, a decision-making model is needed that can evaluate the following criteria: the problem, goal setting (including multiple objectives as well as environmental forces), and the process of finding, assessing and choosing solutions. None of the four models discussed in Paul *et al.* (2015) is detailed enough to be able to evaluate all of these mentioned criteria. Furthermore, the garbage can model (Turpin & Marais, 2004), does not solve all the problems as it ends abruptly when a decision is made. The multiple perspectives model (Turpin & Marais, 2004) focuses on collecting as many stakeholder views of the problem as possible at the expense of the other criteria listed above. The rational, bounded rationality and political models, however, are able (to varying degrees) to evaluate the above-mentioned criteria and are thus discussed further. Additionally, no empirical evidence of these decision-making models being applied in other water resource-related studies has been found.

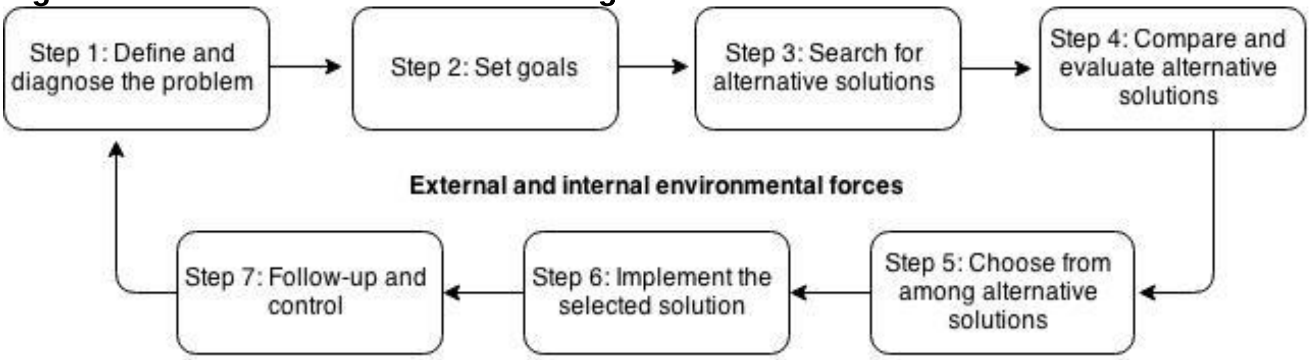
6.2.1 Rational decision-making model

The rational decision-making model describes a set of seven steps that improve the likelihood that a group or individual's decision-making will be reliable and logical (Zindiye, 2012). The rational model aims to achieve the greatest number of goals with the given limitations and does not focus on the appropriateness of the goals themselves (Zindiye, 2012).

The rational model has the following limitations: not all the steps are always followed in order or at all (especially in non-routine decisions); decision-makers are expected to know the alternative options and their various impacts (these can be difficult to quantify in uncertain conditions); and in reality, human decision-making only comes close to the rational model (Zindiye, 2012:261-264; Turpin & Marais, 2004). On the other hand, the rational model has these advantages: it is a logical sequence of steps; it promotes alternatives with the greatest utility; it takes internal and external forces into consideration; and it maximises goal attainment within the given restrictions (Zindiye, 2012:261-264; Turpin & Marais, 2004).

The seven steps of the rational model are affected by internal and external influences, such as stakeholder desires or changes in commodity prices such as concrete (Figure 6.2).

Figure 6.2: The rational decision-making model



(Source: Zindiye, 2012:261)

The seven steps are cyclical in nature (Figure 6.2). The process starts with perceiving (called ‘noticing’), defining (‘interpreting’) and understanding (‘incorporating’) a problem. ‘Noticing’ involves identifying environmental forces that are contributing to the problem, for example a dam collapsed. The identified environmental forces are then assessed as to whether they are root (for example, the dam was structurally unsound) or symptomatic causes (for example, there was above average rainfall before the dam collapsed) of the problem in the ‘interpreting’ stage. Lastly, ‘incorporating’ relates the problem and root causes to the goal setting of Step Two (for example, what goals can dam builders set to make sure the new dam is structurally sound) (Zindiye, 2012).

The second step is to set goals that solve the problem though eradicating the root causes. Under conditions of uncertainty, setting specific goals can be extremely difficult because there is often insufficient information on which to judge the acceptability of the goals. When uncertainty is present, alternative goals are compared and evaluated by the decision-makers and the best option based on the available information is chosen (Zindiye, 2012). After setting the goals, Step Three is to search for alternative solutions to achieve the goals. Alternative solutions are produced through a variety of methods including additional research, data-gathering, calling upon experts and brainstorming sessions. If no alternative solutions are found, then the decision-makers may need to go back to Step Two and revise the goals that were set.

After a range of alternative solutions has been acknowledged in Step Three, the solutions are contrasted and assessed in Step Four (Figure 6.2). The criteria for contrasting and assessing the solutions depends on the specific components of the decision-making process (i.e. the type of problem, the type of decisions and the goals) and the nature of the decision to be made. For example, when deciding how to supply more water to an area, dams and other alternatives can be compared using URVs (refer to section 4.2.6).

The DWS uses a range of criteria and analyses (known collectively as multi-criteria analysis – see section 4.2.7), to contrast and assess alternative water-mix solutions, in order to best provide water to an area. After the alternative solutions are contrasted and assessed, decision-makers must choose a solution or solutions (Step Five). Choosing a solution can be difficult when the problem is unusual and ambiguous (non-programmed – such as deciding on the best option for providing additional water to an area) as the levels of risk and uncertainty are high. After choosing a solution or solutions, they need to be implemented (Step Six). If a solution cannot be implemented for some reason – for example, if it is not supported by the majority of stakeholders – the next best solution should be examined and, if supported, should then implemented (Zindiye, 2012).

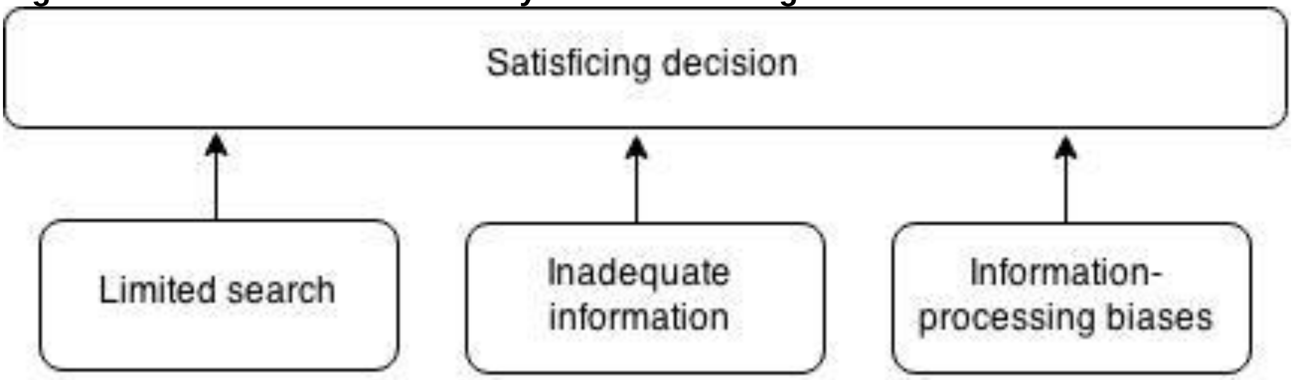
The seventh and final step of the rational process is to review and control the problem(s) and the decision-making. Controlling the implementation process and following up the implementation by assessing the results is essential, because the goal will not be achieved through implementation alone (Zindiye, 2012). Reviewing the problem and implementation of the solution may lead to reviewing the goal (if not successfully implemented) or redefining the problem and starting the rational process again (Zindiye, 2012). Added to this, the internal and external environmental forces which influence every step of the rational process, are continuously changing (think of the petrol price), and these changes may require the problem and/or goals to be redefined.

Some shortcomings of the rational model are: it is not always necessary to utilise all of the above-mentioned steps when making routine decisions, since they are normally made under conditions approaching certainty; and the steps are often not followed in order or not at all in the case of adaptive or innovative decision-making (Zindiye, 2012; Turpin & Marais, 2004; Cohen & Bailey, 1997). Instead, the bounded rationality or political decision-making models are sometimes applied (albeit not always consciously). A further shortcoming summarised by Zindiye (2012) is that, at most, human decision-making only approaches the principle of rationality, which is why people sometimes use the bounded rationality or political models instead.

6.2.2 Bounded rationality decision-making model

The bounded rationality model focuses attention on the shortcomings of rationality (and the rational model) and gives a better view of the decision-making processes that many people use routinely, as shown in Figure 6.3 (Zindiye, 2012; Turpin & Marais, 2004).

Figure 6.3: The bounded rationality decision-making model



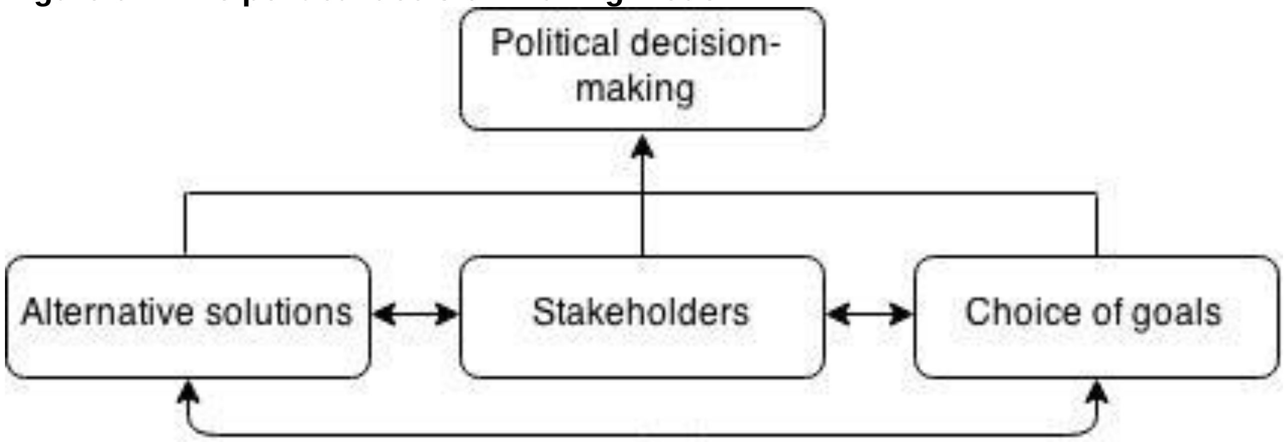
(Source: Zindiye, 2012:264)

The bounded rational model is based on three human tendencies that commonly occur during decision-making (Figure 6.3). First, when a problem occurs, people perform limited searches for suitable goals and alternative solutions (Zindiye, 2012; Turpin & Marais, 2004). People will then search until they find a solution that they deem to be acceptable, not necessarily the best alternative solution or goal. The next tendency is that people often have incomplete or poor information about the problems they are trying to solve, and the external forces that influence the decision-making (Zindiye, 2012; Turpin & Marais, 2004). Thirdly, the bounded rationality model recognises that people have information-processing biases. Examples of these biases are the availability bias (overestimating how often an event transpires based on how many times a decision-maker has personally experienced it) and the concrete information bias (where personal experience can overshadow other information such as statistical suggestions). Together, these three human tendencies lead to decision-making, known as a satisficing decision, which is acceptable but not ideal (Zindiye, 2012). When stakeholder power is more apparent, the political decision-making model is more apt.

6.2.3 Political decision-making model

The political model focuses attention on decision-making that often occurs in governmental problem solving (Zindiye, 2012). Decision-making in the political model as shown in Figure 6.4 is shaped by influential stakeholders, both internal and external, who try to express problems to best benefit themselves (Turpin & Marais, 2004).

Figure 6.4: The political decision-making model



(Source: Zindiye, 2012:266)

In the political model (Figure 6.4), it is likely that disagreement will occur over what goals to set and whether they are conflicting or not (Turpin & Marais, 2004). The influence of stakeholders may be one-sided or relatively equal between a few key stakeholders. In cases where a stakeholder has the majority of the influence, the decision-making will likely reflect the stakeholder's own goals (Turpin & Marais, 2004). When the influence is relatively equal between stakeholders, discussions and compromises regarding goals may occur (Zindiye, 2012).

As with the setting of goals, there is often disagreement over alternative solutions and whether to search for them or not. Disagreements between stakeholders often result in insufficient searching for alternative solutions. Solution disagreement also occurs because stakeholders view information as having influence (or power) and so they use or withhold information to best achieve their own goals, sometimes at the expense of others (Turpin & Marais, 2004). Furthermore, political decision-makers (especially when influence is one-sided) occasionally pursue self-serving goals that are short-termed, constrained and ethically contentious (Zindiye, 2012).

6.2.4 Selection of decision-making model as a framework

The DWS has long been driven by supply-side thinking without a deep consideration of DSM options (DWA, 2013b; DWAF, 2004; DWAF, 1986). This is evident from the fact that over 5 000 dams (with walls of over five metres or a capacity greater than 1 000 000 cubic metres) have been built and registered in South Africa over the past century by the DWs and others (DWS, 2014). Although DSM options have been acknowledged, there has only been limited implementation as they are regularly considered not to be viable options by water decision-makers due to possible lack of knowledge, understanding and base line supply-side information, with which to compare DSM options (Rabe *et al.,* 2012). In the second *National Water Resources Strategy* (DWA, 2013b), DWS has put effort into promoting water conservation and water demand management, calling it an essential part of ensuring that enough water for current and future demand exists. Evidence of successful and continued implementation of DSM by DWS is yet to be seen.

Nevertheless, the supply-side focus would bias decision-making by the DWS, in terms of which solutions are taken seriously and which solutions are considered at only a basic level to satisfy regulations. In the governmental decision to build De Hoop Dam, it is evident that politics, and therefore to some degree the political decision-making model, played a role. Despite this, the political and bounded-rationality models, due to their numerous limitations discussed above, will not be used as a framework to analyse the decision to build the De Hoop Dam. Rather, the rational model is used as a framework in this chapter.

Over and above the limitations of other decision-making models, the rational model was selected because: it is most likely to result in a group or individual's decision-making being reliable and logical; it is a logical step-by-step process; the limitations of the rational model, such as the steps not being followed in order when innovative decisions are made, are not as severe as those of the bounded rationality or political models; and because the rational model actively takes external forces into account at every step (Zindiye, 2012). However, in following the logical process of the rational model, aspects of the bounded rationality and political models may influence some of the steps because, as Zindiye (2012) suggests, human decision-making at best only approaches the principle of rationality.

The seven steps of the rational model are used as a framework to evaluate the quality of the decision-making process used in building the De Hoop Dam. With each step, the decision-making that resulted in the decision to build the De Hoop Dam is compared to the definition, as outlined by Zindiye (2012:262-263), using interview findings and related documentation, to support the comparison.

6.3 RESEARCH METHODS

The data collection methods used in this chapter are documentation (see section 3.3.1) and semi-structured, in-depth interviews (see section 3.3.3). The data analysis methods used in this chapter are intra-case analysis (see section 3.3.5), content analysis (see section 3.3.6) to analyse the interviews and decision-making process (see section 3.3.7). The interview guide (list of questions) is presented in Appendix E. The research design, methodology and methods relevant to this study have been explained in more detail in Chapter Three.

6.4 FINDINGS AND DISCUSSION

This study was undertaken in 2013 when the dam construction was nearly complete; it recognised that the decision to build the dam was driven by supply-side thinking without a deep consideration of DSM options. The study has reviewed the economic costs and benefits of the dam (in Chapter Four) and of IAP management (as a management water-mix option in Chapter Five).

In this chapter the quality of the decision-making process in building De Hoop Dam is interrogated with reference to interviews as well as to DWS and other documents (listed in section 6.4.1) which relate to the decision to build this dam. The interview guide was constructed with the assumption that there is a need for additional water supply in the catchment.

The findings are presented in the following manner: interviewees' perceptions of the decision-making model appear in section 6.4.2; findings relating to interviewees' perceptions of the decision-making process according to the rational decision-making model are discussed in section 6.4.3. A reflection on the interview questions is then presented in section 6.4.5.

6.4.1 Documents relating to the decision to build De Hoop Dam

Documentation together with the results of interviews with key participants (data collection triangulation), is used to construct a narrative of evidence concerning the decision-making involved in building De Hoop Dam. In the documentation, principal references list additional documents that could not be individually sourced and are therefore termed secondary documents in Table 6.2. These secondary documents, by their titles, provide evidence of attention to particular decision-making steps.

The principal and secondary documents relating to the decision to build De Hoop Dam are listed in Table 6.2, and are linked to the relevant step(s) of the RDMM shown in Figure 6.2. The RDMM steps are as follows: Step 1: define and diagnose problem; Step 2: set goals; Step 3: search for alternative solutions; Step 4: compare solutions; Step 5: choose a solution; Step 6: implement chosen solution; and Step 7: follow-up and control. Furthermore, Table 6.2 provides comments on how and why each document relates to the relevant RDMM step(s). Principal documents are labelled D1 to D8 and secondary documents are labelled D1.1, D1.2 and so on.

Table 6.2: Timeline of relevant documents relating to decision to build De Hoop Dam, the Olifants River Water Resources Development Project (ORWRDP) Phase 2A, in relation to the relevant steps of the rational decision-making model (RDMM)

Date	Principal reference	Secondary document	Comments	Relevant RDMM step(s)
1991	Aston, 2000 (D1)	(D1.1) *Water Resources Planning of the Olifants River Basin - Study of Development Potential and Management of the Water Resources*	D1.1 provides the earliest evidence that DWS spent time defining future problems, as well as proposing future goals and alternative solutions. It describes the culmination of a six-year desktop study commencing in 1985 to create a river basin management plan for the Olifants River basin. D1.1 is also briefly mentioned in D2 as part of a list of Olifants River basin planning investigations (DWAF, 2006a).	1, 2, 3

Date	Principal reference	Secondary document	Comments	Relevant RDMM step(s)
2000	Aston, 2000 (D1)	(D1.2) *Pre-feasibility Study on Bulk Water Supply in the Middle Olifants and Steelpoort River Area*	D1.2 provides further evidence of DWS assessing the water supply situation and searching for alternative water resource development solutions in the Steelpoort River area of the Olifants River basin. It also indicates that alternative solutions were assessed. D1.2 is also briefly mentioned in D2 as part of a list of Olifants River basin planning investigations (DWAF, 2006a).	1, 2, 3, 4
2001	DWAF, 2006a (D2)	(D2.1) *Olifants - Sand Water Transfer Scheme: Feasibility of Further Phases*	D2.1 provides additional evidence that alternative solutions were considered by DWS. It forms part of a list of Olifants River basin planning investigations.	3
2003	DWAF, 2006a (D2)	(D2.2) *Olifants River Water Resources Development Plan Study: Water Requirements assessment study for future economic development in the Dikolong Corridor.*	D2.2 provides evidence of an analysis of the (potential) mining water needs in the Steelpoort Catchment and surrounding areas. It updates the water supply needs and planning goals of the Olifants River basin.	1, 2
2003	DWAF, 2006a (D2)	(D2.3) A Strategy to Secure Water in Support of Social and Economic Development in the potential area to be supplied from the Middle Olifants River catchment	D2.3 provides further evidence of DWS defining and refining the water supply needs and goals to satisfy those needs.	3
2003 (14 February)	Mbeki, 2003 (D3)		D3 is the 2003 *State of the nation address of the* [former] *president of South Africa, Thabo Mbeki.* D3 is the first public announcement that a dam would be built on the Olifants River system (See quote below). Officially setting a major goal. D3 is also briefly mentioned in D2 (DWAF, 2006a). "This investment will include … a dam on the Olifants River in the Limpopo Province to provide water for platinum mining and agriculture" (Mbeki, 2003)	2
2004 June	DWAF, 2006a (D2)	(D2.4) Memorandum to Cabinet	D2.4 is the memorandum from the Minister of Water and Sanitation to Cabinet with key project recommendations. It provides evidence of DWS presenting their chosen solution for approval.	5
2004 (9 June)	DWAF, 2006b (D4)	(D4.1) Cabinet Resolution	D4.1 provides evidence that De Hoop Dam was to be built on a fast-track premise (planning and design occurred concurrently). Environmental authorisation was still needed at this point, after which construction would be able to start. D4.1 thus provides evidence of a solution being chosen and conditionally approved.	5, 6

Date	Principal reference	Secondary document	Comments	Relevant RDMM step(s)
2005 (21 November)	DEAT, 2005 (D5)		D5 is the *Record of decision (ROD) for ORWRDP (Phase 2): Infrastructure development.* It provides evidence of the permission and conditions (from the Department of Environmental Affairs and Tourism) that allowed DWS to build the De Hoop Dam. D5 is also referred to extensively in D7 (Couzens & Dent, 2006) and briefly in D4 (DWAF, 2006b). Mining is not mentioned in the RoD as a reason for the project. The first reason given refers to the rural communities' needs.	6
2006 Feb (started September 2005)	DWAF, 2006b (D4)		D4 is *ORWRDP Dam on the Steelpoort River at De Hoop (Phase 2A): Record of Implementation decisions*. It provides evidence of the official handover of Phase 2A from DWS's planning directorate to their construction directorate. D4 represents the official start of the design and building phases of the De Hoop Dam.	6
2006 August (started July 2005)	DWAF, 2006a; (D2)		D2 is *ORWRDP Summary report on detailed planning stage.* It provides evidence that the DWS spent time defining: the anticipated need for additional water in the Olifants River Catchment; how alternative solutions (to meet this need) were searched for, considered and rejected; and how De Hoop Dam became the chosen solution. D2 is also briefly mentioned in D4 (DWAF, 2006b).	1, 2, 3, 4, 5
2006 (16 October)	DEAT, 2006 (D6)		D6 is *Revised Record of decision for ORWRDP (Phase 2): Infrastructure development.* It provides evidence that shows that environmental considerations (and appeals) were given required reflection. D6 is also referred to extensively in D7 (Couzens & Dent, 2006).	5, 6
2006 (31 December)	Couzens & Dent, 2006 (D7)		D7 is an academic paper. Its title is *Finding Nema: The National Environmental Management Act, the De Hoop Dam, Conflict Resolution and Alternative Dispute Resolution in Environmental Disputes.* It provides evidence of the flaws in the environmental impact assessment and record of decision processes. It extensively discusses the failings of D5 (DEAT, 2005) and the remedial Steps of D6 (DEAT, 2006) to rectify the lack of attention given to stakeholders' views and environmental factors, such as the ecological Reserve not being given serious consideration in D5.	5, 6
2010 (November)	DWA, 2010 (D8)		D8 is the *Development of a reconciliation strategy for the Olifants River Water Supply System: Yield Analysis of the De Hoop and Flag Boshielo Dams.* It provides evidence that DWS followed up on some of the information used in the decision to build De Hoop Dam. The document details how the estimated yield of the De Hoop Dam was reassessed and reduced from 80 to 64 million cubic metres.	7

(Source: Researcher's own construction)

6.4.2 Findings relating to interviewees' perceptions of decision-making model use

Interviewees were requested to indicate which model (or models, if any) they thought were used in the decision to build De Hoop Dam (ORWRDP Phase 2A). A summary of their responses is shown in Table 6.3, after which the findings are discussed in relation to the three decision-making models discussed in sections 6.2.1, 6.2.2 and 6.2.3. The discussion draws on responses to the interview question 6b.

Question 6b: In your opinion, which model of decision-making best fits the decision-making that has occurred during the building of De Hoop Dam? (Diagrams of the three models, listed below, were shown to the interviewees for this question):

i. Rational Decision-Making Model (RDMM)
ii. Bounded Rationality Decision-Making Model (BRDMM)
iii. Political Decision-Making Model (PDMM)

Table 6.3: Interviewee perceptions of decision-making models used during ORWRDP Phase 2A

Interviewee	Project stage involvement	Model(s) perceived to be used
P1	Implementation	Rational model
P2	Implementation	Bounded rationality model
P3	Implementation	Rational model – planning Bounded rationality and political models – implementation
P4	Planning	Rational model with political pressure
P5	Implementation	Political model – 'major decisions' Rational model – 'engineering decisions'
P6	Planning	Mix of all three models
P7	Planning	Rational model – planning Political model – implementation
P8	Implementation	Rational model
P9	Planning	Rational model with political model 'a close second'
P10	Planning	Rational model

(Source: Researcher's own construction)

What Table 6.3 shows is that there is little consistency when the interviewee perceptions of the decision-making models used are split by interviewees' project involvement. The interviewees involved in the planning stage (P4, P6, P7, P9, and P10) all agreed that the rational decision-making model was present for at least one of the project stages. Four of the five planning-based interviewees added that political pressure/decision-making was present. While interviewees involved in the implementation stage (P1, P2, P3, P5 and P8) also indicated that the rational model was used, only two of the implementation-based interviewees indicated that political pressure was present. Two of the implementation-based interviewees added that the bounded rationality model was the best fit.

The reason why the planning-based interviewees lean more towards the rational and political models is that planning decisions are often politically driven and need acceptance from political bodies to go ahead (for example, Cabinet). Then, once a political decision is made, the planning directorate can begin the planning process The implementation decisions, meanwhile, are more engineering-based and less political in nature (so long as the project is completed). This can be seen in the following quotations:

> *None of the models fit from inception/conception to operations (P3).*

> [Decisions are made by a] *government department, therefore the political decision-making model occurs when major decisions are made. For most engineering decisions a rational decision-making model route is proposed (P5).*

Furthermore, the frequent occurrence of interviewees (six of ten) indicating that more than one model of decision-making was present, appears to be due to the lack of interaction between project stages, and to the stages overlapping each other. This is portrayed in the following quotations:

> *There is no mechanism in decision-making for revising the planning decisions during construction … once the planning and decisions have been made, the details are cast in concrete in a record of implementation decisions for another branch of DWA to design and construct. So interaction by default is not there. (P3).*

> *Implementation (for example, design) occurred before planning was finished and appeals took close to a year to resolve (P4).*

> *There was a disconnect between the planning and construction of De Hoop Dam (P7).*

The De Hoop Dam project differed from other projects from the start in that there was continuous time pressure, due to an accelerated work programme. This meant that processes that usually follow each other were done in parallel (P10).

From the above quotations, it is apparent that there is a time pressure, a lack of retrospective decision-making analyses, and a lack of interaction between people working on different sections of the project (at times concurrently). This lack of interaction is partly why interviewees have such varied perceptions of which decision-making models were used during ORWRDP Phase 2A. Nevertheless, most interviewees perceived the rational decision-making model as the model that was used in making the decision to build De Hoop Dam.

6.4.3 Findings relating to the decision-making process according to the RDMM

Findings relating to the seven steps of Zindiye's (2012) RDMM are now presented, drawing from the documentation (Table 6.2) and responses to interview questions, as shown in the interview guide (Appendix E). In each step, a primary question is answered from responses to specific questions from the interview guide and relevant documents from Table 6.2. The RDMM steps are: Step 1: define and diagnose problem; Step 2: set goals; Step 3: search for alternative solutions; Step 4: compare solutions; Step 5: choose a solution; Step 6: implement chosen solution; and Step 7: follow-up and control (Zindiye, 2012).

6.4.3.1 Step 1: Defining and diagnosing the problem

The primary question arising from the first step in the RDMM is "Why do we need an additional water supply in the Olifants River basin?" The following documents (D1.1, D1.2, D2.2 and D2) shown in Table 6.2 produced between 1991 and 2006 provide evidence of an ongoing process of addressing the aforementioned question. The questions (1, 1a and 1c) from the interview guide, relevant to addressing this step, were stated as follows:

Question 1: Please can you explain how the need for additional water yield in the Steelpoort Catchment was identified?

Question 1a: Which directorate and/or position in the DWA were responsible for identifying this need?

Question 1c: How was the extent of the need for additional water assessed?

Interviewees had varied opinions concerning how the need for additional yield in the Olifants River Catchment was identified. The interviewees involved in planning (P4, P6, P7, P9 and P10) indicated that the need was identified through various strategic assessments, run by the DWS, over the last 30 years. Evidence from the documents (D1.1, D1.2, D2.2 and D2) shown and commented on in Table 6.2 also supported this finding. The DWS knew that there was a need to improve (and increase) water access to rural communities and platinum mines expressed a need for additional supply. These points are highlighted in the following quotations:

> *The Department of Water and Sanitation was approached by mining houses with plans for new mines. This was a big trigger of the need for additional yield in the area. The site* [where De Hoop Dam is built] *has been known* [to DWS] *for years as one of the best sites in the area. One of the big known problems was the road* [the R555] *that ran through the dam basin (P6).*

> *The mines were quick to exaggerate how much water they needed. They didn't pay attention to the costs initially. The penny dropped and the mines reviewed how much water they needed. The mines didn't want to divulge their mining schemes (and water needs) because competing mines were at the DWS meetings. Therefore it took a long time for the mines' actual requirements to come to light (P6).*

> [The extent of the need for additional water was measured] *through increasing population numbers, unit consumption rates, and the mining companies approaching DWA and motivating their need for water (P7).*

> *There is a lot of potential mining in the area. National development plan identified unlocking the mineral belt of the north as one of its objectives. With the development of mining in the area there were new mines applying for water. There was also the issue of improving service delivery to rural communities, as many rural communities in the area don't have sufficient access to water (P7).*

DWS did their own assessments over time and were quite certain of the need to develop the resource in the Mid-Olifants River catchment (P10).

The Directorate of Options Analysis was responsible for identifying the need for additional yield in the catchment. Other units within the Chief Directorate of Integrated Water Resource Planning and the Limpopo DWA regional office were also involved (P10).

In the first step of the rational model, Zindiye (2012) proposes that three skills are needed to define and diagnose a problem, namely ‘noticing’, ‘interpreting’ and ‘incorporating’. The first of these is noticing, which identifies environmental forces that are contributing to the problem. In the case of the De Hoop Dam, the need for additional water in the Olifants Basin (and within that, the Steelpoort River Catchment) illustrates the skill of noticing. While Question 1 does not ask specifically about the forces contributing to the problem, it does ask how the need for additional water was identified. As is evident from the quotations from P6 and P10 above, the interviewees indicated that DWS knew, through their Chief Directorate of Integrated Water Resource Planning, that they would have to augment water supply in the Steelpoort River Catchment, and lower reaches of the Olifants River because of increasing demand for water. DWS knew about the need for increased domestic water supply from their own detailed assessments (P9). DWS also knew about the mining water needs because the mining companies engage with them regarding future water requirements.

The DWS is not a business; it is a government department and as such, there are many different people involved in the different stages of decision-making throughout a project. In the context of a government decision, knowing which directorate is responsible at this stage is important, so that inter-directorate communication can be acknowledged.

The second skill is interpreting, which assesses the environmental forces identified during the noticing phase as root causes, and those which are symptomatic. The interviewees were not asked to split up the environmental forces into causes and symptoms because the researcher assumed that there were two main root causes. Drawing from the responses as indicated in the previous section and as evident from the ORWRDP project documents (for example, D2 and D6), the need for additional domestic water and the requests for additional mining water were the root causes.

The third skill is incorporating, which relates the problem(s) and causal environmental forces to the goal setting of the second step. Even though this skill was not explicitly dealt with in the interview guide, the interviewees allude to the incorporating skill (for example, P6 and P7, above and D1.2 and D2.2) when they indicated that the need for additional domestic and mining water (the problems) led the DWS to undertake a project to increase the water supply in the Olifants River Catchment (the goal).

Furthermore, to effectively diagnose and define problems, many questions should be posed (Zindiye, 2012). According to interviewee P9, a detailed assessment was undertaken by DWS to define the future water needs in the catchment. Undertaking a detailed assessment implies that many questions were asked. Additionally, DWS had to ask numerous questions to establish how much water the platinum mines actually needed as the mines did not readily divulge this information accurately since competitors were present at the same DWS meetings.

Interviewees were asked who was responsible for identifying the water yield problems in the catchment.

6.4.3.2 Step 2: Setting goals

The primary question rising from the second step in the decision-making process is, "What is the additional supply (in the Olifants River basin) needed for?" Documents D1.1, D2.2, D2, and D3 (Table 6.2) produced between 1991 and 2006, provide evidence of a process that was undertaken and updated by the DWS to address the above-mentioned question. However, the interview guide was constructed with the assumption that there was already a need for additional water supply in the catchment and thus interview questions focused on reviewing the goals post construction, i.e. establishing whether the goals were achieved or not.

Nevertheless, some of the interviewees' responses referred to goals. The primary goal was to increase the yield in the Olifants River Catchment so that water supply would equal or exceed demand (for example, P5 below). Secondary goals were set when the specific solution (the dam) was chosen, such as P5, below. Two of the main secondary goals dealt with the finishing date and cost of the project, such as P3 below.

> *The accelerated construction was allocated R120 million to achieve partial impoundment by 2009 and only realised this in 2013 (P3).*

> *The main goal, finishing the dam, will be achieved. The social goals as described by the social compact (De Hoop charter) were broadly achieved. Some goals, such as 50 per cent of the workforce must be females, were not achieved (P5).*

While the goals have been influenced by many different stakeholders (for example, public consultations, SANParks and mining companies), the final recommendations rested with the DWS. The goals were recommended by DWS through a chain of command, resulting in the Minister of DWS presenting them to Cabinet for approval, for example, D2.4 and D4.1 (Table 6.2).

6.4.3.3 Step 3: Searching for alternative solutions

The primary question arising from the third step in the decision-making process is, **"**How could the forecasted increase in demand for water be met?" Documents D1.1, D1.2, D2.1, D2.3 and D2 (Table 6.2) produced between 1991 and 2006, provide evidence that the DWS searched for alternative solutions. The questions (3a, 3b, 3d and 3e) from the interview guide, relevant to addressing this step, were stated as follows:

Question 3a: Were other infrastructure-based alternatives (such as other dams or inter-basin transfers) considered?

Question 3b: If so, what were they?

Question 3d: Were other non-infrastructure-based alternatives (such as demand-side or catchment management) considered?

Question 3e: If so, what were they?

The questions pertaining to infrastructure referred to alternatives such as dams and inter-basin transfers, while the non-infrastructure-related questions referred to alternatives such as DSM and catchment management solutions to better understand the different options that were investigated. All the interviewees agreed that infrastructure-based alternatives were considered. The interviewees' perceptions of the consideration of infrastructure-based alternatives are highlighted in the following quotations:

> *A site at Rooipoort on the Olifants River was the main alternative* [to De Hoop Dam]*. All the other potential sites were eliminated at a very early stage of the field study (P4).*

> [Infrastructure-based] *options considered included: development of surface water resources; development of groundwater resources, and the transfer of water from the Vaal catchment. Development of surface water considered the following options: a possible new dam at a location named Rooipoort on the Olifants River; a possible new dam on the farm De Hoop, on the Steelpoort River; the possible construction of a new dam at Groenvlei on the Sterk River or a dam on the Lephalala River, as secondary options (P9).*

From the above quotations (P4, P9), it is evident that a number of infrastructure-based alternative solutions were investigated. Most of these alternatives were in the form of potential new dams. Of all the potential infrastructure-based solutions, only the De Hoop and Rooipoort dam sites were considered sufficiently viable for the DWS to perform feasibility studies on them. Some non-infrastructure-based solutions were also investigated.

All but one interviewee (P1 below) agreed that non-infrastructure-based alternative solutions were considered in the decision-making process. However, interviewee P1 indicated that no non-infrastructure-based alternatives were considered because no feasible non-infrastructure-based options existed. The rest of the interviewees perceived that a number of non-infrastructure-based alternative solutions were investigated (at least in initial options analysis). According to the interviewees (P4, P7 and P10 below), the need for additional water was greater than any non-infrastructure-based solutions could consistently provide. P4, P7 and P9 (below) list examples of non-infrastructure alternatives, which they indicated were considered. These points are highlighted in the following quotations:

No, because no feasible non-infrastructure-based options existed (P1).

Water use efficiency was a key aspect. The development need made clear that infrastructure was needed in the catchment. When mining houses first approached the DWA, they were told to go and have a look at invasive alien plant eradication and whether they could buy out or transfer the irrigation water rights to industrial use. The extent of the need is so big that water resource development was taken forward as the best option (P4).

Water demand management, reallocation of water rights, water re-use and the eradication of invasive alien plants were all considered (P7).

Water conservation and demand management is a key non-infrastructure measure that is to be implemented. It will only contribute a small portion of the water needed, however (P7).

A number of management options were considered including: water conservation and demand management; re-use of effluent; leasing of water; re-allocation of water; allocations not fully utilised; the assurance of supply optimisation; and the leasing of water rights from currently dormant irrigation enterprises downstream of Flag Boshielo Dam as an interim measure (P9).

The quantity of water demand-side management would have saved would have been realistically insufficient (P10).

As is evident from the above statements, a wide range of non-infrastructure-based alternative solutions were considered, many of which re-used or altered the use of existing water supplies (IAP management would increase the water supply somewhat and DSM which would decrease the demand for water). However, no evidence of a deep, analytical consideration of non-infrastructure-based options could be found. These responses (for example, P4 above) indicate how little IAP management was considered as one part of a water supply solution, despite the possible detrimental long-term water security consequences, as discussed in Chapter Five, of not implementing IAP management.

There is evidence of a mine – the Blue Ridge platinum mine – in the Olifants River basin which, in 2009 (three years after the De Hoop decision), agreed to clear and maintain an area of IAPs upstream of the Loskop Dam in order to receive an allocation of water from the fully subscribed Loskop Dam (DWAF, 2009b). The mine was then licensed to receive most of the additional yield (from the Loskop Dam) that was made available through the IAP clearing (DWAF, 2009b). This was the first time that the DWS acknowledged that IAP clearing is a way to secure water for mining activities.

6.4.3.4 Step 4: Comparing and evaluating the alternative solutions

The fourth step of the rational decision-making model is to compare and evaluate the alternative solutions. The primary question pertaining to this is, “Which is the best option to meet supply and why?” The following documents (D1.2 and D2) shown in Table 6.2 and produced between 2000 and 2006, provide evidence of an ongoing process of comparing and evaluating alternative solutions. The questions (3c, 3f and 4) from the interview guide, relevant to addressing this Step, were stated as follows:

Question 3c: Why, in your opinion, were these alternative infrastructure-based solutions not selected?

Question 3f: Why, in your opinion, were these non-infrastructure-based solutions not selected?

Question 4: How were the alternative infrastructure-based and non-infrastructure-based solutions compared and evaluated?

Based on Step 4, interviewees indicated how alternative infrastructure- and non-infrastructure-based solutions were compared and evaluated, and why most of the infrastructure-based solutions (question 3c) and non-infrastructure-based (question 3f) were not selected. The various methods and assessments that were used to compare and evaluate alternative solutions (such as URVs, CBAs and social-environmental analyses) are highlighted in the following quotations:

The focus is on infrastructure development as a substantive job creator in the short term (P3).

URVs, engineering and economics assessments and other socio-economic and environmental factors are all put into a decision-making framework and from there a final decision is made (P4).

Evaluations were not done in the 'handbook prescribed' way. Some options were shot down politically (for example, buy out of irrigation rights). Only two options compared economic, social and environmental impacts. These options were the two dam sites, De Hoop and Rooipoort (P6).

In addition to the cost of water resource developments, account was also taken of the cost of conveying the water to users, for equitable comparison of the overall cost associated with the respective options (P9).

Preliminary design and cost estimation were performed for the water resource development options, all to the same level of detail and using the same design standards and norms as well as the same basis for costing, to ensure the unbiased comparison of options (P9).

DWA also looked at the engineering, social, environmental, and political aspects. They also consulted with various other decision-makers and stakeholders through an intensive public participation process. A decision on the size of the project was also based on a comparison of the optimum scheme against the next best water augmentation option as it was known that future water resource development options in the area are limited (P10).

From the above quotations, it is evident that the interviewees perceived that many of the alternative options were eliminated early on in the selection process for a variety of reasons including political influence (P6 above). As an example, the practice of buying irrigation water rights and transferring them for mining or domestic use was shut down politically because of the expected social impact (i.e. loss of agricultural jobs) it would cause. The selection process was finally narrowed down to two alternative solutions (the De Hoop and Steelpoort dams), which were compared and evaluated using a wide range of criteria such as financial cost and engineering feasibility, as well as potential socio-economic and environmental impacts.

6.4.3.5 Step 5: Choose among alternative solutions

The fifth step of the rational decision-making model entails choosing an alternative solution to implement. Choosing a solution is immensely difficult, especially since the problem of insufficient water supply is complex, multi-faceted and has high levels of risk and uncertainty. The primary question arising from the fifth step is, “How was the choice to build the dam, from amongst the alternative solutions, made?” Documents D2.4, D4.1, D2, D6 and D7 (Table 6.2) produced between 2004 and 2006, provide evidence of an alternative solution being chosen. The questions (1b, 2, 2b, 3c, 3f, 5 and 5a) from the interview guide, relevant to addressing this step, were stated as follows:

Question 1b: When was a supply side measure selected?

Question 2: Which directorate and/or position in the DWA recommended the decision to build the De Hoop Dam?

Question 2b: When was the decision to build De Hoop Dam made?

Question 3c: Why, in your opinion, were these alternative infrastructure-based solutions not selected? (The alternative infrastructure-based solutions mentioned here are the same as the ones mentioned in Step 4.)

Question 3f: Why, in your opinion, were these non-infrastructure-based solutions not selected? (The alternative non-infrastructure-based solutions mentioned here are the same as the ones mentioned in Step 4.)

Question 5: How was the De Hoop Dam chosen from among all the alternative solutions?

Question 5a: What processes where used in choosing a solution to fulfil the need for additional yield?

When questioned about how the De Hoop Dam was chosen from amongst the all the alternative solutions and what processes were used in making this choice, interviewees' replied with a range of reasons and processes. These reasons and processes are highlighted in the following quotations:

> [De Hoop Dam was chosen because of] *the location (most practical option) and the cost (cheapest) (P1).*

> *The last stage compared the De Hoop Dam site to the Rooipoort site. De Hoop Dam site had better hydrology because it was more undeveloped. From a social point of view Rooipoort had many rural communities in the potential dam basin and more irrigated land that would be lost. From a cost constraint point of view, additional conveyance would be needed at the De Hoop site but not at Rooipoort; however, the De Hoop Dam was still more economical (P4).*

> *Water balancing, taking into account hydrological risks and water demand projections were used. There is a risk that there would be serious shortages, in the Olifants Catchment, during a drought. Projecting water quantities by nature is uncertain. These hydrological uncertainties had to be addressed and the risks managed (P6).*

> *In building the very large dam wall, only a few 300 millimetres holes are drilled in the ground as part of the planning phase of the foundations, which lead to uncertainties. There were economic uncertainties and risks from labour actions and changes in steel prices. In the dam basin there were opportunity costs in terms of potential mineral resources and specific, important vegetation, which was relocated. There were social and political risks in removing graves and relocating families from the dam basin (P7).*

> *From the investigations it is apparent that a dam at De Hoop will be able to yield more water, at a substantially lower unit cost and at an earlier date than a dam at Rooipoort. Constructing a dam at Rooipoort will have significant social impacts (the loss of 313 houses, 124 businesses, 8 schools and 583 graves), as well as the loss*

of irreplaceable fertile communal land in the dam basin. Furthermore the construction of a dam at De Hoop is also the only option that would enable the supply of water to Jane Furse and the Nebo Plateau (P9).

The 'do nothing' option would not have helped the situation either. The dam is a must in my view (P10).

Through the discarding of many alternative solutions for various reasons such as location (P1), financial, social and environmental costs (P1, P9), hydrology (P4), potential yield (P9) and water balancing (P6), the DWS were left with two options from which to choose a solution. These two solutions were the De Hoop (Steelpoort River) and Rooipoort (Olifants River) dam sites. According to the statements of interviewees P9 and P4 above, planning analyses showed that there are many reasons why De Hoop site was regarded as the better of the two. These reasons include: social impacts (more people lived in the Rooipoort Dam basin than in the De Hoop Dam basin); hydrological aspects (there are already seven large dams on the Olifants River and none on the Steelpoort River); environmental impacts (the Rooipoort site was found to have a smaller impact than the De Hoop site); and financial impacts (the De Hoop Dam option was estimated to be cheaper, despite the additional conveyance needed). Overall the De Hoop site was considered to be the superior option (P1, P4, P9, above).

6.4.3.6 Step 6: Implement the selected solution

The sixth step in the rational decision-making process is the implementation of the selected solution. The primary question arising from the sixth step is, "How did dam building commence and thereafter proceed?" The following documents (D2, D4, D4.1, D5, D6 and D7) shown in Table 6.2 and produced between 2004 and 2006, provide evidence of the implementation of the selected solution. A question (6a) from the interview guide, relevant to addressing this step, was stated as follows:

Question 6a: Which directorate and/or position in the DWA has been responsible for making decisions during the building of the dam?

In the case of the De Hoop Dam, Step 6 includes the planning, design and construction of the De Hoop Dam. Step 6 began once Cabinet approved the go-ahead of the dam (in mid-

2004) and it will end when construction is completed (in 2015). When questioned about the possible strengths and weakness of decision-making during construction, and about who in the DWS was responsible for the decision-making during construction, the interviewees indicated that there had been a number of strengths and weaknesses and that this was a sensitive topic. Furthermore, interviewees indicated that the DWS's National Water Resources Infrastructure Chief Directorate was responsible for decision-making during construction (P5 below). The interviewees' perceptions of the implementation of De Hoop Dam are highlighted in the following quotations:

> *There have been differences of opinion between the designer, contractors and engineers. There were unnecessary additions to the scope of the project; this had major implication on the time and cost of the project. A major risk is the lack of planning and difference of opinions between the civil and mechanical departments (P1).*

> *It was intended that the Project should be conducted like a private sector contract to prove that DWA Construction Management could perform like a private contractor. This was wishful thinking, because in reality it was not possible for 'a government department' to perform in the same way as a private sector construction company, due to the dysfunctional bureaucracy. The employment of labour had to follow stringent DWA processes with political requirements, whereas a private contractor would hire according to the skills level required. The decision for government bodies (in-house) to handle the relocation and compensation process was not successful (P2).*

> *The construction slows down more and more and more, knowing that in this environment, employment won't be terminated. This is reflected in the rate of construction where the last four per cent of work has taken two to three years to complete. Note that there is no penalty for in-house constructions being slow, wasteful or anything else (P3).*

> *The decision to go to full supply capacity was challenged following the revised hydrology, for which a smaller dam capacity would be required; however top management rejected this proposal to facilitate avoiding early labour redundancy*

associated with construction to avoid a perception being created of inept planning components (P3).

There were problems with the foundations, and consequently excavations had to be much deeper than planned. There has also been an overburden in quarry areas and a larger area has been opened for construction materials. There are no ways of checking inefficiencies. The roller compacted concrete method of pouring concrete took longer than expected and contributed to cost overruns (P4).

By using a department construction unit, one can start construction easily, immediately (no contracts or tenders needed). Also construction was a constructor's market at the time (contractors' resources were all in use for example, 2010 stadiums and Gautrain). By using an internal team, once they got the job they didn't have the required skills on site for a successful implementation. If decent people were on the site, the contract would have finished two years ago. Departmental construction means a lot of interference from top management (for example, a two-week strike compared with an eight-week strike) (P5).

[Decision-making during construction rests with] *construction management, civil engineering and infrastructure development, which are all part of National water resources infrastructure chief directorate (P5).*

This is a sensitive topic. Government insisted in building the dam themselves, so there was no tendering process. The end result of this was that the De Hoop Dam took twice as long to build compared with private company estimates. Government was the contractor and the controlling authority which meant that they controlled the budget and timeframe and that they could hide design errors and oversights (P7).

Infrastructure- and water-resource-wise [De Hoop Dam] *is the right decision. Implementation by government was the wrong decision. Had another option been implemented by government it would also have gone over budget (P7).*

The main goal of De Hoop Dam starting to store water has occurred. However, there are no means to supply the water to users as the conveyance is lacking (P4).

The DWS built the De Hoop Dam themselves through their Chief Directorate of National Water Resource Infrastructure (P5 above). DWS built the dam themselves firstly, to prove that they could compete with the private sector firms (P2 above), and secondly, because there was an abundance of construction work available (for example, the 2010 World Cup stadiums and the Gautrain) and few private sector firms large enough to undertake such big projects (P5, above). The DWS expected the cost of the project to escalate, if they contracted a private firm to build the dam because of this shortage of available private sector capacity. The interviewees indicated that while the De Hoop Dam should have been built, it should not have been built by the DWS (P1, P2, P7 above). Additionally, a proposal to build a dam (with a smaller capacity and therefore fewer jobs) that was based on revised hydrology was rejected by DWS because they did not want their planning to be perceived as inexpert, through having to implement early job dismissals (P3 above). Furthermore, interviewees thought that construction by the DWS meant that the dam was slower and more expensive to build than if it had been contracted out to the private sector (P5 and P7 above).

The De Hoop Dam will be finished nearly five years after the initially planned finishing date in 2010, and nearly three years after the revised, planned date in 2012. Furthermore the cost of the De Hoop, as discussed in Chapter Four, increased from an estimated R1.744 billion (in 2012 rand values) to an actual cost of R3.030 billion (in 2012 rand values). This represents an increase of 174 per cent. Some of the other perceived reasons for the increase in costs include: the 2008/2009 economic recession, which stifled the development of mines in the area which were expected to sign agreements to pay a portion of the costs; the foundations needing to be deeper than expected and subsequently a large amount of additional concrete being needed (P4 above); unanticipated rainfall events which impacted on construction; worker strikes taking longer than would have been the case if the project had been undertaken by a private firm (P5 above); and the slowing rate of construction towards the end of the project (P3 above) as well as the granting of bonuses to accelerate construction.

In addition, the estimated yield of the dam was reassessed as part of a reconciliation strategy for the Olifants River basin (D8: Table 6.2, DWA, 2010). The original yield estimate for De Hoop Dam (calculated as part of the feasibility study) was 80 million cubic metres per annum. The reassessment (based on updated hydrological models and inflow data) estimated the yield to be 66 million cubic metres per annum (representing a decrease of 17.5%). A separate study, namely the *Olifants Water Availability Assessment Study* (DWAF, 2010) which made slightly different assumptions, estimated the yield to be 64 million cubic metres per annum. The DWS now assumes the figure of 66 million cubic metres to be correct as it was calculated using the most up-to date estimates.

These underestimated costs and overestimated benefits (yield) are largely different from the estimates that the decision to build the dam was originally based on. This difference is in line with Ahiaga-Dagbui and Smith (2014), Ansar *et al.* (2014) and Flyvbjerg (2009, 2005), all of whom state that cost overruns and overestimation of benefits occur in large infrastructure projects. Flyvbjerg (2005) even has a formula for megaproject approval which states that project approval (which makes the idea look good on paper) is equal to underestimated costs plus overestimated benefits plus undervalued environmental impacts plus overvalued economic development. Flyvbjerg's formula fits the De Hoop Dam decision in addition to the above-mentioned issues, since it was found that the environmental impact assessment and approval process were inadequate (D7: Table 6.2, Couzens & Dent, 2006) and many of the jobs that were expected to boost economic and social development have not yet materialised. Ansar *et al.* (2014) add that large dams have detrimental environmental and social impacts. Finally, Couzens and Dent (2006, D7: Table 6.2) and Flyvbjerg (2005) comment that after implementation has begun, infrastructure development creates a momentum that is hard to halt.

In building the De Hoop Dam, the DWS struggled with a project of larger scope than anything they had previously undertaken. It has been demonstrated through the issues raised in the preceding paragraphs that the DWS decision-making regarding the building phase of the De Hoop Dam project was unsatisfactory.

A further finding relating to the implementation is that, while nearly half the yield from the De Hoop Dam is allocated for rural community use, the water will take a long time to reach the communities and may not reach them at all (D2, D8, in Table 6.2). Although the dam is storing water in 2015, the bulk pipelines to transport the water are not yet complete (P4 above). Furthermore, the bulk pipelines do not run directly to the communities (D4, D5 in Table 6.2). Rather it is the responsibility of the local municipalities, and thus a political decision, to build the additional, smaller pipelines from the bulk pipelines to these communities.

6.4.3.7 Step 7: Follow-up and control

The seventh step of the rational decision-making model is to control implementation, and then to follow up and evaluate the results. If acceptable results have not been achieved from the evaluation of the implementation, the problem and/or goals made need to be redefined, or the whole decision-making process repeated. One of the common reasons for implementation not being acceptable is that the impacts of environmental forces continue to change during the decision-making process (Zindiye, 2012).

The primary question arising from the seventh step is, “How was the decision evaluated in terms of the goals set?” Document D8 (Table 6.2) produced in 2010, provides some evidence of follow-up and control. The questions (7, 7a, 7b, 7c, 7d 8, 8a and 8b) from the interview guide, relevant to addressing this step, were stated as follows:

Question 7: Have any decision-making processes been evaluated?

Question 7a: To date, has the building of De Hoop Dam been on course to achieve all the goals that were planned, in their specified time frames?

Question 7b: If not, then which goals were not on course to be achieved as planned and why not?

Question 7c: What goals were achieved and how?

Question 7d: Have any decisions been retrospectively analysed?

Question 8: My understanding is that Phase 2A (building De Hoop Dam) was forecast to cost approximately R1.744 billion (in December 2012 rand values). To date, it has cost R3.03 billion (in December 2012 rand values). How can this difference be explained in terms of the decision-making process?

Question 8a: Do you think a different decision-making process would have been followed if the cost-to-date (the actual cost) of the project had been projected as the estimated cost?

Question 8b: Given your answer in 8a, do you think a different decision would then have been made?

The interviewees indicated that while the implementation was controlled, little follow-up and evaluation of the results had occurred. This was partially due to the fact that when the interviews took place in 2014, the building of the dam was not yet complete. These points are highlighted in the following quotations:

> *The decision to sign an acceleration agreement possibly had a detrimental effect on the contractor's decisions. Acceleration to provide early delivery of water did not make sense when the delivery pipeline and water treatment works were not in place. In reality the contractor was unable to accelerate the works in accordance with the milestones in the agreement (P2).*

> *The accelerated construction was allocated R120 million to achieve partial impoundment by 2009 and only realised this in 2013 (P3).*

> *The post-planning decision is influenced by ambitious implementation acceleration, so as to solicit glamour and personal shine on individuals for having created at least a perception of service delivery to come, and creation of some job opportunities. The implications of this acceleration are incomplete or incompetent detailed implementation planning and programming for the site-specific option selected. The contractor thus starts construction without detailed knowledge of the end product and it's to be achieved. Added to this, is the use of an aged or geriatric approved professional persons (or APPs for short) to lead the design for large dams as required by law results in ultraconservative designs and insensitivity to cost (P3).*

> *There is no mechanism in decision-making for revising the planning decisions during construction … once the planning and decisions have been made, the details are cast in concrete in a record of implementation decisions for another branch of DWA to design and construct. So interaction by default is not there (P3).*

Construction of the De Hoop Dam and its conveyance systems are running late and are far behind. The main reasons are that an off-funding model is being used (50% of the budget from the fiscal and 50% supposed to be off-budget from mining). The water supply agreements have, however, not been completed. There are multiple potential water users at different stages of development and they are not ready to make investment decisions and the difficulty to get commitments upfront (P4).

Planning and programming by contractors could have been more proactive. It was not on the top of their priorities to get the job done (P5).

The DWA should have been more hardnosed with the mines to lessen the risks. While it is accepted that government must take decisions in faith when building infrastructure; too much risk was shifted to the state (P6).

Completion time and adherence to budget are not on track to be achieved as planned. Self-control by government lacked certain administration arrangements, for example relocation of people living in the dam basin. There was poor management by government (P7).

From the above quotations (P2, P3, P4, P5 and P7), it is apparent that the control of implementation was less than ideal. Time and budget goals were not met, despite monetary incentives being made to accelerate construction (P3, P5 above). Some further issues were: the use of inefficient designs from older decision-makers who may be set in their ways; implementation being started before detailed implementation planning was finished; not getting funding support from the mines and a lack of interaction between DWS directorates (P3, P4, P6 above).

An example of the lack of inter-directorate interaction which came to light from the interviews, is that the interviewees involved in the building of the De Hoop Dam (P1, P2, P3, P5 and P8) did not know much about the early decision-making in the project during the planning stage. These interviewees routinely suggested approaching the DWS Planning Directorate: Options Analysis, to obtain the relevant information.

The issues raised in the previous two paragraphs, show that control of implementation was less than ideal. However, they do not discuss the second part of the seventh RDMM step, which focuses on follow-up evaluations. Interviewees' perceptions of the follow-up evaluations to date, of ORDRDP Phase 2A, are now highlighted in the following quotations:

> *I haven't seen any evidence of decisions being retrospectively analysed. Maybe it is too early yet as the project is not complete (P2).*

> *There is not adequate reflection on* [these] *decisions by people in power (P3).*

> *Yes, the hydrology has been revised post-decision and the interviewee believes that the demand has/is being re-evaluated, especially since the platinum price has plummeted by about 35 per cent between 2006 and 2014 (P3).*

> *The job creation has been only partially achieved because the mining development predicted did not realise, and so substantive job creation resulting from the dam development hasn't happened to date. However, for a relatively small group of local labour, there has been employment for longer than anticipated for more persons typically associated with such a construction project (peaking at 1200 persons) (P3).*

> *There is no mechanism in decision-making for revising the planning decisions during construction (P3).*

> *The main goal of De Hoop Dam starting to store water has occurred. However, there are no means to supply the water to users as the conveyance is lacking (P4).*

> *I am not aware of any decisions that have been retrospectively analysed. Looking at planning there is one thing that is different; a reassessment of the river after planning was done and construction was underway. The reassessment caused some rethinking of distribution of the piping. Even given the reassessment information, the decisions would not have changed (P7).*

The interviewees indicated that there has been insufficient follow-up and evaluation of the decision-making process in the implementation of De Hoop Dam (P2, P3, P7 above). This is partially because the project has not yet been finished and partially because it is perceived that after the planning stage it is not possible for a decision to be revised (P2, P3 above). So far there has only been a review of hydrology (P7 above) through a yield analysis that resulted in a 17.5 per cent decrease in estimated yield (D8: Table 6.2).

Interviewees were questioned whether they thought that, had the decision-makers known what they now know about the cost overruns, decrease in estimated yield and slow implementation of new mines, a different decision would have been made regarding the chosen solution. The interviewees indicated that a different decision would not have been made, as highlighted in the following quotations:

> *No, a different decision would not have been made because the comparison is done at the same time with the same unit costs, rates for various infrastructure options, so the same errors in cost estimates would have surfaced in the comparison in the feasibility study (P3).*

> *No, a different decision would not have been made. Extra water was needed in the catchment and De Hoop Dam was still the best decision at the time based on the available information. If we knew what we know now, the scope of the project may have changed after 2008 when the mines pulled out and potential demand dropped. For example, the dam could have been built in two phases – a smaller dam initially and a wall raising at a later date (P5).*

> *How do you decide what to build where? It is very difficult. There are many aspects to consider, especially over time and it is not clear-cut (P6).*

The interviewees agreed that a different solution would not have been chosen, but that the scope of the project may have changed, for example building the dam in two stages or a smaller dam (P5 above). Interviewees also indicated that water supply decision-making has high levels of uncertainty and risk, leading to difficult decision-making and complex decisions needing to be made (P6 above).

From the evidence provided by the interviews and documentation presented within the seven steps of the RDMM, it is apparent that while the goal of building the De Hoop Dam will certainly be achieved, some of the smaller goals were not achieved. It is also evident that decision-making process did not follow the steps of the RDMM in sequential order, and in some cases, not at all: for example, the seventh step has not yet been adequately followed. On this issue, Zindiye (2012) explains that when making adaptive or innovative decisions, like the decision to build the De Hoop Dam, the seven steps are rarely followed in order and sometimes steps may even be ignored. Zindiye (2012) summarises this by suggesting that at most, human decision-making only approaches the principle of rationality.

Part of the seventh step of the RDMM entails reflecting on the decision-making process. Consequently, a self-critique of the questions in the interview guide (Appendix E) is now presented. This reflection provides a chance to acknowledge the shortcomings of the interview guide.

6.4.4 Reflection on the interview questions

In hindsight, while the questions covered the different stages of the decision-making process according to the rational decision-making model, they were not as clear and specific as they could have been. The research questions would have been better structured and more to the point if the researcher had had a better understanding of what he wanted to ask, how the questions fitted into the research and why they were worth asking. An example of the lack of clarity is in Questions 2 and 2a where the focus should have been specifically on goals rather than on recommendations (which is a less specific term).

Furthermore, some of the questions may have seemed to be repetitive. For example, one question asked how De Hoop Dam was chosen as the selected solution and another asked what processes were used in choosing an alternative solution. The difference in the questions could have been made clearer. Similarly, clarity regarding the questions relating to uncertainty and risks in different aspects of the decision-making process would have helped.

6.4.5 Discussion

The findings have shown that, while the DWS did follow a logical decision-making process in their recommendation to build De Hoop Dam, their decision-making process did not appear to have included all the components or steps of the RDMM (Zindiye, 2012). In particular, there appeared to be limited evidence of following up and controlling implementation (Step 7). Although construction has yet to be officially completed, and thus only interim analyses could be expected, this appears to have been the tendency for such schemes.

Although the decision-making process was articulated by the interviewees, the seriousness with which the range of solutions appears to have been taken, was clearly limited. There were suggestions that the size of the dam was inflated, possibly owing to vested positions taken by mining interests arguing for this capacity. However, it was also articulated that the global financial crisis in 2008, as well as unfavourable foundation conditions, were reasons for adjustments that have been made. Another area of concern articulated was the focus on using internal capacity in the Department, which was felt to have led to an inflation of the costs.

The reality is that the actual cost of the dam was almost twice what was estimated, and the yield was recalculated to be significantly lower than originally proposed to the Minister. Even so, evidence suggests that, if the actual cost and yield of De Hoop Dam had been known at the start of the project, a different solution would not have been chosen. However, the scope of the project may have changed. This is partially because, logically, there were fewer viable alternative options to the De Hoop Dam, in comparison to, for example, the Berg River Dam case, which had far greater demand-side management and wider conservation of supply alternative options.

The DWS appears to continue to deal with water balance issues through prioritising infrastructure development. Considering that more than 95 per cent of South Africa's surface water has already been allocated, and that much of the remaining surface water is far from priority demand, there is limited potential for future water supply infrastructure development (Claassen, 2010). It must be mentioned that DWS is trying to broaden the base of water-mix alternatives which they consider, collaborate on and implement, especially concerning water re-use, evidence of which is present in DWS strategies (DWA, 2013b; DWAF, 2004). Despite this, however, DWS continues to build large dams and inter-basin transfer schemes (DWS, 2014, DWS, 2013b), and has had limited success and investment in alternatives such as demand-side management interventions, conservation of supply (catchment management) options, or conjunctive use of ground water (Hedden & Cilliers, 2014; Herold, 2009). For the De Hoop Dam, for example, it was clear from the interview responses that virtually no investments were planned for such alternative or concurrent options.

Two of the main reasons for the DWS's continued focus on water-infrastructure development are their concern with water security, and with control. Large dams increase the year-round water supply security (countering low flows), by holding more water than the equivalent average MAR. De Hoop Dam, which holds three times the MAR, is an example of this. Added to this fact, DWS has markedly more control over infrastructure development projects than over other alternative solutions. For example, when desalination is chosen to increase water supply in an area (for example, Durban), DWS has to collaborate and share decision-making power with provincial and local governments, as well as with other groups. Having control over which alternatives are considered, and how the chosen alternative is implemented, gives the DWS more power and reduces some of the uncertainty surrounding these alternatives

6.5 CONCLUSIONS

In this chapter, the third objective of the study, namely evaluating the decision to build De Hoop Dam using the rational decision-making model (RDMM), was addressed. The literature concerning decision-making models was first discussed and the reasons for choosing the RDMM were presented. Thereafter the decision to build De Hoop Dam (ORWRDP Phase 2A), was evaluated using the seven steps of the RDMM (Zindiye, 2012). Each step was interrogated using an analysis of documents and semi-structured, in-depth interviews relating to the De Hoop Dam project.

The first conclusion from this chapter is that, while the DWS did not follow the RDMM, it did follow a logical decision-making process in reaching the decision to build the De Hoop Dam. Evidence of some of the steps, for example, the following up and controlling of implementation (Step 7) was limited. Construction has yet to be officially completed and thus only interim analyses could be expected.

The second conclusion drawn from the interviews is that the decision to build the De Hoop Dam was based on sub-optimal evidence. Fast-tracking procedures and actions happening simultaneously resulted in planning and design of the dam occurring concurrently. This rush, and the fact that former President Mbeki announced that the De Hoop Dam would be built during the initial phase of planning, meant that it was difficult to include any other options concurrently or together with the De Hoop Dam.

A logical framework for decision-making would have sought to evaluate all competitive options, and develop the optimal water-mix recommendation for the Minister’s consideration. The interview process suggests that the decision to build the dam would still have been taken, even if this had been done. The analysis of invasive alien plants in the catchment, from Chapter Five, appears to corroborate this, for the additional yield potential is relatively small.

The planners in DWS did themselves investigate the potential benefits of clearing invasive alien plants in the catchment of the Olifants River, concluding that it would have released sufficient water to enable the proposed Blue Ridge platinum mine to go ahead (DWAF, 2009b). There is clearly a degree of understanding and willingness to explore such options, in the DWS.

What Chapter Five has shown through the calculations of the potential impact of Invasive alien plants on the water security of De Hoop Dam is that in order to ensure the long-term value of the dam, there is a need to implement additional measures, which should be part of the final planning. Interventions such as the management of invasive alien plants, and the erosion problems (mentioned in Chapter Two) will have to be made. What is also known, and should have been known by the decision-makers, is that the sooner the work is done on such alternatives, the less expensive it will be in real terms.

The following chapter (Chapter Seven) provides a general conclusion to the whole thesis.

CHAPTER SEVEN
CONCLUSIONS

The main purpose of this study was to evaluate the costs and benefits of selected water supply options and of the decision-making associated with those options. Specifically, this study sought to analyse the expected and actual unit reference values (URVs) as well as the impacts and costs of invasive alien plant management on four dams (the Inyaka, Nandoni, Berg River and De Hoop dams) and their catchments. Additionally, the decision-making process that led to the decision to build De Hoop Dam (the most recently built case study) was analysed using the rational decision-making model as a framework. In doing so, this study set out to understand the decision-making processes followed to enable the Minister of Water and Sanitation to make informed decisions regarding long-term water security in different parts of South Africa. From these analyses a number of conclusions can be drawn.

The first major conclusion is that, given the difficulty that was experienced in obtaining water-resources data from the Department of Water and Sanitation, the maintenance of data on water resources is problematic. Obtaining expected and actual construction costs as well as operational and maintenance (O&M) costs for the four cases from the Department of Water and Sanitation turned out to be extremely challenging, as data was often not readily available, or, in the case of the Inyaka Dam's O&M costs, incomplete. Furthermore, there is a possibility that not all incurred costs were reflected in the actual costs. Whether this is true, and whether it would have further increased the actual costs, cannot be speculated upon. But it may well reflect on how retrospective analysis is not being optimally used to help to inform Ministers in their decision-making.

A second important conclusion is that there is considerable variation between the estimated costs (at the time that the decision to build the dams was taken) and the actual costs of building the dams. In addition to the capital costs, the unit reference value analysis used Department of Water and Sanitation O&M guidelines costs in all four cases, and additional Department of Water and Sanitation O&M cost data in the Nandoni and Berg cases. The URV analyses, using an eight per cent discount rate, revealed that in both the Inyaka (27 per cent less expensive than planned) and Nandoni (twelve or 35 per cent less expensive depending if O&M guideline costs or data costs were used) cases the actual cost was less than expected. In the Berg River case, the actual cost was 21 per cent more than expected when O&M guideline costs were used; but fourteen per cent less than expected when available O&M data costs were used. This was possibly due to the big difference between the O&M costs from the guidelines and the data. The De Hoop Dam URV calculation was the highest by a long way (74 per cent more expensive than estimated); however this was further exacerbated in real terms by an eighteen per cent decrease in estimated yield.

A third pertinent conclusion is that the URV analysis is a limited tool in that it does not adequately take the long-term costs and benefits of different options into consideration. The clearest example of this limitation is that yield does not grow with interest and therefore, in reality, cannot be discounted to a present value. Nevertheless it was found that, at an eight per cent discount rate, and in December 2012 rand values, the actual cost of water is getting more expensive in real terms. URVs estimated that the cost of water per cubic metre was: R1.13 from Inyaka Dam, R0.50 to R0.67 from Nandoni Dam, R2.00 to R2.82 from Berg River Dam and R3.79 from the De Hoop Dam.

A fourth important conclusion is that externalities were, at best, a limited consideration in the costs of the four cases. Other than for the Berg River Dam (and the De Hoop Dam to a limited degree), none of the estimates included an in-depth analysis of the catchment management alternatives or supplementary actions as an option for the conservation and enhancement of water supply. None of the proposals to the relevant Minister included a budget for a concurrent DSM intervention, although this was mentioned in the case of the Berg River Dam. None of the proposals looked at the conservation of supply in terms of aspects such as leaks, aging distribution infrastructure and other aspects of unaccounted-for water.

A fifth conclusion is that the clearing of invasive alien plants alone, i.e. not in combination with other catchment management interventions and demand-side management, could not compensate for the level of yield achieved through building each one of the dams. In terms of the immediate needs for water security, then, the clearing of invasive alien plants in the catchments of the four dams was not remotely a competitive option, and the Minister was put in a position to make an informed decision, in each case, in that regard.

A sixth, and major, conclusion is that a failure to clear invasive alien plants in the catchments will reduce water security in the long-term. For example, over a period of 45 years, the invasions in the catchments of the Berg River Dam could, if not controlled, lead to a potential 46 per cent reduction in the mean annual runoff. Potential reductions in the mean annual runoff of the other cases are modelled to be: a 44 per cent reduction De Hoop Dam, a sixteen per cent reduction for the Inyaka Dam, and a seven per cent reduction for the Nandoni Dam. The variation in the projections is caused by the differences in catchment conditions such as low initial invasions in the Inyaka and Nandoni cases. Given more time the invasions would continue to increase in size and density. It is thus postulated that it makes no sense to be concerned about long-term water security in the form of building a dam, and yet have no immediate strategy to deal with the threat from invasive alien plants to being able to fill the dam and meet the Reserve requirements (RSA, 1998). It is also clear that any delay in the control of invasive alien plants will have greater costs than immediate control, in real terms, and that it therefore makes sense to undertake the interventions for control immediately. In other words, the Ministers did not make informed decisions in this regard, other than for the Berg River Dam.

A rider to the above conclusions is that decisions should also be made in the context of other costs and benefits, seeking to optimise the outcomes, and their impacts. In this regard, the implication of creating jobs given the prioritization of unemployment, inequity and poverty in the National Development Plan (National Planning Commission, 2012), and the adverse effects of invasive alien plants, such as loss of ecosystem services and biodiversity, and the related increased risks of flooding, disease, erosion, and siltation, should have been put into the decision-making equation. If two options can achieve similar long-term outcomes, but the one has considerably higher associated benefits, then this ought to be part of decision-making in the long-term interests of governance and the allocation of limited resources.

A seventh conclusion is that, while the Department of Water and Sanitation did not follow the rational decision-making model, it did follow a logical decision-making process to reach the decision to build the De Hoop Dam. Evidence of some of the rational decision-making model steps, for example, the following up and controlling of implementation (Step 7) was limited. A rider here is that construction has yet to be officially completed and thus only interim analyses could be expected. Although the decision-making process was articulated by the interviewees, the seriousness with which the range of solutions appears to have been taken, was clearly limited. There were suggestions that the size of the dam was inflated, possibly owing to vested positions taken by mining interests arguing for this capacity. However, it was also articulated that the global financial crisis in 2008, as well as unfavourable foundation conditions, were reasons for adjustments that have been made. Another area of concern articulated was the focus on using internal capacity in the Department, which was felt to have led to an inflation of the costs. The reality of the decision is that the cost of the dam was almost twice what was originally estimated, and the yield was recalculated to be significantly lower than originally proposed to the Minister.

An eighth argument is made, that there is little evidence of retrospective analysis by the Department of Water and Sanitation, in terms of understanding the full costs and benefits of dams that have been built, and learning lessons that can enable Ministers to make more informed decisions in the future. This is a problem in many infrastructure projects, as was highlighted in Chapter Four.

The final conclusion is that the Ministers have clearly not been put in positions to make a fully informed decision regarding each of the dams analysed in this research. There are major investments being made regarding dams, for long-term water security, but insufficient effort being made to address the conservation of the supply of water through the management of the catchments, as shown through the consideration of the clearing of invasive alien plants.

Balancing water demand and supply in South Africa involves high levels of uncertainty. It is thus recommended that, in future decision-making, the DWS needs to investigate the incorporation of multiple alternative options into an overarching solution, rather than to adopt a single solution, as it has tended to do. Furthermore, the DWS needs to ensure that decision-makers are put into a position to make as fully informed decisions as may be feasible, and which take short- and long-term considerations into account.

This study has retrospectively compared the expected and actual costs of building selected dams (using URV analysis), as well as the current and estimated potential costs and impacts of IAPs on water supply of the dam catchments. There were other important interventions (notably erosion and siltation, ground-water options, and especially demand-side management) that were not possible in this study, but are pertinent considerations that decision-makers should interrogate. It is hoped that this study will lead to further studies to improve the decision-making and management of water supply in South Africa.

END NOTE

Figure 7.1: Pine trees invading in the Langeberg Mountains in the Western Cape

(Source: Blignaut, 2015)

The dead pine in the centre of Figure 7.1 was ring-barked by the author in 2007. At the time, it was a lone pine. Some of the seed pollution, probably from this lone specimen, can be seen, notwithstanding follow-up weeding in 2009. If not controlled, these swiftly-multiplying pines, high up in a mountain catchment, would soon deplete the natural runoff.

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APPENDIX A

Guidelines for the economic life, and annual operational and maintenance costs

Component	Economic Life	Annual Maintenance and Operational Costs (excluding energy)
Dams, tunnels and siphons		
Civil works	50 years	0.25% per annum
Mechanical and electrical	30 years	4.0% per annum
Pipelines and canals		
Civil works	50 years	0.25% per annum
Mechanical and electrical	30 years	4.0% per annum
Pumping stations		
Civil works	50 years	0.25% per annum
Mechanical and electrical	30 years	4.0% per annum
Hydroelectric power stations		
Civil works	75 years	0.25% per annum
Mechanical and electrical	50 years	Guidance to be obtained from Eskom

(Source: DWAF, 1996b)

APPENDIX B

Consumer price index (CPI) history from 1960 onwards (December 2012 = 100%)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1960	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
1961	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
1962	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
1963	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
1964	1,5	1,5	1,5	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
1965	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
1966	1,6	1,6	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7
1967	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7
1968	1,7	1,7	1,7	1,7	1,7	1,7	1,8	1,8	1,8	1,8	1,8	1,8	1,8
1969	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,9	1,9	1,9	1,8
1970	1,9	1,9	1,9	1,9	1,9	1,9	1,9	2,0	2,0	2,0	2,0	2,0	1,9
1971	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,1	2,1	2,1	2,1	2,1	2,0
1972	2,1	2,1	2,1	2,1	2,1	2,1	2,2	2,2	2,2	2,3	2,3	2,3	2,2
1973	2,3	2,3	2,3	2,4	2,4	2,4	2,4	2,4	2,4	2,5	2,5	2,5	2,4
1974	2,5	2,5	2,6	2,6	2,6	2,7	2,7	2,7	2,8	2,8	2,8	2,8	2,7
1975	2,9	2,9	2,9	3,0	3,0	3,0	3,1	3,1	3,1	3,1	3,2	3,2	3,0
1976	3,2	3,2	3,3	3,3	3,3	3,4	3,4	3,5	3,5	3,5	3,5	3,5	3,4
1977	3,6	3,6	3,6	3,7	3,7	3,7	3,7	3,8	3,8	3,8	3,8	3,9	3,7
1978	3,9	3,9	3,9	4,0	4,0	4,0	4,2	4,2	4,3	4,3	4,3	4,3	4,1
1979	4,4	4,4	4,5	4,5	4,5	4,6	4,8	4,8	4,9	4,9	4,9	5,0	4,7
1980	5,0	5,1	5,1	5,1	5,2	5,3	5,4	5,4	5,5	5,7	5,7	5,8	5,4
1981	5,8	5,9	5,9	5,9	6,0	6,1	6,2	6,3	6,5	6,5	6,6	6,6	6,2
1982	6,6	6,7	6,9	6,9	7,0	7,0	7,1	7,2	7,3	7,4	7,5	7,5	7,1
1983	7,5	7,7	7,7	7,8	7,9	7,9	8,0	8,1	8,1	8,2	8,3	8,3	8,0
1984	8,4	8,4	8,5	8,7	8,8	8,8	8,9	9,0	9,1	9,2	9,3	9,4	8,9
1985	9,5	9,8	9,8	10,1	10,2	10,3	10,3	10,5	10,6	10,7	10,9	11,1	10,3
1986	11,4	11,5	11,7	11,9	11,9	12,1	12,3	12,5	12,7	12,9	13,0	13,1	12,3
1987	13,3	13,5	13,7	13,9	14,0	14,1	14,2	14,4	14,7	14,8	15,0	15,1	14,2
1988	15,2	15,2	15,5	15,6	15,8	15,9	16,1	16,3	16,5	16,7	16,8	17,0	16,1
1989	17,2	17,4	17,7	17,9	18,2	18,3	18,5	18,8	18,9	19,1	19,3	19,6	18,4
1990	19,8	20,0	20,3	20,4	20,7	20,8	21,0	21,3	21,6	21,8	22,3	22,4	21,0
1991	22,7	23,0	23,1	23,5	23,8	24,0	24,3	24,6	25,0	25,4	25,7	26,0	24,3
1992	26,4	26,6	26,8	27,2	27,3	27,6	27,9	28,2	28,3	28,4	28,6	28,6	27,7
1993	28,9	29,0	29,4	30,1	30,2	30,4	30,6	30,8	30,9	31,1	31,2	31,3	30,3
1994	31,7	31,8	32,0	32,2	32,4	32,6	33,1	33,6	34,0	34,2	34,3	34,3	33,0
1995	34,8	35,0	35,4	35,8	35,9	35,9	36,1	36,2	36,2	36,3	36,5	36,7	35,9
1996	37,2	37,3	37,5	37,8	38,0	38,4	38,7	38,8	39,2	39,6	39,8	40,2	38,5
1997	40,6	40,9	41,1	41,5	41,7	41,8	42,2	42,2	42,5	42,6	42,5	42,6	41,9
1998	43,0	43,1	43,4	43,6	43,8	44,0	45,0	45,5	46,3	46,5	46,5	46,5	44,8
1999	46,8	46,8	46,8	46,9	46,9	47,1	47,1	47,0	47,1	47,3	47,4	47,5	47,1
2000	48,1	47,9	48,4	49,0	49,3	49,6	50,0	50,2	50,4	50,6	50,7	50,8	49,6
2001	51,5	51,6	51,9	52,2	52,4	52,6	52,6	52,5	52,6	52,6	52,9	53,1	52,4
2002	54,1	54,6	55,2	56,0	56,4	56,8	57,7	57,9	58,6	59,4	59,7	59,7	57,2
2003	60,3	60,2	60,9	61,0	60,9	60,7	60,7	60,9	60,7	60,3	59,9	59,9	60,5
2004	60,4	60,7	61,1	61,2	61,2	61,4	61,6	61,6	61,6	61,8	62,1	62,0	61,4
2005	62,2	62,3	62,9	63,2	63,2	63,1	63,7	63,9	64,2	64,2	64,2	64,2	63,4
2006	64,6	64,7	65,0	65,4	65,7	66,2	66,9	67,4	67,6	67,7	67,6	68,0	66,4
2007	68,5	68,4	69,0	69,9	70,3	70,9	71,6	71,9	72,5	73,1	73,4	74,0	71,1
2008	74,8	75,1	76,3	77,7	78,5	79,6	81,2	81,8	81,9	81,9	82,0	81,1	79,3
2009[2]	81,4	82,3	83,4	83,8	84,1	84,5	85,4	85,6	86,0	86,0	86,0	86,2	84,6
2010	86,4	87,0	87,7	87,8	88,0	88,0	88,6	88,6	88,7	88,9	89,0	89,2	88,2
2011	89,6	90,2	91,3	91,6	92,0	92,4	93,2	93,4	93,8	94,2	94,5	94,6	92,6
2012	95,2	95,7	96,8	97,2	97,2	97,5	97,8	98,0	98,9	99,5	99,8	100,0	97,8
2013	100,3	101,3	102,5	102,9	102,6	102,9	104,0	104,3	104,8	105,0	105,1	105,4	103,4
2014	106,1	107,3	108,7	109,2	109,4	109,7	110,6	111,0	111,0	111,2	111,2	111,0	109,7
2015	110,8	111,5											

(Source: Statistics South Africa; 2015)

APPENDIX C

Unit reference value (URV) calculations

The tables presented in this appendix are structured as follows in this example:

Estimated URV Calculation																							
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	…	y37	**y38**	y39	…	y50	y51	y52
Capital		Mil ZAR	584	545	509	105	105	105	105	105	105	105											
O&M 1	Civil	Mil ZAR	28	22	18								2	2	2	…	2	**2**	2	…	2	2	2
O&M 2	Mechanical / electrical	Mil ZAR	460	359	291								29	29	29	…	29	**73**	29	…	29	29	29
Total		Mil ZAR	909	767	668	105	105	105	105	105	105	105	31	31	31	…	31	**75**	31	…	31	31	31
Yield		Mil m3	637	499	406								41	41	41	…	41	**41**	41	…	41	41	41
URV: Estimated		Calc:	1.43	1.54	1.64																		
Estimated Cost (in Millions of Rands				732																			

<u>Explanations:</u>

‘**Capital**’	Capital cost of the dam.
‘O&M’	Operational and maintenance costs are split into civil works (0.25% of capital cost/year) and mechanical / electrical components (4% of capital costs/year), which need to be replaced every 30 years.
‘Yield’	the annual amount of useable water from the dam.
‘URV’	Unit reference value is the cost, in rands, of a cubic metre of water.
‘Calc’	Calculation
‘Mil ZAR’	Number in millions of rands
‘Mil m3’	Million cubic metres of water
‘6%’, ‘8%’ and ‘10%’	Discount rates used to bring the costs back to a present value.
‘y1’	Year one (in this example the dam took seven years to build and thereafter O&M costs are calculated for a further 45 years).
‘y38’	30 years after the end of the construction of the dam (in this example y38) the O&M for mechanical and electrical components is 10% of capital cost to fund the replacement costs of these components.

1. Inyaka Dam calculations

Estimated URV Calculation																							
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	...	y37	**y38**	y39	...	y50	y51	y52
Capital		Mil ZAR	584	545	509	105	105	105	105	105	105	105											
O&M 1	Civil	Mil ZAR	28	22	18								2	2	2	...	2	**2**	2	...	2	2	2
O&M 2	Mechanical / electrical	Mil ZAR	460	359	291								29	29	29	...	29	**73**	29	...	29	29	29
Total		Mil ZAR	909	767	668	105	105	105	105	105	105	105	31	31	31	...	31	**75**	31	...	31	31	31
Yield		Mil m3	637	499	406								41	41	41	...	41	**41**	41	...	41	41	41
URV: Estimated		Calc:	1.43	1.54	1.64																		
Estimated Cost (in Millions of Rands				732																			

Actual URV Calculation																							
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	...	y37	**y38**	y39	...	y50	y51	y52
Capital		Mil ZAR	428	399	373	77	77	77	77	77	77	77											
O&M 1	Civil	Mil ZAR	21	16	13								1	1	1	...	1	**1**	1	...	1	1	1
O&M 2	Mechanical / electrical	Mil ZAR	337	263	214								21	21	21	...	21	**54**	21	...	21	21	21
Total		Mil ZAR	666	562	490	77	77	77	77	77	77	77	23	23	23	...	23	**55**	23	...	23	23	23
Yield		Mil m3	637	499	406								41	41	41	...	41	**41**	41	...	41	41	41
URV: Actual		Calc:	1.05	1.13	1.21																		
Actual Cost (in Millions of Rands)				537																			

2. Nandoni Dam calculations

Estimated URV Calculation																							
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	...	y37	**y38**	y39	...	y50	y51	y52
Capital		Mil ZAR	662	617	577	119	119	119	119	119	119	119											
O&M 1	Civil	Mil ZAR	32	25	20								2	2	2	...	2	**2**	2	...	2	2	2
O&M 2	Mechanical / electrical	Mil ZAR	521	407	330								33	33	33	...	33	**83**	33	...	33	33	33
Total		Mil ZAR	1030	869	757	119	119	119	119	119	119	119	35	35	35	...	35	**85**	35	...	35	35	35
Yield		Mil m3	1444	1131	921								93	93	93	...	93	**93**	93	...	93	93	93
URV: Estimated		Calc:	0.71	0.77	0.82																		
Estimated Cost (in Millions of Rands)				830																			

Actual URV Calculation 1 (based on DWS guidelines)																							
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	...	y37	**y38**	y39	...	y50	y51	y52
Capital		Mil ZAR	581	542	507	104	104	104	104	104	104	104											
O&M 1	Civil	Mil ZAR	28	22	18								2	2	2	...	2	**2**	2	...	2	2	2
O&M 2	Mechanical / electrical	Mil ZAR	458	357	290								29	29	29	...	29	**73**	29	...	29	29	29
Total		Mil ZAR	904	763	665	104	104	104	104	104	104	104	31	31	31	...	31	**75**	31	...	31	31	31
Yield		Mil m3	1444	1131	921								93	93	93	...	93	**93**	93	...	93	93	93
URV: Actual 1		Calc:	0.63	0.67	0.72																		
Actual Cost (in Millions of Rands)				729																			

Nandoni Dam calculations continued…

Actual URV Calculation 2 (based on DWS data)

		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	…	y37	**y38**	y39	…	y50	y51	y52
Capital		Mil ZAR	581	542	507	104	104	104	104	104	104	104											
O&M		Mil ZAR	50	36	27								1	2	2	…	3	**73**	3	…	3	3	3
Total		Mil ZAR	614	563	521	104	104	104	104	104	104	104	1	2	2	…	3	**73**	3	…	3	3	3
Yield		Mil m3	1444	1131	921								93	93	93	…	93	**93**	93	…	93	93	93
URV: Actual 2		Calc:	0.43	0.50	0.57																		
Actual Cost (in Millions of Rands)				729																			
				y8	y9	y10	y11	y12	y13														
DWS O&M Costs				**2007**	**2008**	**2009**	**2010**	**2011**	**2012**														
Consumer Price Index (CPI)				0.77	0.79	0.85	0.88	0.93	0.98														
Actual (Mil ZAR)				0.41	1.77	1.99	1.73	2.48	2.65														
Actual (Mil ZAR) in Dec 2012 Rands				0.53	2.23	2.35	1.96	2.68	2.71														

3. Berg River Dam calculations

Estimated URV Calculation																				
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	...	y34	**y35**	y36	...	y47	y48	y49
Capital		Mil ZAR	1133	1083	1037	327	327	327	327											
O&M 1	Civil	Mil ZAR	51	40	32					3	3	3	...	3	**3**	3	...	3	3	3
O&M 2	Mechanical / electrical	Mil ZAR	822	641	520					52	52	52	...	52	**131**	52	...	52	52	52
Total		Mil ZAR	1824	1584	1414	327	327	327	327	56	56	56	...	56	**134**	56	...	56	56	56
Yield		Mil m3	866	678	552					56	56	56	...	56	**56**	56	...	56	56	56
URV: Estimated		Calc:	2.11	2.34	2.56															
Estimated Cost (in Millions of Rands)				1308																

Actual URV Calculation 1 (based on DWS guidelines)																				
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	...	y34	**y35**	y36	...	y47	y48	y49
Capital		Mil ZAR	1371	1310	1254	396	396	396	396											
O&M 1	Civil	Mil ZAR	61	48	39					4	4	4	...	4	**4**	4	...	4	4	4
O&M 2	Mechanical / electrical	Mil ZAR	994	775	629					63	63	63	...	63	**158**	63	...	63	63	63
Total		Mil ZAR	2206	1915	1710	396	396	396	396	67	67	67	...	67	**162**	67	...	67	67	67
Yield		Mil m3	866	678	552					56	56	56	...	56	**56**	56	...	56	56	56
URV: Actual 1		Calc:	2.55	2.82	3.10															
Actual Cost (in Millions of Rands)				1582																

Berg River Dam URV calculations continued…

Actual URV Calculation 2 (Based on DWS data)																					
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	…	y34	**y35**	y36	…	y47	y48	y49
Capital		Mil ZAR	1371	1310	1254	396	396	396	396											
O&M		Mil ZAR	88	64	49					3	4	7	…	4	**158**	4	…	4	4	4
Total		Mil ZAR	1440	1357	1287	396	396	396	396	3	4	7	…	4	**158**	4	…	4	4	4
Yield		Mil m3	866	678	552					56	56	56	…	56	**56**	56	…	56	56	56
URV: Actual 2		Calc:	1.66	2.00	2.33															
Actual Cost (in Millions of Rands)				1582																

DWS O&M Costs	y5 **2008**	y6 **2009**	y7 **2010**	y8 **2011**	y9 **2012**
Consumer Price Index (CPI)	0.771	0.793	0.846	0.882	0.926
Actual (Mil ZAR)	2.262	3.409	5.581	5.553	3.514
Actual (Mil ZAR) in Dec 2012 Rands	2.934	4.299	6.597	6.296	3.795

4. De Hoop Dam URV calculations

Estimated URV Calculation: Yield = 66 Million m3																								
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	...	y38	**y39**	y40	...	y51	y52	y53
Capital		Mil ZAR	1354	1253	1163	218	218	218	218	218	218	218	218											
O&M 1	Civil	Mil ZAR	67	53	43									4	4	4	...	4	**4**	4	...	4	4	4
O&M 2	Mechanical / electrical	Mil ZAR	1096	855	694									70	70	70	...	70	**174**	70	...	70	70	70
Total		Mil ZAR	2084	1743	1507	218	218	218	218	218	218	218	218	74	74	74	...	74	**179**	74	...	74	74	74
Yield		Mil m3	1020	799	651									66	66	66	...	66	**66**	66	...	66	66	66
URV: Estimated		Calc:	2.04	2.18	2.32																			
Estimated Cost (in Millions of Rands)				1745																				

Actual URV Calculation: Yield = 66 Million m3																								
		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	...	y38	**y39**	y40	...	y51	y52	y53
Capital		Mil ZAR	2352	2177	2021	379	379	379	379	379	379	379	379											
O&M 1	Civil	Mil ZAR	117	92	75									8	8	8	...	8	**8**	8	...	8	8	8
O&M 2	Mechanical / electrical	Mil ZAR	1903	1485	1205									121	121	121	...	121	**303**	121	...	121	121	121
Total		Mil ZAR	3620	3029	2618	379	379	379	379	379	379	379	379	129	129	129	...	129	**311**	129	...	129	129	129
Yield		Mil m3	1020	799	651									66	66	66	...	66	**66**	66	...	66	66	66
URV: Actual		Calc:	3.55	3.79	4.02																			
Actual Cost (in Millions of Rands)				3031																				

De Hoop Dam URV calculations continued…

Estimated URV Calculation: Yield = 80 Million m3

		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	…	y38	**y39**	y40	…	y51	y52	y53
Capital		Mil ZAR	1354	1253	1163	218	218	218	218	218	218	218	218											
O&M 1	Civil	Mil ZAR	67	53	43									4	4	4	…	4	**4**	4	…	4	4	4
O&M 2	Mechanical / electrical	Mil ZAR	1096	855	694									70	70	70	…	70	**174**	70	…	70	70	70
Total		Mil ZAR	2084	1743	1507	218	218	218	218	218	218	218	218	74	74	74		74	**179**	74		74	74	74
Yield		Mil m3	1236	969	789									80	80	80	…	80	**80**	80	…	80	80	80
																	…				…			
URV: Estimated		Calc:	1.69	1.80	1.91																			
Estimated Cost (in Millions of Rands)				1745																				

Actual URV Calculation: Yield = 80 Million m3

		Unit	6%	8%	10%	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	…	y38	**y39**	y40	…	y51	y52	y53
Capital		Mil ZAR	2352	2177	2021	379	379	379	379	379	379	379	379											
O&M 1	Civil	Mil ZAR	117	92	75									8	8	8	…	8	**8**	8	…	8	8	8
O&M 2	Mechanical / electrical	Mil ZAR	1903	1485	1205									121	121	121	…	121	**303**	121	…	121	121	121
Total		Mil ZAR	3620	3029	2618	379	379	379	379	379	379	379	379	129	129	129		129	**311**	129		129	129	129
Yield		Mil m3	1236	969	789									80	80	80	…	80	**80**	80	…	80	80	80
																	…				…			
URV: Actual		Calc:	2.93	3.13	3.32																			
Actual Cost (in Millions of Rands)				3031																				

APPENDIX D

Appendix D shows projections of invasive alien plant (IAP) growth, over a 45 year period, if no management of IAPs takes place. Only the calculations with a densification rate of one per cent are shown. In the Inyaka and De Hoop cases the projections are split into riparian and dryland calculations, after which these calculations are combined in summary tables that show both densification rates (one and five per cent). Assumptions for the calculations appear at the bottom of each table.

1a. Inyaka Dam - riparian calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	0	0	0	0	0	0
2009	1069.0	0.010	10.7	1069.0	0.18	0.07
2010	1122.4	0.060	67.3	53.4	1.17	0.46
2011	1175.6	0.110	129.3	53.2	2.24	0.87
2012	1228.5	0.160	196.6	52.8	3.41	1.32
2013	1280.7	0.210	268.9	52.2	4.66	1.82
2014	1331.9	0.260	346.3	51.3	6.01	2.34
2015	1382.0	0.310	428.4	50.1	7.43	2.90
2016	1430.8	0.360	515.1	48.8	8.93	3.48
2017	1478.0	0.410	606.0	47.2	10.51	4.10
2018	1523.5	0.460	700.8	45.5	12.15	4.74
2019	1567.2	0.510	799.3	43.7	13.86	5.40
2020	1608.9	0.560	901.0	41.7	15.63	6.09
2021	1648.6	0.610	1005.6	39.7	17.44	6.80
2022	1686.2	0.660	1112.9	37.6	19.30	7.52
2023	1721.6	0.710	1222.4	35.5	21.20	8.26
2024	1755.0	0.760	1333.8	33.4	23.13	9.02
2025	1786.3	0.810	1446.9	31.3	25.09	9.78
2026	1815.5	0.860	1561.3	29.2	27.08	10.56
2027	1842.7	0.910	1676.8	27.2	29.08	11.33
2028	1868.0	0.960	1793.2	25.3	31.10	12.12
2029	1891.4	1.000	1891.4	23.4	32.80	12.79
2030	1913.0	1.000	1913.0	21.6	33.18	12.93
2031	1932.9	1.000	1932.9	19.9	33.52	13.07
2032	1951.3	1.000	1951.3	18.3	33.84	13.19
2033	1968.1	1.000	1968.1	16.8	34.13	13.31
2034	1983.5	1.000	1983.5	15.4	34.40	13.41
2035	1997.6	1.000	1997.6	14.1	34.65	13.51
2036	2010.5	1.000	2010.5	12.9	34.87	13.59
2037	2022.3	1.000	2022.3	11.8	35.07	13.67
2038	2033.0	1.000	2033.0	10.7	35.26	13.74

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2039	2042.8	1.000	2042.8	9.8	35.43	13.81
2040	2051.6	1.000	2051.6	8.9	35.58	13.87
2041	2059.7	1.000	2059.7	8.1	35.72	13.93
2042	2067.0	1.000	2067.0	7.3	35.85	13.97
2043	2073.6	1.000	2073.6	6.6	35.96	14.02
2044	2079.6	1.000	2079.6	6.0	36.07	14.06
2045	2085.1	1.000	2085.1	5.4	36.16	14.10
2046	2090.0	1.000	2090.0	4.9	36.25	14.13
2047	2094.5	1.000	2094.5	4.5	36.33	14.16
2048	2098.5	1.000	2098.5	4.0	36.40	14.19
2049	2102.1	1.000	2102.1	3.6	36.46	14.21
2050	2105.4	1.000	2105.4	3.3	36.52	14.23
2051	2108.4	1.000	2108.4	3.0	36.57	14.25
2052	2111.1	1.000	2111.1	2.7	36.61	14.27
2053	2113.5	1.000	2113.5	2.4	36.66	14.29

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	10%
Maximum invadable area in ha (K)	2135.5
Mean initial density	1%
Density increase per year	5%

Total mean annual runoff (MAR) (Middleton & Bailey, 2008):

Total MAR (million m^3/yr)	80.32
Total MAR (m^3/yr) assuming riparian vol. = 10% of MAR	8,031,830

Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014):

Sprouting tree spp.	R 17,344

Estimated optimal riparian reduction in MAR (Le Maitre et al., 2013):

Eucalyptus species (m^3/ha/yr)	6761

1b. Inyaka Dam - dryland calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	0	0	0	0	0	0
2009	276.6	0.010	2.8	276.6	0.03	0.009
2010	302.9	0.060	18.2	26.3	0.20	0.06
2011	331.5	0.110	36.5	28.6	0.41	0.12
2012	362.7	0.160	58.0	31.2	0.65	0.19
2013	396.6	0.210	83.3	33.9	0.93	0.27
2014	433.4	0.260	112.7	36.8	1.26	0.37
2015	473.3	0.310	146.7	39.9	1.64	0.48
2016	516.6	0.360	186.0	43.3	2.07	0.61
2017	563.4	0.410	231.0	46.8	2.58	0.75
2018	614.0	0.460	282.5	50.6	3.15	0.92
2019	668.6	0.510	341.0	54.6	3.80	1.11
2020	727.4	0.560	407.3	58.8	4.54	1.33
2021	790.6	0.610	482.3	63.2	5.38	1.58
2022	858.3	0.660	566.5	67.8	6.32	1.85
2023	930.9	0.710	660.9	72.5	7.37	2.16
2024	1008.3	0.760	766.3	77.4	8.55	2.50
2025	1090.7	0.810	883.5	82.5	9.86	2.89
2026	1178.3	0.860	1013.3	87.6	11.31	3.31
2027	1271.0	0.910	1156.6	92.7	12.90	3.78
2028	1368.9	0.960	1314.2	97.9	14.66	4.29
2029	1472.0	1.000	1472.0	103.0	16.42	4.81
2030	1580.0	1.000	1580.0	108.0	17.63	5.16
2031	1692.9	1.000	1692.9	112.9	18.89	5.53
2032	1810.3	1.000	1810.3	117.5	20.20	5.92
2033	1932.1	1.000	1932.1	121.8	21.56	6.31
2034	2057.9	1.000	2057.9	125.7	22.96	6.72
2035	2187.1	1.000	2187.1	129.2	24.40	7.15
2036	2319.3	1.000	2319.3	132.2	25.88	7.58
2037	2454.0	1.000	2454.0	134.7	27.38	8.02
2038	2590.6	1.000	2590.6	136.5	28.90	8.47
2039	2728.3	1.000	2728.3	137.7	30.44	8.92
2040	2866.6	1.000	2866.6	138.3	31.98	9.37
2041	3004.7	1.000	3004.7	138.1	33.52	9.82
2042	3142.0	1.000	3142.0	137.3	35.05	10.27
2043	3277.7	1.000	3277.7	135.7	36.57	10.71
2044	3411.3	1.000	3411.3	133.6	38.06	11.15
2045	3542.1	1.000	3542.1	130.8	39.52	11.57
2046	3669.5	1.000	3669.5	127.4	40.94	11.99
2047	3793.0	1.000	3793.0	123.5	42.32	12.39
2048	3912.2	1.000	3912.2	119.2	43.65	12.78
2049	4026.8	1.000	4026.8	114.5	44.92	13.16

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2050	4136.4	1.000	4136.4	109.6	46.15	13.51
2051	4240.7	1.000	4240.7	104.4	47.31	13.86
2052	4339.7	1.000	4339.7	99.0	48.41	14.18
2053	4433.2	1.000	4433.2	93.5	49.46	14.49

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	10%
Maximum invadable area in ha (K)	5532.0
Mean initial density	1%
Density increase per year	5%

Total mean annual runoff (MAR) (Middleton & Bailey, 2008):

Total MAR (million m^3/yr)	80.32
Total MAR (m^3/yr) assuming dryland vol. = 90% of MAR	72,286,474

Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014)

Non-sprouting tree spp.	R 11,156

Estimated optimal dryland reduction in MAR (Le Maitre et al., 2013):

Pinus species (m^3/ha/yr)	3268

1.c Inyaka - combined calculation summary using a densification rate of 1%

Summary table of combined riparian and dryland calculation. Densification = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to clear invasion in 2013 rands (Million ZAR)	% cost increase*
2008	0	0	0%	0	0%	0	-
2023	2,652	442	5.77%	2.43	3.02%	6.67	3084%
2038	4,624	1,479	19.29%	7.05	8.77%	20.42	9442%
2053	6,547	2,946	38.42%	12.95	16.12%	38.75	17919%

* Per cent cost increase calculations are based on the 2009 cost to clear because 2008 = 0.

Riparian summary table: 6761 m^3/ha/yr riparian Euc reduction. Densification rate = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0.00	0	0.00	0	-
2023	1,722	281	13.15	1.90	23.64	4.87	2627
2038	2,033	633	29.65	4.28	53.30	10.98	5924
2053	2,113	951	44.54	6.43	80.06	16.49	8897

Dryland summary table: 3268/m^3/ha/yr dryland pine reduction. Densification rate = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0.00	0	0.00	0	-
2023	931	161	2.92	0.53	0.73	1.80	5832
2038	2,591	846	15.29	2.76	3.82	9.44	30578
2053	4,433	1,995	36.06	6.52	9.02	22.26	72124

1.d Inyaka - combined riparian and dryland summary. Densification rate = 5%

Summary table of combined riparian and dryland calculation. Densification = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase*
2008	0	0	0%	0	0%	0	-
2023	2,652	2,100	27.39%	11,52	14.34%	31,68	14650%
2038	4,624	4,771	62.22%	22,73	28.30%	65,87	30457%
2053	6,547	6,547	85.38%	28,78	35.83%	86,11	39819%

* Per cent cost increase calculations are based on the 2009 cost to clear because 2008 = 0.

Riparian summary table: 6761 m^3/ha/yr riparian Euc reduction. Densification rate = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0.00	0	0.00	0	-
2023	1,722	1,334	62.46	9,02	112.27	23,13	12477
2038	2,033	2,043	95.66	13,81	171.95	35,43	19109
2053	2,113	2,113	98.97	14,29	177.90	36,66	19771

Dryland summary table: 3268/m^3/ha/yr dryland pine reduction. Densification rate = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	0	0	0.00	0	0.00	0	-
2023	931	766	13.85	2,50	3.46	8,55	27704
2038	2,591	2,728	49.32	8,92	12.33	30,44	98637
2053	4,433	4,433	80.14	14,49	20.04	49,46	160276

2. Nandoni Dam - calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	11037.5	0.056	620.6		10.76	0.27
2009	11961.5	0.106	1270.6	924.0	22.04	0.55
2010	12946.6	0.156	2022.6	985.1	35.08	0.87
2011	13994.1	0.206	2885.9	1047.4	50.05	1.24
2012	15104.6	0.256	3870.2	1110.5	67.12	1.67
2013	16278.5	0.306	4984.9	1173.9	86.46	2.15
2014	17515.5	0.356	6239.4	1237.0	108.21	2.69
2015	18814.5	0.406	7642.9	1299.0	132.56	3.29
2016	20173.8	0.456	9203.8	1359.3	159.63	3.97
2017	21590.8	0.506	10929.8	1417.0	189.56	4.71
2018	23062.2	0.556	12827.8	1471.4	222.48	5.53
2019	24583.9	0.606	14903.4	1521.7	258.49	6.42
2020	26150.8	0.656	17160.8	1566.9	297.63	7.40
2021	27757.1	0.706	19602.7	1606.3	339.98	8.45
2022	29396.3	0.756	22230.2	1639.2	385.55	9.58
2023	31061.2	0.806	25042.3	1664.9	434.32	10.79
2024	32744.2	0.856	28036.4	1682.9	486.25	12.08
2025	34437.0	0.906	31207.7	1692.8	541.25	13.45
2026	36131.4	0.956	34549.7	1694.4	599.22	14.89
2027	37818.8	1.000	37818.8	1687.4	655.92	16.30
2028	39490.9	1.000	39490.9	1672.1	684.92	17.02
2029	41139.6	1.000	41139.6	1648.6	713.51	17.73
2030	42757.0	1.000	42757.0	1617.4	741.56	18.43
2031	44335.9	1.000	44335.9	1579.0	768.95	19.11
2032	45870.0	1.000	45870.0	1534.0	795.55	19.77
2033	47353.3	1.000	47353.3	1483.3	821.28	20.41
2034	48780.9	1.000	48780.9	1427.7	846.04	21.02
2035	50148.9	1.000	50148.9	1368.0	869.76	21.61
2036	51454.0	1.000	51454.0	1305.1	892.40	22.18
2037	52694.1	1.000	52694.1	1240.0	913.91	22.71
2038	53867.6	1.000	53867.6	1173.5	934.26	23.22
2039	54974.1	1.000	54974.1	1106.4	953.45	23.69
2040	56013.5	1.000	56013.5	1039.4	971.48	24.14
2041	56986.7	1.000	56986.7	973.2	988.36	24.56
2042	57895.0	1.000	57895.0	908.3	1,004.11	24.95
2043	58740.2	1.000	58740.2	845.2	1,018.79	25.32
2044	59524.5	1.000	59524.5	784.3	1,032.37	25.66
2045	60250.5	1.000	60250.5	725.9	1,044.96	25.97
2046	60920.7	1.000	60920.7	670.3	1,056.59	26.26
2047	61538.2	1.000	61538.2	617.5	1,067.30	26.52
2048	62105.9	1.000	62105.9	567.7	1,077.14	26.77
2049	62626.8	1.000	62626.8	520.9	1,086.18	26.99

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2050	63104.0	1.000	63104.0	477.2	1,094.45	27.20
2051	63540.4	1.000	63540.4	436.4	1,102.02	27.39
2052	63938.9	1.000	63938.9	398.5	1,108.93	27.56
2053	64302.3	1.000	64302.3	363.4	1,115.23	27.71

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	10%
Maximum invadable area in ha (K)	67792.0
Mean initial density	5.6%
Density increase per year	5%

Total mean annual runoff (MAR) (Middleton & Bailey, 2008):

Total MAR (million m^3/yr)	199.66
Total MAR (m^3/yr)	199,662,839

Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014)

Sprouting tree spp.	R 17,344

Estimated optimal reduction in MAR (Le Maitre et al., 2013):

Eucalyptus species (m^3/ha/yr)	431

3. Berg River Dam – calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	1175.0	0.315	370.1		4.13	1.90
2009	1334.5	0.325	433.7	159.5	4.84	2.23
2010	1513.2	0.335	506.9	178.6	5.66	2.60
2011	1712.4	0.345	590.8	199.3	6.59	3.03
2012	1933.8	0.355	686.5	221.4	7.66	3.52
2013	2178.6	0.365	795.2	244.8	8.87	4.08
2014	2448.0	0.375	918.0	269.4	10.24	4.71
2015	2742.7	0.385	1055.9	294.7	11.78	5.42
2016	3063.0	0.395	1209.9	320.4	13.50	6.21
2017	3408.9	0.405	1380.6	345.9	15.40	7.09
2018	3779.6	0.415	1568.6	370.7	17.50	8.05
2019	4173.7	0.425	1773.8	394.1	19.79	9.10
2020	4589.0	0.435	1996.2	415.2	22.27	10.24
2021	5022.4	0.445	2235.0	433.5	24.93	11.47
2022	5470.5	0.455	2489.1	448.1	27.77	12.77
2023	5929.0	0.637	3776.7	458.4	42.13	19.38
2024	6392.9	0.647	4136.2	463.9	46.14	21.23
2025	6857.2	0.657	4505.2	464.3	50.26	23.12
2026	7316.8	0.667	4880.3	459.5	54.45	25.04
2027	7766.4	0.677	5257.9	449.6	58.66	26.98
2028	8201.4	0.687	5634.4	435.0	62.86	28.91
2029	8617.6	0.697	6006.5	416.2	67.01	30.82
2030	9011.5	0.707	6371.2	393.9	71.08	32.70
2031	9380.5	0.717	6725.8	369.0	75.03	34.52
2032	9722.7	0.727	7068.4	342.2	78.86	36.27
2033	10037.1	0.737	7397.3	314.4	82.53	37.96
2034	10323.5	0.747	7711.6	286.4	86.03	39.58
2035	10582.3	0.757	8010.8	258.8	89.37	41.11
2036	10814.4	0.767	8294.6	232.1	92.54	42.57
2037	11021.2	0.777	8563.5	206.8	95.54	43.95
2038	11204.4	1.000	11204.4	183.2	125.00	57.50
2039	11365.8	1.000	11365.8	161.4	126.80	58.33
2040	11507.4	1.000	11507.4	141.5	128.38	59.05
2041	11630.9	1.000	11630.9	123.6	129.76	59.69
2042	11738.5	1.000	11738.5	107.5	130.96	60.24
2043	11831.7	1.000	11831.7	93.2	132.00	60.72
2044	11912.3	1.000	11912.3	80.6	132.90	61.13
2045	11981.9	1.000	11981.9	69.6	133.67	61.49
2046	12041.8	1.000	12041.8	59.9	134.34	61.80
2047	12093.2	1.000	12093.2	51.4	134.91	62.06
2048	12137.3	1.000	12137.3	44.1	135.41	62.29

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2049	12175.2	1.000	12175.2	37.8	135.83	62.48
2050	12207.5	1.000	12207.5	32.4	136.19	62.65
2051	12235.2	1.000	12235.2	27.7	136.50	62.79
2052	12258.8	1.000	12258.8	23.6	136.76	62.91
2053	12279.0	1.000	12279.0	20.2	136.99	63.01

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	15.0%
Maximum invadable area in ha (K)	12,394.8
Mean initial density	31.5%
Density increase per year	1.0%
Episodical density increase (in 2023, 2038 and 2053)	40.0%

Total mean annual runoff (MAR) (Middleton & Bailey, 2008):

Total MAR (million m^3/yr)	136.34
Total MAR (m^3/yr)	136,341,786

Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014)

Non-sprouting tree spp.	R 11,156

Estimated optimal reduction in MAR (Le Maitre et al., 2013):

Pinus species (m^3/ha/yr)	5,132

4a. De Hoop Dam – riparian calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	21270.1	0.100	2118.6		36,74	1,79
2009	21817.9	0.150	3264.0	547.8	56,61	2,75
2010	22338.1	0.200	4458.8	520.2	77,33	3,76
2011	22830.2	0.250	5698.5	492.1	98,83	4,81
2012	23293.9	0.300	6978.9	463.7	121,04	5,89
2013	23729.3	0.350	8295.8	435.4	143,88	7,00
2014	24136.8	0.400	9645.1	407.5	167,28	8,14
2015	24516.9	0.450	11022.9	380.1	191,18	9,30
2016	24870.5	0.500	12425.4	353.6	215,50	10,49
2017	25198.5	0.550	13849.2	328.0	240,20	11,69
2018	25502.0	0.600	15291.1	303.5	265,20	12,91
2019	25782.1	0.650	16748.2	280.1	290,47	14,14
2020	26040.1	0.700	18217.8	258.0	315,96	15,38
2021	26277.2	0.750	19697.5	237.1	341,63	16,62
2022	26494.8	0.800	21185.3	217.5	367,43	17,88
2023	26694.0	0.850	22679.3	199.2	393,34	19,14
2024	26876.1	0.900	24177.9	182.2	419,33	20,41
2025	27042.4	0.950	25679.6	166.3	445,38	21,67
2026	27194.1	1.000	27183.3	151.6	471,46	22,94
2027	27332.2	1.000	27332.2	138.1	474,04	23,07
2028	27457.8	1.000	27457.8	125.6	476,22	23,17
2029	27572.0	1.000	27572.0	114.2	478,20	23,27
2030	27675.6	1.000	27675.6	103.6	479,99	23,36
2031	27769.6	1.000	27769.6	94.0	481,63	23,44
2032	27854.9	1.000	27854.9	85.2	483,10	23,51
2033	27932.1	1.000	27932.1	77.2	484,44	23,57
2034	28001.9	1.000	28001.9	69.9	485,66	23,63
2035	28065.2	1.000	28065.2	63.2	486,75	23,69
2036	28122.4	1.000	28122.4	57.2	487,74	23,74
2037	28174.1	1.000	28174.1	51.7	488,64	23,78
2038	28220.7	1.000	28220.7	46.7	489,45	23,82
2039	28262.9	1.000	28262.9	42.2	490,18	23,85
2040	28301.0	1.000	28301.0	38.1	490,84	23,89
2041	28335.4	1.000	28335.4	34.4	491,44	23,92
2042	28366.4	1.000	28366.4	31.0	491,98	23,94
2043	28394.4	1.000	28394.4	28.0	492,46	23,96
2044	28419.6	1.000	28419.6	25.2	492,90	23,99
2045	28442.3	1.000	28442.3	22.7	493,29	24,01
2046	28462.8	1.000	28462.8	20.5	493,65	24,02
2047	28481.3	1.000	28481.3	18.5	493,97	24,04
2048	28498.0	1.000	28498.0	16.7	494,26	24,05
2049	28513.0	1.000	28513.0	15.0	494,52	24,06

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2050	28526.5	1.000	28526.5	13.5	494,75	24,08
2051	28538.7	1.000	28538.7	12.2	494,96	24,09
2052	28549.7	1.000	28549.7	11.0	495,15	24,10
2053	28559.6	1.000	28559.6	9.9	495,33	24,10

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	10%
Maximum invadable area in ha (K)	28,649
Mean initial density	10.0%
Density increase per year	5%

Total mean annual runoff (MAR) (Middleton & Bailey, 2008):

Total MAR (million m^3/yr)	134.33
Total MAR (m^3/yr) assuming riparian vol. = 10% of MAR	13,433,199

Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014):

Sprouting tree spp.	R 17,344

Estimated optimal riparian reduction in MAR (Le Maitre et al., 2013):

Eucalyptus species (m^3/ha/yr)	844

4b. De Hoop Dam – dryland calculation

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2008	152367.9	0.100	15176.4		169.31	6.19
2009	156292.3	0.150	23381.9	3924.4	260.85	9.54
2010	160018.9	0.200	31940.4	3726.6	356.33	13.03
2011	163543.8	0.250	40821.1	3524.9	455.41	16.66
2012	166865.4	0.300	49993.5	3321.6	557.7	20.40
2013	169984.5	0.350	59427.2	3119.0	662.98	24.25
2014	172903.4	0.400	69092.9	2919.0	770.82	28.19
2015	175626.6	0.450	78962.4	2723.2	880.92	32.22
2016	178159.7	0.500	89009.2	2533.0	993.01	36.32
2017	180509.3	0.550	99208.6	2349.7	1,106.80	40.48
2018	182683.3	0.600	109537.6	2174.0	1,222.03	44.69
2019	184690.0	0.650	119975.3	2006.7	1,338.47	48.95
2020	186538.1	0.700	130502.8	1848.1	1,455.92	53.25
2021	188236.7	0.750	141103.0	1698.6	1,574.18	57.57
2022	189795.0	0.800	151760.8	1558.3	1,693.08	61.92
2023	191222.1	0.850	162463.0	1427.1	1,812.48	66.28
2024	192527.0	0.900	173198.0	1304.8	1,932.24	70.66
2025	193718.3	0.950	183955.6	1191.3	2,052.25	75.05
2026	194804.5	1.000	194727.4	1086.3	2,172.43	79.45
2027	195793.8	1.000	195793.8	989.2	2,184.32	79.88
2028	196693.7	1.000	196693.7	899.9	2,194.36	80.25
2029	197511.4	1.000	197511.4	817.8	2,203.49	80.58
2030	198253.9	1.000	198253.9	742.5	2,211.77	80.89
2031	198927.4	1.000	198927.4	673.5	2,219.28	81.16
2032	199538.0	1.000	199538.0	610.5	2,226.10	81.41
2033	200091.0	1.000	200091.0	553.0	2,232.27	81.64
2034	200591.7	1.000	200591.7	500.7	2,237.85	81.84
2035	201044.6	1.000	201044.6	453.0	2,242.90	82.03
2036	201454.3	1.000	201454.3	409.6	2,247.47	82.19
2037	201824.5	1.000	201824.5	370.3	2,251.60	82.34
2038	202159.0	1.000	202159.0	334.5	2,255.34	82.48
2039	202461.2	1.000	202461.2	302.1	2,258.71	82.60
2040	202733.9	1.000	202733.9	272.8	2,261.75	82.72
2041	202980.1	1.000	202980.1	246.2	2,264.50	82.82
2042	203202.3	1.000	203202.3	222.1	2,266.98	82.91
2043	203402.7	1.000	203402.7	200.4	2,269.21	82.99
2044	203583.4	1.000	203583.4	180.7	2,271.23	83.06
2045	203746.3	1.000	203746.3	163.0	2,273.05	83.13
2046	203893.2	1.000	203893.2	146.9	2,274.68	83.19
2047	204025.7	1.000	204025.7	132.4	2,276.16	83.24
2048	204145.0	1.000	204145.0	119.3	2,277.49	83.29

Year	Total area invaded (ha)	Density of invasion (maximum = 1)	Condensed area invaded (ha)	Annual expansion of total area (ha)	Cost to clear invasion in 2013 rands (Million ZAR)	Reduction in mean annual runoff (MAR) (Million m^3)
2049	204252.5	1.000	204252.5	107.5	2,278.69	83.34
2050	204349.4	1.000	204349.4	96.9	2,279.77	83.37
2051	204436.7	1.000	204436.7	87.3	2,280.75	83.41
2052	204515.4	1.000	204515.4	78.6	2,281.62	83.44
2053	204586.2	1.000	204586.2	70.8	2,282.41	83.47

Assumptions

Time step formula used to calculate growth in total area invaded

$N_t = N_{t-1}+r(1-N_{t-1}/K)N_{t-1}$

N_t is area invaded at time t

N_{t-1} is area at previous time step

Rate of spread (r)	10%
Maximum invadable area in ha (K)	205,226
Mean initial density	10%
Density increase per year	5%
Total mean annual runoff (MAR) (Middleton & Bailey, 2008):	
Total MAR (million m^3/yr)	134.33
Total MAR (m^3/yr) assuming dryland vol. = 90% of MAR	1,208,988,859
Total costs to clear per condensed ha in 2013 rands (Wannenburgh, 2014)	
Non-sprouting tree spp.	R 11,156
Estimated optimal dryland reduction in MAR (Le Maitre et al., 2013):	
Pinus species (m^3/ha/yr)	408

4.c De Hoop - combined calculation summary using a densification rate of 1%

Summary table of combined riparian and dryland calculation. Densification = 1%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	173,638	17,295	7.39%	7.98	5.94%	206.06	-
2023	217,916	54,393	23.26%	25.10	18.68%	648.04	314%
2038	230,380	92,061	39.36%	42.48	31.62%	1,096.83	532%
2053	233,146	128,138	54.79%	59.12	44.01%	1,526.66	741%

Riperian summary table: 844/m^3/ha/yr riperian Euc reduction. Densification rate = 1%

Year	Total area invaded (ha)	Condensed invaded ha	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	21,270	2,119	7.39	1.79	13.31	36.74	-
2023	26,694	6,663	23.26	5.62	41.86	115.56	314
2038	28,221	11,277	39.36	9.52	70.85	195.59	532
2053	28,560	15,696	54.79	13.25	98.62	272.23	741

Dryland summary table: 408/m^3/ha/yr dryland pine reduction. Densification rate = 1%

Year	Total area invaded (ha)	Condensed invaded ha	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	152,368	15,176	7.39	6.19	5.12	169.31	-
2023	191,222	47,730	23.26	19.47	16.11	532.49	314
2038	202,159	80,784	39.36	32.96	27.26	901.24	532
2053	204,586	112,441	54.79	45.88	37.95	1,254.42	741

4.d De Hoop - combined calculation summary using a densification rate of 5%

Summary table of combined riparian and dryland calculation. Densification = 5%

Year	Total area invaded (ha)	Condensed area invaded (ha)	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	173,638	17,295	7.39%	7.98	5.94%	206.06	-
2023	217,916	54,393	23.26%	85.43	63.59%	2,205.82	1070%
2038	230,380	92,061	39.36%	106.30	79.13%	2,744.79	1332%
2053	233,146	233,146	99.69%	107.58	80.08%	2,777.74	1348%

Riperian summary table: 844/m^3/ha/yr riperian Euc reduction. Densification rate = 5%

Year	Total area invaded (ha)	Condensed invaded ha	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	21,270	2,119	7.39	1.79	13.31	36.74	-
2023	26,694	22,679	79.16	19.14	142	393.34	1070
2038	28,221	28,221	98.51	23.82	177	489.45	1332
2053	28,560	28,560	99.69	24.10	179	495.33	1348

Dryland summary table: 408/m^3/ha/yr dryland pine reduction. Densification rate = 5%

Year	Total area invaded (ha)	Condensed invaded ha	% of invadable ha	Reduction of MAR (million m^3)	% reduction of MAR	Cost to Clear invasion in 2013 rands (Million ZAR)	% cost increase
2008	152,368	15,176	7.39	6.19	5.12	169.31	-
2023	191,222	162,463	79.16	66.28	54.83	1,812.48	1070
2038	202,159	202,159	98.51	82.48	68.22	2,255.34	1332
2053	204,586	204,586	99.69	83.47	69.04	2,282.41	1348

APPENDIX E

1. Interview cover letter

RHODES UNIVERSITY
DEPARTMENT OF MANAGEMENT
Where leaders learn

Tel: (046) 603 8245 – Fax: (046) 603 8913 – email: L.Louw@ru.ac.za

Dear Participant

The purpose of this study is to investigate the decision-making process in the security of water supply in South Africa. More specifically, this research is looking at the decision-making process in building of De Hoop Dam as the best way to secure additional yield in the Steelport Catchment.

I request you to share your insights into and perceptions of the decision-making process in the selection of De Hoop Dam as the best way to secure additional yield in the Steelport Catchment in this in-depth semi-structured interview. The interview will take between 45 to 60 minutes to complete and the questions will focus on decision-making during the selection of De Hoop Dam as the chosen scheme to secure yield in the Steelpoort Catchment and the building of the De Hoop Dam. There are no right or wrong responses, only your insights are important. Your responses will not be inferred in any way to a political context and will be used for research purposes only.

Please note that your participation in this **interview is voluntary, completely anonymous and confidential**. Once the research has been conducted the data will be handed to the research supervisor, Professor L. Louw, for private storage for research purposes. The research has been approved by the Faculty of Commerce Higher Degrees Committee and the Department of Management Human Ethics Committee. The final research thesis will be made available via the Rhodes University Library.

These interviews form part of the research conducted for the purposes of completing a Masters of Commerce degree in Management at Rhodes University, Grahamstown.

Thank you for your cooperation.

Yours sincerely
Ian Preston

2. Interview guide

1. Please can you explain how the need for additional water yield in the Steelpoort Catchment, was identified?
    a. Which directorate and/or position in the DWA were responsible for identifying this need?
    b. When was a supply side measure selected?
    c. How was the extent of the need for additional yield assessed?
    d. How has risk and uncertainty been mitigated?

2. Which directorate and/or position in the DWA recommended the decision to build the De Hoop Dam?
    a. Who would have been consulted when the recommendation went to the minister?
    b. When was the decision to build De Hoop Dam made?
    c. What was the role of uncertainty in making the decision to build De Hoop Dam?

3. In considering alternative solutions:
    a. Were other **infrastructure-based** alternatives (such as other dams or inter-basin transfers) considered?
    b. If so, what were they?
    c. Why, in your opinion, where these alternative infrastructure-based solutions not selected?
    d. Were other **non-infrastructure-based** alternatives (such as demand-side or catchment management) considered?
    e. If so, what were they?
    f. Why, in your opinion, where these non- infrastructure-based solutions not selected?

4. How where the alternative infrastructure based and non-infrastructure based solutions compared and evaluated?

5. How was the De Hoop Dam chosen from among all the alternative solutions?
    a. What processes where used in choosing a solution to fulfil the need for additional yield?
    b. How were risk and uncertainty mitigated in choosing to build De Hoop Dam?
    c. In the decision to build the DHD were any decisions made to mitigate the risks to catchment management?
    d. If so, what were these decisions?

6. What were the strengths and possible weaknesses in the decision-making during the building of the De Hoop Dam?
    a. Which directorate and/or position in the DWA have been responsible for making decisions during the building of the dam?

Interview guide continued…

b. In your opinion, which model of decision-making best fits the decision-making that has occurred during the building of De Hoop Dam:

   i. Rational Decision-Making Model (RDMM)
   ii. Bounded Rationality Decision-Making Model (BRDMM)
   iii. Political Decision-Making Model (PDMM)
   (The models are shown in full at the end of the guide)

7. Have any decision-making processes been evaluated?
   a. To date, has the building of De Hoop Dam been on course to achieve all the goals that were planned, in their specified time frames?
   b. If not, then which goals were not on course to be achieved as planned and why not?
   c. What goals were achieved and how?
   d. Have any decisions been retrospectively analysed?

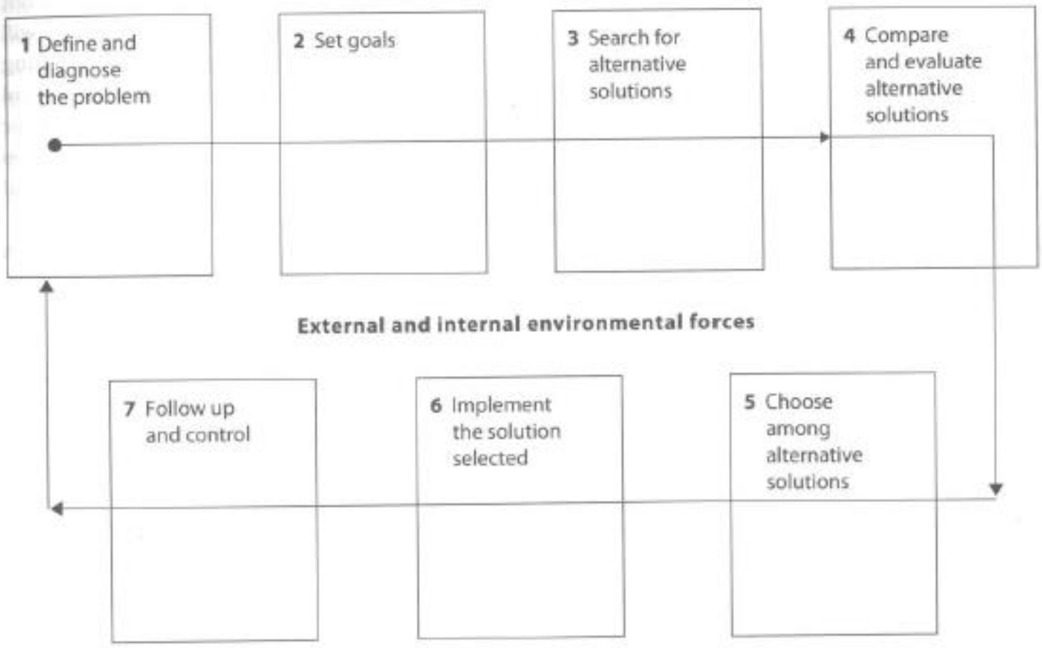
8. My understanding is that Phase 2A (building De Hoop Dam) was forecast to cost approximately R1.744 Billion (in 2012 Rands), to date it has cost R3.035 Billion. How can this difference be explained in terms of the Decision-making process?
   a. Do you think a different decision-making process would have been followed if the cost to date (the actual cost) had been projected as the estimated cost?
   b. Do you think a different decision would then have been made?

Interview guide continued…

For Question 6B: decision-making models (Zindiye, 2012)

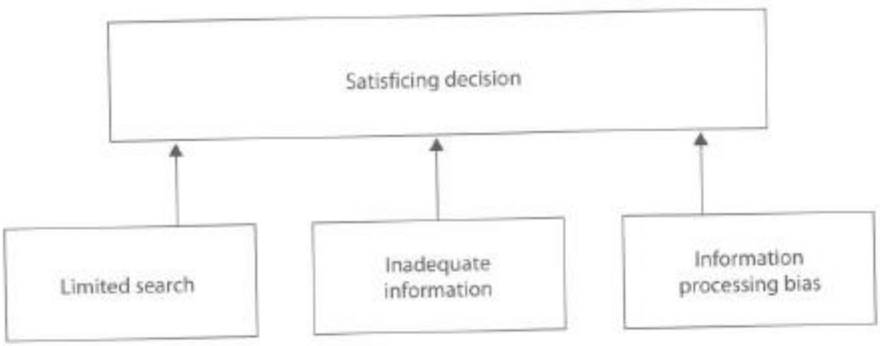
i. Rational Decision-Making Model

Figure 7.5 Rational decision-making model



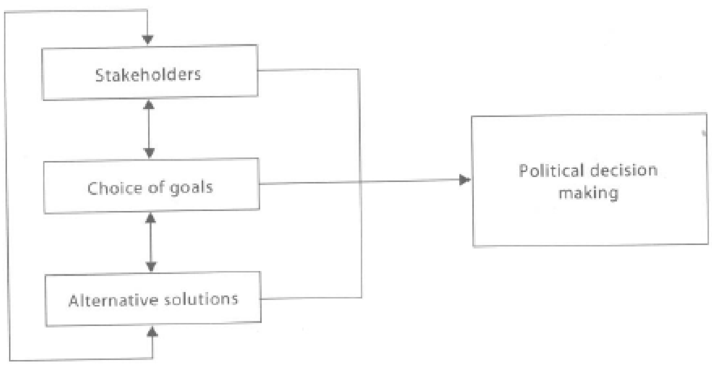
ii. Bounded Rationality Decision-Making Model

Figure 7.6 Factors influencing a satisficing decision



iii. Political Decision-Making Model

Figure 7.7 Factors affecting the political decision-making process



3. Example of informed consent form

RHODES UNIVERSITY

INFORMED CONSENT FORM

Department of Management

Research Project Title:	Water supply development decision-making in South Africa
Principal Investigator(s):	Ian Preston

Participation Information
• I understand that participation in this study is done on a voluntary basis • I understand the purpose of the research study and my involvement in it • I understand the risks of participating in this research study • I understand the benefits of participating in this research study • I understand that I may withdraw from the research study at any stage without any penalty • I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential • I understand that I will receive no payment for participating in this study • I understand that my answers will in no way be inferred into a political context • I understand that once the research has been conducted the data will be handed to the research supervisor, Professor L. Louw, for private storage. • I understand that this consent explicitly excludes minors and other vulnerable populations that need bystanders • I understand that the interviewer will email me his notes so that I can check that what he wrote is accurate.

Informed consent form continued…

Information Explanation
The above information was explained to me by: **Ian Preston**
The above information was explained to me in: ☐English ☐Afrikaans ☐isiXhosa ☐isiZulu ☐Other: and I am in command of this language **OR**, it was comprehensibly translated to me by:

Voluntary Consent		
I,______hereby voluntarily consent to participate in the above-mentioned research.		
Signature:	**OR**, right hand thumb print Witness signature:	Date: / /

Informed consent form continued…

Investigator Declaration	
I, Ian Preston, declare that I have explained all the participant information to the participant and have truthfully answered all questions ask me by the participant.	
Signature:	Date: / /

Translator Declaration	
I, , declare that I translated a factually correct version of: 1. all the contents of this document 2. all questions posed by the participant 3. all answers given by the investigator In addition, I declare that all information acquired by me regarding this research will be kept confidential.	
Signature	Date: / /