

# DESIGNING AN INTEGRATIVE APPROACH TO REGIONAL WATER SCHEMES IN SOUTH AFRICA



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January 2015



# Designing an Integrative Approach to Regional Water Schemes in South Africa

**Information**

MSc. thesis System Engineering, Policy Analysis and Management  
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29 January 2015

**Academic Information**

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**Keywords**

Design Science, Estuarine Negotiation, Regional Water Schemes, Operating Rules, Coastal System Negotiation, Social-Ecological Systems, Boundary Object, Citizen Participation, Participatory Systems Design



## ACKNOWLEDGMENTS

This thesis is the concluding part of my master System Engineering Policy Analysis and Management at the Technical University of Delft. The research is conducted in line with the Marie Curie collaboration between the Technical University of Delft (TUD) and the Council for Scientific and Industrial Research (CSIR). This collaboration provided me with the opportunity to perform this research together with a three month exchange to South Africa.

The level of independence I have had during this research in South Africa provided me with ample opportunity to choose my path in the project and has allowed me to, for this limited amount of time, embed myself into the South African culture. This resulted in a high level of commitment to the problem situation and enthusiasm in my attempt to tackle the challenges that I faced. Therefore I would like to express my gratefulness for the opportunity that has been granted to me by the Marie Curie collaboration, the Technical University of Delft and the Council for Scientific and Industrial Research.

More concrete, I would like to thank my graduation committee: Wil Thissen, Jill Slinger and Sander van Splunter for their guidance, ideas, support and enthusiasm during the project. I would like to thank my colleagues at the CSIR: Marius, Nikki, Elliot, Karen, Richard and Winile thank you for your incredibly warm welcome in South Africa, the birthday parties, rugby game, braai, Soweto tour and Christmas dinner meant so much to me and go beyond what I would describe as hospitality. Stephen, I would like to thank you especially for your substantive contributions to this research through our regular meetings in Pretoria or between transfers at Johannesburg airport. Lara, Susan and Piet thank you very much for having me at CSIR Stellenbosch. Thanks for seeing the potential and spending as much time in our discussion and workshop sessions. Thanks to the 43 other participants in my interviews or discussions, your names have been mentioned in the appendix. I would like to thank Yzelle, Dries, Monique and Estie for making my place to stay in Pretoria my South African home. And finally the many friends I have made that took me for fantastic nights out, a birthday weekend at the Vaal dam, sleepovers at Brenton at Sea, safari trips, festivals and much more.

Unfortunately, this research also concludes my student life in Delft. I thoroughly enjoyed my student life with the many friends I have made along the years. These friends I would like to thank, it was amazing.

Rob van Waas, January 29, 2015

## SUMMARY

### Research Problem

South Africa has to cope with a varying freshwater supply. In doing so it has constructed over 500 dams that capture half of the countries annual rainfall. Despite this shortages do occur and are expected to become more prevalent due to a combination of population and economic growth and an increase in the variability in the freshwater supply. Researchers indicate that the current decision-making processes to govern the allocation and rationing of water are inadequate.

The aim of this research is to gain understanding in the functioning of the South African water management and design an improvement for the allocation and rationing of water during periods of drought. The main research question for this research is as follows: *how does water management work in South Africa? And how can decision-making on water management be improved?*

### Analysis of the South African Water system

The South African water institutions have undergone major changes after the democratic elections in 1994 and the new National Water Act in 1998. The main pillars of the National Water Act are sustainability, efficiency and equity. Each different water resource should be evaluated by an elaborate classification process which determines the balance between utilizing and protecting the water resources. However, there is an observed difference between the rules in form and the processes that are currently being used and that in practice govern the water resources. It is identified that the classification processes lack progress and are currently not governing the water resources. The water resources are at this moment governed by professionals in the water sector bridging old and new institutions. The Regional Water Scheme has been identified as governing the water resources in practice at this moment. Therefore it is chosen to focus this research on the currently used decision-making process to a Regional Water Scheme.

### Research approach

For this research theoretical lenses that exhibit fit and potential for aiding in answering the research question have been selected. Concepts and methods from Policy Analysis, (The Ladder of) Citizen Participation, Participatory Systems Design, Social-Ecological Systems and Boundary Objects have been utilized and brought together in this research. For this research a design oriented approach is adopted in which a decision-making process to a Regional Water Scheme including the use of a model as a Boundary Object is to be designed. System Dynamics is chosen for the simulation model since it is able to quantitatively model dynamic systems in an accessible white box causal structure. The Mossel Bay region, with the Wolwedans dam as a main water source, has been chosen to act as case area. Reasons for this were that the system is representative in water management, type and size of user groups and the ecosystem. Also the region is geographically compact and data-rich because of the high amount of studies over the past 10 years.

### Design of intervention

In designing the artifact first objectives for the design have been determined. The design should support the decision-making process that leads to higher sustainability, efficiency and equity. The objectives of the design are therewith: support decision-making to Regional Water Schemes by adding **transparency, representation**, making it more **valid** and ensuring **progress** without excessive **cost**.

The System Dynamics model has been conceptualized and specified in an engaged modeling process in which experts have been involved by means of interviews and modeling workshops. High level knowledge of the experts is incorporated into the model. The simulation model is able to have the different expertise areas interact. The simulation model can improve the validity and transparency.

The decision-making process that is designed will use the model to generate outcomes of interest for citizens and stakeholders. These outcomes can be translated into easily understandable non-numerical scorecards. This allows citizens to participate into the decision-making process by expressing their preferences and values via ranking the scorecards. This increases the representation of the decision-making process. The democratically chosen representatives can now make a decision on what alternative for the Regional Water Scheme to implement. The extra information that has been gained in the process will help the representatives to make a decision without losing progress.

### **Validation**

The high level knowledge of the experts has successfully incorporated into the System Dynamics model that has been developed for the Mossel Bay region. The only issue occurred with the ecosystem in which discussion remained on the level of abstraction the model should have. The model is still found to be a valid model for its purpose. It was also validated that the model functioned as a Boundary Object across the boundaries of the different disciplines. Finally, the impact on the decision-making process to Regional Water Schemes in South Africa could not be validated of the process as a whole, since the process has not been tested yet. The design can improve the first steps of the process and for the further steps further validation is required.

### **Conclusions and Recommendations for the decision-making process**

The answer to the research question: *how does water management work in South Africa? And how can decision-making on water management be improved?* Would be that water management works through a combination of old and new institutions together with professionals in the sector coping with this. This could be improved by using a model as a Boundary Object in the decision-making process.

In performing the decision-making processes that are currently ongoing and planned it is recommended to value progress over rigor. The South African department of Water and Sanitation has set very ambitious standards for the decision-making process, however there is very little progress in these processes. It is recommended to (temporarily) lower the ambitions for the sake of progress. It is recommended to invest in knowledge on a system level. There are many interdisciplinary studies being performed, however there is little integration over discipline boundaries. It is recommended to invest in boundary spanning skills and knowledge. It was very beneficial for this research to have access to the results of the many studies that have been performed. It is recommended to keep the current level of transparency in research outcomes.

The thesis can recommend further research into the translation of model outcomes to scorecards, the way in which citizens experience working with scorecards, the deliberative character of the designed process and the actual water use of agricultural users.

### **Limitations of the research**

The research focusses on the Regional Water Schemes which are the current governing structure in practice. This is a deliberate choice to increase usability, however if the rules in form would be implemented and used, then parts of this research should be adjusted to the new situation. The validation process hasn't been completed, so it is unclear whether the improvements in the decision-making process that have been validated will constitute to an

## 0 Summary

improvement of the decision-making process as a whole. The study should be generalizable towards regions with small to medium size cities, however it can probably not be easily translated to the largest cities of South Africa such as Cape Town, Pretoria, Johannesburg or Durban.

### **Reflection**

The thesis has attained the aim of the research to a large degree. Understanding of the system has been used to develop a partially validated decision-making process involving a model used as a Boundary Object. The relevance of the issues that have been addressed is high and the proposed method of using a Boundary Object could be a step towards a more deliberative process. The ideas that this thesis bring forth are however in their early stages and can only be developed if adopted by both researchers as well as practitioners in the water sector.



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## ACRONYMS AND ABBREVIATIONS

CMA	Catchment Management Agency
MS	Catchment Management Strategy
CPR	Common pool resources
CSIR	Council for Scientific Industrial Research
DUT	Delft University of Technology
DWA	Department of Water Affairs (now DWAS)
DWAF	Department of Water Affairs and Forestry (now DWAS)
DWAS	Department of Water Affairs and Sanitation
EHI	Estuarine Health Index
ERC	Ecological Reserve Category
ESDMA	Exploratory System Dynamics Modeling Analysis
EWR	Environmental Water Requirement
FBW	Free Basic Water
NIC	Newly Industrialized Country
NWA	National Water Act. Act No. 36 of 1998
NWRS	National Water Resource Strategy
PA	Policy analysis
PES	Present Ecological Status
RDM	Resource Directed Measures
RWSS	Regional Water Supply Scheme
SA	System analysis
SANPAD	South African Netherlands Partnership for Alternatives in Development
SD	System Dynamics
SES	Social-Ecological System
WMA	Water Management Area
WTW	Water Treatment Works
WUA	Water User Association
WWTW	Wastewater Treatment Works

# SECTION I: INTRODUCTION AND PROBLEM EXPLORATION

## 1 INTRODUCTION

Although the average rainfall in South Africa is 450 mm per annum<sup>1</sup> (DWA, 2013), this is spread unevenly over the country<sup>2</sup> and in time. Accordingly, South Africa has to cope periodically with freshwater scarcity. The high variability is inherent to the main source of freshwater: rainwater that is caught as runoff in rivers and streams in a limited number of dams. Groundwater and desalination account for a very small share of the water supply (Karagiannis & Soldatos, 2008). In addition to the fact that the flow of rainwater fed into rivers is variable, South African river flows are identified as amongst the most variable in the world (Hughes & Mallory, 2009; McMahon, 1979). Figure 1 shows the difference between South African rivers and rivers in the United Kingdom. The steeper the curve, the more variable the river flow. As opposed to rivers in the UK, South African rivers cannot supply a guaranteed minimum flow all of the time. A flow below 5% of the mean daily flow occurs 8% of the time for the South African river (SA1) and 35% of the time for the South African river (SA2) indicating that they fall dry at times.

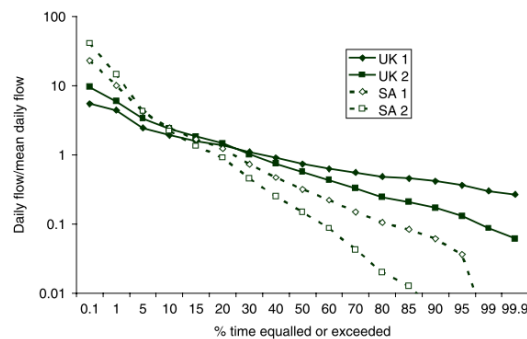


Figure 1: Flow duration curves for two rivers in the UK and two in South Africa (Hughes & Mallory, 2009, p. 733)

Dams can be used to store water and serve as a buffer for dry spells. About half of South Africa's annual rainfall is stored in more than 500 dams (Water Research Commission, 2009). Although the existing buffer capacity in dams provides a certain level of security of supply, freshwater crises still occur (Makana, 2013; Mokhema, 2013; Mossel Bay Advertiser, 2009; Mossel Bay Municipality, 2011; PE Herald, 2011; Steyn, 2013). The construction of a dam has high social and environmental impacts and requires the terrain to have certain geographical characteristics (Goldsmith & Hildyard, 1986). Therefore new dams are very rarely built. Another option for dealing with dry spells and low water levels in dams is the rationing of the use of water. When the water levels in a dam fall below an agreed level, users are then rationed in their water supply, receiving less water than they would ideally require. Figure 2 shows a hypothetical example of rationing with two rationing point (at 60% and at 30%). It is seen that with the rationing a longer dry spell can be bridged.

<sup>1</sup> The average in for example the Netherlands is 850 mm per annum (KNMI, 2010).

<sup>2</sup> Varying from 100 mm per annum in the east and 1500 mm per annum in the west (DWA, 2013).



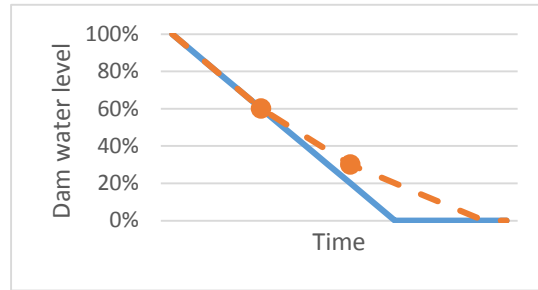


Figure 2: Hypothetical example of rationing (dashed line) versus non-rationing (non-dashed line) for a prolonged dry spell

This research project will investigate the decision-making regarding the rationing of water during dry spells.

### 1.1 CONTEXT

Since this research project takes place in South Africa and is executed by a Dutch student from the Delft University of Technology in the Netherlands it is insightful and meaningful to sketch the South African context in which the project takes place. To help with sketching this context, the four layer model, originally proposed by Williamson (1979, 1998) is used to interpret different levels in the South African context (Figure 3).

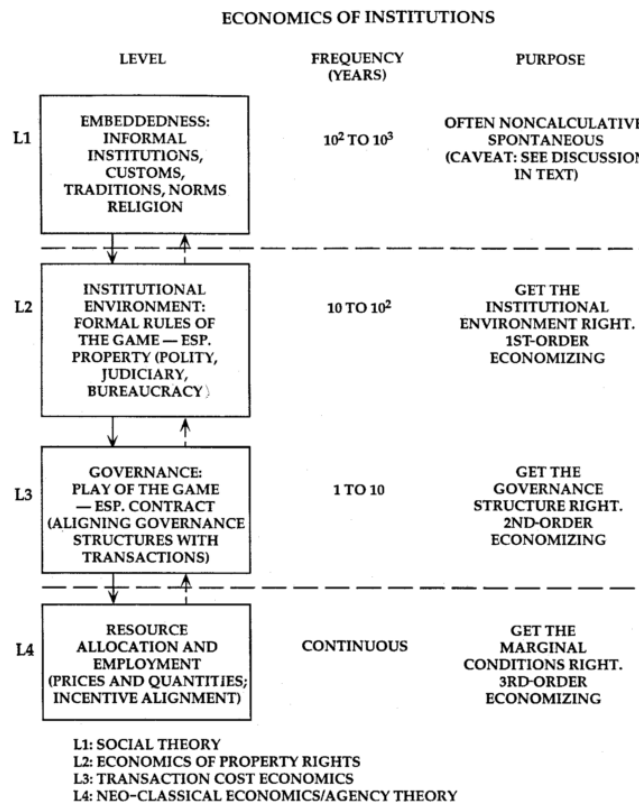


Figure 3: Four Level Model of Institutional Analysis by Williamson (1998, p. 23)

## 1 Introduction

The **first level** of institutional analysis is the social embeddedness level. At this level norms, customs, mores, traditions, religion etc. are located (Williamson, 1998). The time horizon of items in this level is indicated by Williamson to be about a century to a millennium. This does not mean that there isn't a possibility for an abrupt change, but it is unlikely that a major shift occurs every decade. The changes at this level are mostly not the result of purposeful design, but occur spontaneously (Williamson, 1998). This is an interesting level applied to the South African context, since recently<sup>3</sup> significant changes have occurred on this level. The abolition of the apartheid regime and the first democratically elected government in 1994 is a huge shift in the first layer (Worden, 2000). This year the twenty years of democracy are celebrated and the transition to a society of equality is still ongoing and debated. I won't attempt to fully capture or review the post-apartheid period. I am however mentioning it, since it has an impact on the research and should be taken into account during the research and design process.

The **second level** in this model is the level of the institutional environment. According to Williamson this is relatively stable and has a characteristic time horizon of about a decade to a century. It is arguable how this time horizon will play out for South Africa given the degree of change in the first level of institutional analysis, but the South African water law is located in this level. The water law provides a framework for the use of water resources<sup>4</sup>. The South African water law has Roman-Dutch origins and was originally a combination of *dominus fluminis*: water in the public domain, and riparian: water can be property (Thompson, 2006). In 1912 the riparian-based National Water Act was enacted and in 1956 industrial users were added to the National Water Act. However in 1998 the new National Water Act was promulgated (Republic of South Africa, 1912, 1956, 1998). This was influenced by the revision of the South African constitution in 1996 (Republic of South Africa, 1996). The National Water Act embraces the main principles of *sustainability, equity and efficiency*. These three main pillars recognize basic human needs, the need to redress past discrimination, the protection of water resources, the establishment of water institutions and the participation of stakeholders and users in decisions that affect them (Republic of South Africa, 1998). For this research, items in this level can be viewed as exogenous. This means that the research will not propose changes on this level, it will be seen as a constraint to fit the design into this level.

The **third level** is referred to by Williamson as governance, or the play of the game. This entails the more specific legislation and the execution or operation of the rules in form in the second level. The time horizon of this level is indicated by Williamson as between one and ten years. The research scope is at this level. This implies that the proposed intervention should be rigid enough to last for somewhat ten years and adaptable enough to be undergo changes on a scale of a year.

The **fourth level** holds the actual allocation of the water resource. Williamson argues that this is changed continuously. This can be seen as the negotiation process for allocating the water to different uses and the execution of the actual rationing rules determined in the third level on a daily basis.

Having sketched this general institutional framing, the next section will the scope of the problem.

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<sup>3</sup> On a time horizon of a century to a millennium.

<sup>4</sup> By water resources are meant: groundwater, wetlands, streams, rivers, estuaries and the ocean (Republic of South Africa, 1998).

## 1.2 RESEARCH PROBLEM

Rationing of the supply of water to users is a method for coping with the varying supply of water within the constraints of the limited amount of storage. By timely rationing the water the dry spell should not be having such a large effect on the service delivery as was seen in the news articles in the introduction. There seems to be an issue with the rationing, given the experienced service delivery failures.

Influential South African hydrologists Hughes and Mallory (2009) argue that the current process for establishing the rationing schemes is inadequate. Their argument is that the scarcity will increase in the coming years due to a combination of population growth, economic development and an increased variability in rainwater. During scarce periods competition for the water resource will occur and groups cannot be supplied with their full supply requirement. The current process for establishing the rationing schemes would be unable to deal with the increased competition over the resource Hughes and Mallory argue. In the article Hughes and Mallory explicitly ask social and economic sciences to step in. In their view the currently used, mainly technical, knowledge is insufficient for understanding the water system as a whole.

This raises the question whether the current process leads to the highest levels for the three objectives that are set out in the National Water Act, namely sustainability, efficiency and equality. It is unclear still what exactly is going wrong, so this research will go into that and see if improvements can be suggested.

Clearly, there could be tension between sustainability and efficiency. South Africa wants to use<sup>5</sup> its water resources to the maximum potential. Meaning to facilitate social and economic growth. However it also wants to conserve or restore its aquatic and associated ecosystems. This means balancing between protection and utilization. Equity is a slightly difficult concept to define. It could be seen as the *fairness* in distributing the benefits from the water resources: *do all groups benefit equally from the exploitation of water resources?* However there is also an aspect of time and specific to South Africa: *does the current water distribution redress the results of past racial discrimination?* The research will have to deal with these issues.

## 1.3 RESEARCH OBJECTIVES, DELIVERABLES AND RELEVANCE

To set research objectives the project execution context needs to be taken into account. In this case the project is a master thesis research project of which three months took place in South Africa. There was no budget besides a reimbursement for personal expenses in South Africa. The objectives of the research and the success criteria are set up taking this into account.

The objective of this research is to improve the decision-making process for coping with dry spells in South Africa. This objective can be further divided into four parts:

- First, to gain insight into the formal processes in place in the institutional environment of the water system of South Africa. This is gaining insight into the **second level** of the four-level model of Williamson (page 13). This will be considered the environment for this research and exogenous for the intervention in this research.
- Secondly, to gain insight into the practices for coping with dry spells in South Africa. This entails an analysis of the processes that are being used in practice in governing the water system in South Africa in relation to coping with dry spells. This corresponds to the **third level** in Williamson and is seen as the area of application for the intervention in the research.

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<sup>5</sup> Defined as: taking, diverting or affecting the quality (Republic of South Africa, 1998)

## 1 Introduction

- Thirdly, to see in what way improvements can be made to the current decision-making process.
- Fourthly, to provide a proof-of-concept for an improvement to the decision-making process.

The deliverables associated with the research objectives are the following:

1. An analysis of the institutional environment for coping with dry spells.
2. An analysis into the practices for coping with dry spells in South Africa.
3. An analysis on how to improve the current decision-making process. This would be a problem analysis combined with a design space for improving the process.
4. The proof-of-concept for the proposed improvement. This will entail a design of the improvement and a proof-of-concept consisting of a limited amount of validation and testing of the designed improvement.

For graduating in the master program of System Engineering, Policy Analysis and Management it needs to be clear that the research has both a scientific as well as a societal relevance. At this point the societal relevance is clear: the research aims at improving the water management which serves society by specifically raising sustainability, efficiency and equity in managing the water resources. The scientific relevance is mostly in the analysis of how to improve the current decision-making process and the proof-of-concept that is provided. There will be a symbiotic relation in which the research grounds itself in the state-of-the-art theories and publications and provides back its design artifacts. The scientific relevance will become clearer when more is known on the proposed concept.

### 1.4 RESEARCH QUESTIONS

The main research question is exploratory in nature and focusses on describing and structuring the problems with water management in South Africa.

#### ***How does water management in South Africa work? And how can decision-making on water management be improved?***

In the process of answering the main research question the following sub-questions will be answered:

1. What are the rules in form and the rules in use in South African water management?
2. What theoretical lenses can be used in designing an improved decision-making process for water management?
3. How can an improved decision-making process for water management be designed and validated?
4. Which design can improve the decision-making on water management in South Africa?
5. Can the design be validated enough to speak of a proof-of-concept?

The subsequent research questions built on the knowledge gained from the preceding research questions. Question one is used to gain more insight into the problem. With that insight research question two can go into which theoretical lenses will be used to address the problem. Using the insights into the problem combined with the lenses that are going to be used research question three can be answered. This provides a methodology for designing, choosing and validating a design that is aimed at improving the decision making on water management in South-Africa. Strictly speaking only research question four and five are needed to answer the main research question. However research question one, two and three are required for research question four and five to be answered.

## 1.5 OUTLINE OF THE RESEARCH

In Figure 4 the structure of the report is summarized.

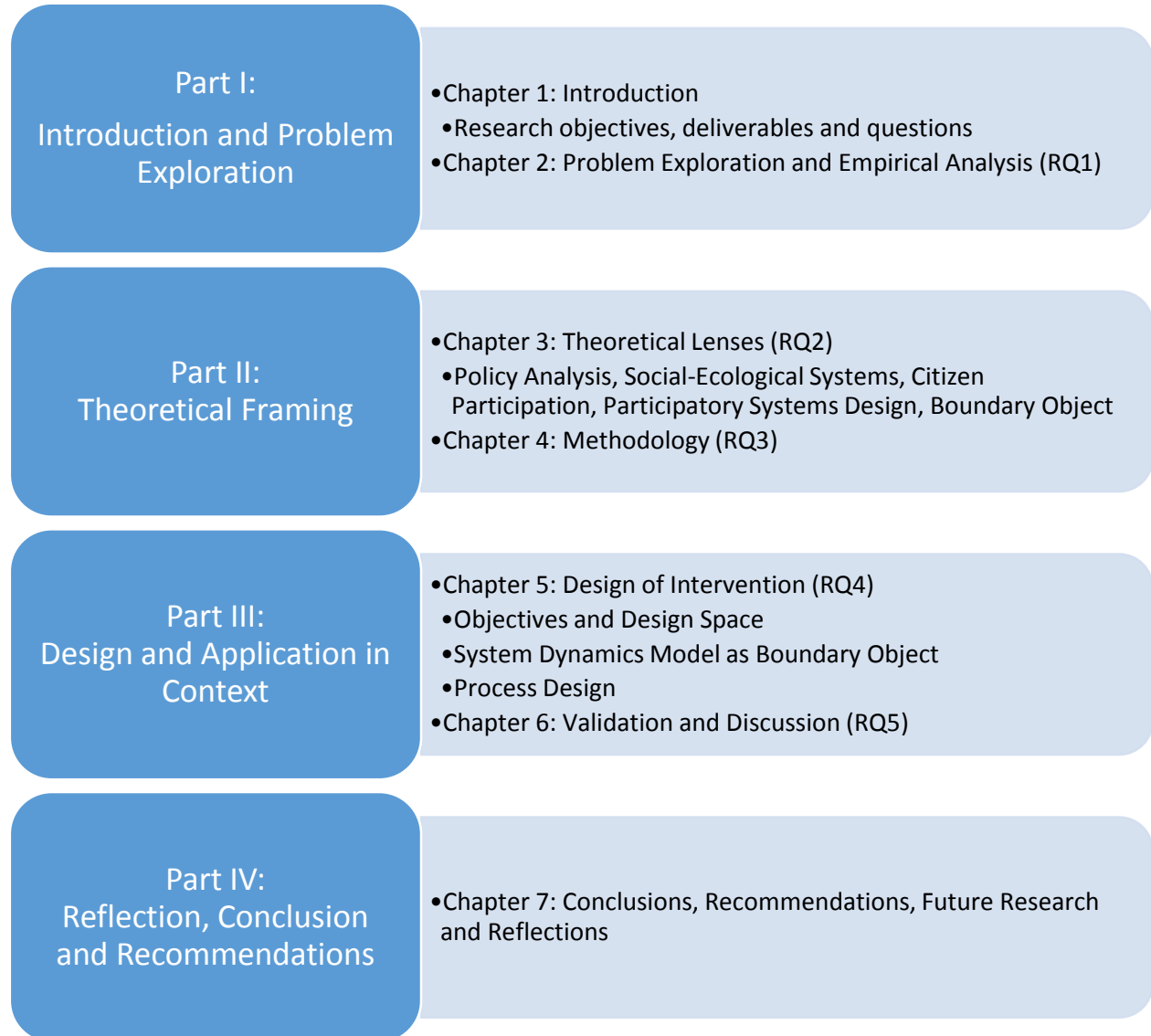


Figure 4: Outline of the report

### 2 ANALYSIS OF THE CURRENT DECISION-MAKING PROCESS

The analysis in chapter one identified a problem in the process for determining freshwater rationing for coping with dry spells in South Africa. This chapter provides an analysis of the South African water system specified to the current decision-making process freshwater rationing. The chapter is written using various sources. For the most part the chapter is based on interviews with professionals operating within the water system. Documentation of the interactions with professionals is found in Appendix B. Specifically on water law interview with Hubert Thompson, member of the South African Water Tribunal and author of the book *Water Law: A Practical Approach to Resource Management and the Provision of Services* (2006) (Appendix C contains a report on the interview). Written sources such as the National Water Act (Act 36, 1998) are cited. There was an observed difference between the *rules in form* and *rules in use*. Often this is not explicitly written down, expressed or even known by the professionals in the water sector, but it can be deduced from the comparison between the observation of *rules in use* and the *rules in form* that are documented. Therefore the differences between the *rules in form* and *rules in use* are in this research based on observations by me as a researcher. These observations are documented in the best possible way given the thesis scope. For further questions it is advised to contact me, the researcher.

#### Structure

In paragraph 2.1 the water system is institutionally analyzed. Here the rationing of water is further explored and the concept of Regional Water Schemes and Operating Rules is introduced in the context to South African water law. Followed by this is an analysis of the classification process. This process balances the protection and utilization of water resources. This paragraph is concluded with an examination of Public Participation in the South African Water System. Paragraph 2.2 describes an observed general process for setting a Regional Water Scheme and paragraph 2.3 elaborates on this with an example of this process specifically for the Mossel Bay regional Water Scheme. Paragraph 2.4 takes on a multi-actor perspective with regards to the process of setting a Regional Water Scheme. In paragraph 4.4 the chapter is concluded by answering research question 1: *What are the rules in form and the rules in use in South African water management?*

#### 2.1 HIGH LEVEL DESCRIPTION OF THE WATER SYSTEM

The South African water system is divided into catchment areas. Catchment areas are areas in which all the water from rainfall drains into a common place, such as a river or the ocean. The South African government has assigned these natural catchment areas into nine<sup>6</sup> institutional catchment areas and gave them the status of water management area (WMA). The NWA 1998 sets the objective for each WMA to have a regional Catchment Management Agency (CMA) with powers delegated from the Minister. Currently only two CMAs are operational, namely the Inkomanti-Usuthu and Breede-Overberg (DWA, 2013). See Figure 5 for an overview of the different WMAs and CMAs associated with them.

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<sup>6</sup> Originally 19 CMAs would be formed, however this has been conjoined to nine CMAs (DWA, 2012)



Figure 5: Map with previous 19 CMAs and present 9 CMAs (Republic of South Africa, 2012)

Each WMA should have a catchment management strategy (CMS) on how the water-resources will be governed (NWA 1998, sec. 79). The CMS sets principles for allocating water to existing and new water users, provides the framework for managing water resources within the water management area and should ensure that water resources in the water management area are protected, used, developed, conserved, managed and controlled. A Regional Water Scheme (RWS) is developed for a region that is connected and supplied by one or multiple dams. An RWS contains Operating Rules which are heuristics to determine which user is supplied by which source and at what water level in dams should rationing occur. This is interesting regarding the rationing of water. First see how water is allocated in non-drought situations.

The main power in the South African water sector lies with the minister of the Department of Water and Sanitation. The minister is the public trustee (NWA 1998, sec. 3). Her powers are the following:

- Publish the National Water Resource Strategy (NWRS) (NWA 1998, sec. 5–7);
- Set Resource Directed Measures (RDM) (NWA 1998, sec. 12–18);
- Set additional general regulation (e.g. no mining within 500 meters of a river);
- Establish new institutions (such as Catchment Management Agencies) (NWA 1998, sec. 26).

In a normal situation water is allocated according to the legal framework as set out in the 1998 National Water Act. This act sets only one *right* to water, which is called the reserve (Nat. Water Act 1998, sec. 16–18). The reserve consists of the *basic human needs* and the *ecological reserve* this should provide all people and the ecology with their

## 2 Analysis of the Current Decision-Making Process

basic water needs. The amount of water that can be distributed to other uses equals the total amount of water minus the reserve (see Figure 6).

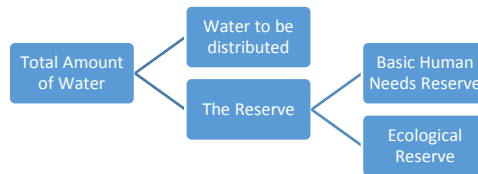


Figure 6: The Reserve as a part of the total amount of water

The other uses of water, which are defined in South African law as: *Taking* water from a body (river, basin, aquifer); *discharging waste water* into a water body and *storing* water (NWA 1998, sec. 21–22). Should be authorized in one of the following three categories (Figure 7):

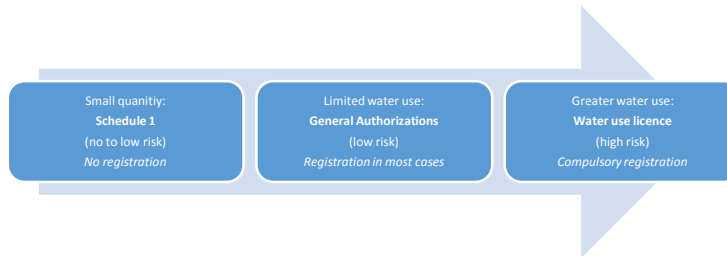


Figure 7: Categories of authorization in order of risk of impact to the water resource

These categories are in order of risk of impact to the water resource. Schedule 1 does not require registration or licenses and is for domestic use directly from the water resource, storing and using run-off from a roof, using water surface for recreational purposes, etc. There are two other kinds of use of water that do not require licensing: Continuation of Existing Use, or Existing Lawful Use (this will disappear and serves as a transition period) and General Authorization. General Authorizations can be granted by the minister and authorize a certain type of usage for a specific water resource. Examples could be storing water in a dam or extraction from groundwater sources. In exceptional situations the minister can call for a Compulsory Licensing procedure. In this case all existing and new water users should (re)apply for licenses (NWA 1998, sec. 43–48). The minister could use this measure to achieve a more fair allocation of the water resource, improve efficiency and protect the water quality etc.

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### 2.1.1 RATIONING AND OPERATING RULES IN THE SOUTH AFRICAN WATER LAW

When a dry spell occurs and dam water levels are getting low different water uses can be rationed. In Figure 8 the text regarding shortage or upcoming shortage of water is copied. It says that the water management agencies can ration water as they see fit. It should be published in the *Gazette* or in a written notice to the individual users. It also says that the decision should consider the factors mentioned in sub item (3). These factors support the necessity of a plan that is thought of before the actual shortage to help in making the right crisis situation decisions. Operating rules are guidelines for rationing that consider the factors in sub item (3) and can be put to effect to cope with a water shortage.



**Catchment management agencies may temporarily control, limit or prohibit use of water during periods of water shortage**

6. (1) If a catchment management agency on reasonable grounds believes that a water shortage exists or is about to occur within an area it may, despite anything to the contrary in any authorisation, by notice in the *Gazette* or by written notice to each of the water users in the area who are likely to be affected -
- (i) limit or prohibit the use of water;
  - (ii) require any person to release stored water under that person's control;
  - (iii) prohibit the use of any waterwork; and
  - (iv) require specified water conservation measures to be taken.
- (2) A notice contemplated in subitem (1) must -
- (a) specify the geographical area or water resource to which the notice relates;
  - (b) set out the reason for the notice; and
  - (c) specify the date of commencement of the measures.
- (3) In exercising the powers under subitem (1), the catchment management agency must -
- (a) give preference to the maintenance of the Reserve;
  - (b) treat all water users on a basis that is fair and reasonable; and
  - (c) consider -
    - (i) the actual extent of the water shortage;
    - (ii) the likely effects of the shortage on the water users;
    - (iii) the strategic importance of any water use; and
    - (iv) any water rationing or water use limitations by a water services institution having jurisdiction in the area in question under the Water Services Act, 1997 (Act No. 108 of 1997).
- (4) If the owner or person in control of a waterwork contravenes a notice issued under subitem (1), the catchment management agency may -
- (a) modify, or require the owner of the waterwork to modify the waterwork so that it cannot be used to take more water than that allowed for in the notice; or
  - (b) remove the waterwork or require the owner to remove the waterwork if the notice contains a prohibition on the use of that waterwork.
- (5) A catchment management agency may recover from the owner any reasonable costs incurred by it in acting under subitem (4).

**Figure 8: Legislation on Water Shortage (NWA 1998, sec. 3, item 6)**

Operating rules are a set of heuristics linking the demand to the supply of water. They determine from what source (mostly what dam) the different demands are met and sets out rationing in case of diminished water supply. As an example a March 2013 report on operating rules for dams surrounding the municipality of Mossel Bay is used (Mallory, Ballim, & Forster, 2013).

**Case information: Mossel Bay region water supply and demand**

The region around Mossel Bay is supplied from four dams: Hartbeeskul dam, Klipheuwel dam, Ernest Robertson dam and the Wolwedans dam. Besides that there is a possibility to use the desalination and recycling plant. The main competing uses are domestic use by the larger municipality, industrial use by PetroSA and water for the ecosystem. More detailed info can be found in Appendix A.

To get a better idea of operating rules a paraphrase of the operating rules that are recommended in the report follows:

- *“ Utilize Klipheuwel dam first for Mossel Bay's full demand until the water level drops below 50%;*
- *Then switch Mossel Bay to Wolwedans dam until the water level drops below 40%, then switch back to Klipheuwel dam;*
- *PetroSA (local industry) will be fully supplied from Wolwedans dam;*
- *Desalination and recycling plants are to be used at full capacity when the Wolwedans dam water level drops below 40%;*
- *Supply the full Environmental Water Requirement (EWR) to the ecosystem from the Wolwedans dam, until the water level drops below 70%, if it does 1 million m<sup>3</sup> per year at the estuary managers request”* (Mallory et al., 2013, pp. 7–1 to 7–6).

The above rules guide which usage demand is to be supplied from which source. A rationing scheme goes along with this to avoid running out of water during a dry spell. This scheme sets out the rationing of different users under certain dam water level conditions. The following are recommended in the Mossel Bay study:

Table 1: Proposed rationing scheme Mossel Bay from water supply schemes report (Mallory et al., 2013, pp. 7–1)

Domestic restrictions		PetroSA restrictions		Irrigation restrictions	
Dam water level	Rationing	Dam water level	Rationing	Dam water level	Rationing
>50%	0%	>10%	0%	>50%	0%
20 to 50%	10%	<10%	100%	20 to 50%	30%
10 to 20%	15%			10 to 20%	70%
<10%	20%			<10%	100%

The operating rules allocate water and set restrictions linked to dam water levels. Without rationing the water would run out at a faster pace. This introduction to operating rules provides us with an understanding of what operating rules are and what effect they might have on users.

### 2.1.2 THE CLASSIFICATION PROCESS

In the previous paragraph the reserve and operating rules were introduced. The reserve is a right to water that serves to protect the *basic human use* and the *ecosystem*. The protection of the water resources in South Africa is aimed at finding a balance between the **protection** and the **utilization** of the water resources. It is recognized that there is a relation between the health of an ecosystem and the amount of services that it can provide. If it is over utilized, the health will drop and consequentially the ecosystem produces less services. The aim of the protection is to ensure that the current and future state of the resources are of a high enough quantity and quality.

To achieve and maintain this balance the DWAS has the Chief Directorate: Resource Directed Measures (RDM). The objective is to ensure the protection of water resources by providing a framework for utilization of water resources and auditing the water resources accordingly. This process to which RDM operates is defined in the NWA of 1998 as the classification process and is illustrated in Figure 9. In the classification of the water resources it is assessed how much water is required for the ecosystem to retain its health and abilities to deliver services to the social, economic and ecological systems. The combination of determining the resource quality objectives and the reserves should then balance the protection and utilization.

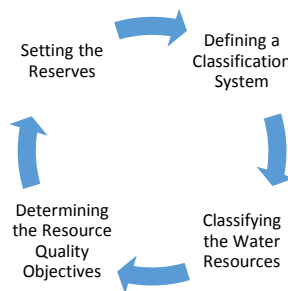


Figure 9: The Water Resource Protection Process

In the course of the classification process all the water resources need to be classified, quality objectives need to be set and a reserve needs to be determined. The following sub-paragraphs will go into each of the four steps in the water resource protection process in Figure 9.

- **Defining a Classification System:** The classification system is a set of guidelines for classifying ecosystems. A classification level will tell something about the *level of protection* that is required for the water resource and the *extent to which the water can be used*. The system sets out a methodology for classifying the water resources. The classification system is used in the way that is illustrated in Figure 10. The present state is identified, the level of protection and abstraction of water is set and finally the expected future state is predicted. The required level of protection and the amount of water that can be used are influencing the expected future state. The process in the NWA dictates that the DWA or the minister sets the Resource Quality Objectives for each resource. With the present state and this desired future state the required level of protection and amount of usable water can be determined.



Figure 10: The Classification of a Water Resource

- **Classifying the Water Resources:** The classification process has to be executed for all major water resources in South Africa according to the classification system set in the NWA. Outcomes of the classification process are the present state of the ecosystem and several impact scenarios for different amounts of water allocated to the ecosystem. The reserve cannot yet be determined, since *resource quality objectives* are required to determine the desired future state.
- **Determining the Resource Quality Objectives:** The minister is required to publish resource quality objectives in the Government Gazette for all major water resources. The resource quality objectives will contain objectives for: the quantity of water, the quality of water, the condition of the river bank habitat and the condition of the aquatic animal and plant life. There are extensive guidelines for determining the quality objectives which are oriented to retaining or heightening the classification level of the water resources. However the minister may diverge from the recommended quality objectives for various reasons.
- **Setting the Reserves:** The final part of the classification process is setting the reserve for the water resource. The *reserve* is divided into an *Ecological Reserve* and a *basic human needs reserve*. The *Basic Human Reserve* dictates that each household should receive at least the Free Basic Water (about 6.000 liters per household per month or 25 liter per day per person) (Water Services Act 108, 1997). The *Ecological Reserve* is determined by reconciling the classification, resource quality objectives and the effects of reduced flow on the water system.

This overview of the classification process is highly simplified for explanatory purposes. The in depth classification process has changed over time. Since 2005, the Chief Directorate: RDM published their inception report on the development of a national water resource classification system (DWAF, 2005). This led up to the latest proposal for a 7-step classification system (Chief Directorate: RDM, 2007). The procedures are set out in four volumes which provide guidelines for ecological, hydrological, water quality, socio-economic and decision-analysis (including the stakeholder engagement process) in the classification process (Chief Directorate: RDM, 2007 Vol 1 - 4).

## 2 Analysis of the Current Decision-Making Process

During the empirical study many reports related to the classification process and reserve setting were encountered however, for neither the classification process nor the reserve setting a definite report together with a publication in the Government Gazette was found. As described above, the resource quality objectives needs to at least be published before the definite reserves can be set. To investigate on this, a small study on different water resources is performed to look at the reports that have been linked to the classification process and see what outcomes these reports hold. In Table 2 the outcomes of this inventory have been presented.

**Table 2: Illustration of classification processes and the current progress**

Water resource	Present Ecological Status (PES)	Estuarine/ Ecological Importance Scores (EIS)	Social Importance (SI)	Recommended Ecological Reserve Category	Ecological Reserve Category (ERC)
Great Brak Estuary	D+: Largely modified <sup>7</sup>	72 - important <sup>7</sup>	<i>Not found</i>	C <sup>7</sup>	<u>Not ratified</u>
Seekoei/Kromme Rivers	Specified in seven EWRs and two estuaries in the rows below.				
EWR 1	C <sup>8</sup>	Moderate <sup>8</sup>	Low <sup>8</sup>	C <sup>8</sup>	<u>Not ratified</u>
EWR 2	D <sup>8</sup>	Moderate <sup>8</sup>	Low <sup>8</sup>	D <sup>8</sup>	<u>Not ratified</u>
EWR 3	D/E <sup>8</sup>	High <sup>8</sup>	Low <sup>8</sup>	D <sup>8</sup>	<u>Not ratified</u>
EWR 4	C/D <sup>8</sup>	Moderate <sup>8</sup>	Moderate <sup>8</sup>	C/D <sup>8</sup>	<u>Not ratified</u>
EWR 5	C <sup>8</sup>	Moderate <sup>8</sup>	Low <sup>8</sup>	C <sup>8</sup>	<u>Not ratified</u>
EWR 6	B <sup>8</sup>	Moderate <sup>8</sup>	Low <sup>8</sup>	B <sup>8</sup>	<u>Not ratified</u>
EWR 7	C/D <sup>8</sup>	Moderate <sup>8</sup>	Low <sup>8</sup>	C/D <sup>8</sup>	<u>Not ratified</u>
Seekoei Estuary	D <sup>8</sup>	Important (high) <sup>8</sup>	High <sup>8</sup>	B <sup>8</sup>	<u>Not ratified</u>
Kromme Estuary	D <sup>8</sup>	Important (high) <sup>8</sup>	High <sup>8</sup>	C <sup>8</sup>	<u>Not ratified</u>
Letaba River	B or C <sup>9</sup>	High <sup>9</sup>		B/C or B <sup>9</sup>	<u>Not ratified</u>
Letsitele River	C/D <sup>9</sup>	Moderate <sup>9</sup>		C <sup>9</sup>	<u>Not ratified</u>

The map in Figure 11 shows the progress of the reserve determination across South Africa in 2010. What is seen is that only in in WMA 17: Olifants/Doorn (now Berg-Olifants) and WMA 2: Letaba (now Olifants) a significant amount of comprehensive reserve studies have been conducted. What is observed is that extensive studies are performed on the water resources, however that the complete classification process is not completed.

<sup>7</sup> (van Niekerk et al., 2009)

<sup>8</sup> (Scherman, 2012)

<sup>9</sup> (Scherman, 2006)

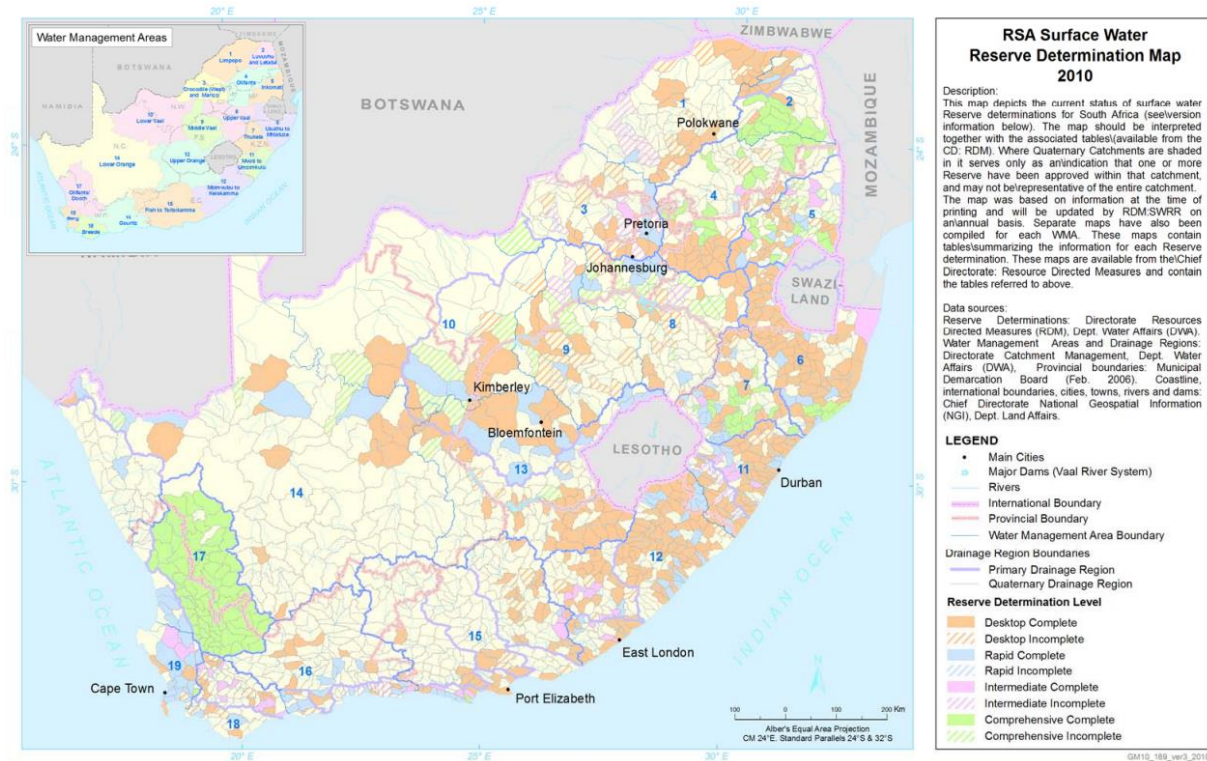


Figure 11: Reserve Determination Map (Chief Directorate: RDM, 2010)

To illustrate the extensiveness of the studies performed I have listed the different disciplines that were part of the project team for the study on the Great Brak estuary. To this project 34 researchers and 23 officials contributed. At least one person in each of these expert areas was present: a hydraulics engineer, geomorphologist, botanist, fish ecologist (river and estuarine), water quality specialist (river and estuarine), system analyst, sedimentologist, estuarine microalgae specialist, estuarine macrophyte specialist, estuarine invertebrate ecologist, ornithologist, resource ecologist, groundwater and socio-economist.

### 2.1.3 PARAGRAPH CONCLUSIONS

Concluding this paragraph, we have seen that the classification system is a *rule in form* since 1998, however it has not been converted to a *rule in use*:

- The decentralized Catchment Management Agencies have not been set up for most of the Water Management Areas. Only two out of nine agencies are operating to this date.
- To balance between utilizing and protecting the natural resources the Chief Directorate of Resource Directed Measures controls the classification process.
- The content in the classification process can be regarded as extensive and of high quality. However, the progress of the process is limited to the extent that for no classification process all steps have been completed. No Resource Quality Objective or reserve setting has been ratified and published in the Government Gazette by the minister of DWAS yet.

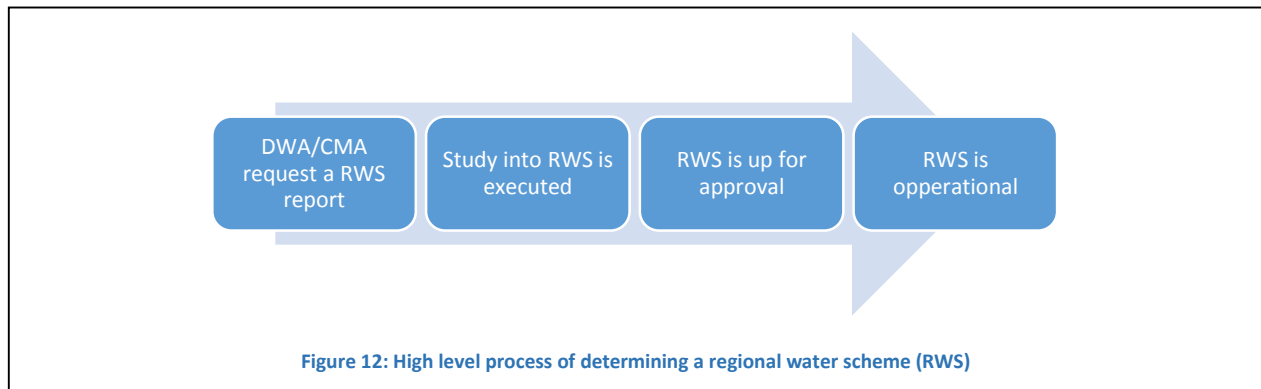
## 2 Analysis of the Current Decision-Making Process

*Rules in use* deriving from preexisting institutions together with the efforts of practitioners in the water sector to best adhere to the 1998 National Water Act are currently in balancing the utilization and protection of the water resources in practice. Therefore we find the *rules in use* to be a combination of older institutions, the new *rules in form* and coping by the practitioners by using their discretionary leeway.

### 2.2 OBSERVED GENERAL PROCESS FOR SETTING A REGIONAL WATER SCHEME

In this paragraph the process for determining a Regional Water Scheme and setting operating rules will be described as they were observed during the empirical research phase of this thesis in South Africa. The paragraph hereafter will provide a case example of such a process specified for the Mossel Bay regional water scheme of which the Great Brak is a part.

The process of determining a regional water scheme (RWS) starts with the DWAS. They are responsible for putting an RWS study out to tender. The external consultant that is awarded with the contract will then execute a study on the RWS. This will be reviewed and approved before the scheme that is selected becomes operational.



The external consultant will set operating rules taking into account the uncontrollable input into the water system such as rainfall. It will also see the different users in the water system such as the ecosystem, human consumption, agricultural use etc. Further it will evaluate the outcomes of certain allocations of water and will see the influence of the controllable input factors, proposed policies or operating rules. Figure 13 schematically addresses the different aspects that are taken into account.

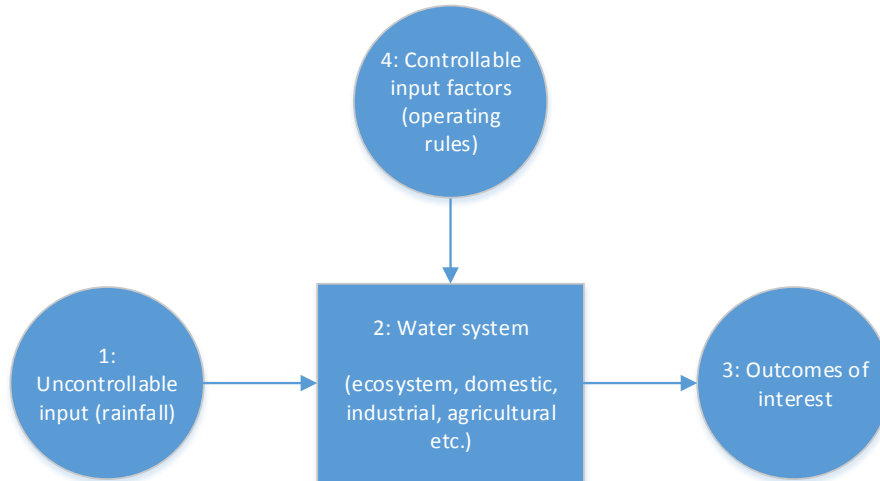


Figure 13: Systems view of the water system

The different aspects: (1) uncontrollable input, (2) water system, (3) outcomes of interest and (4) controllable input factors. Will be examined in order of the numbers that are seen in Figure 13:

1. **Uncontrollable input (hydrological models):** First the uncontrollable input into the water system is investigated with the use of hydrological simulation models. The models include amongst others rainfall, runoff, seepage and evaporation over time. From the simulations that are made with the hydrological models flow-duration graphs can be constructed. These graphs have the flow over a certain period on the Y-axis and time on the X-axis. When these flow-duration graphs are ordered by amount of flow it can be used as a probabilistic toll to represent runoff over a certain period. In that case the time axis will be a cumulative percentage of time. The time-base on which these are constructed is important, since having a larger time base will average out more extreme values. A shorter time basis will give a steeper slope of the curve. In Figure 14 an example of a flow-duration curve is illustrated. Information from such a curve is for example that in 97% of the years an annual runoff of at least 8 million cubic meters occurs. Or in other words: a drought in which there is less than 8 million cubic meters runoff has a 1 in 33 year probability of occurrence.

## 2 Analysis of the Current Decision-Making Process

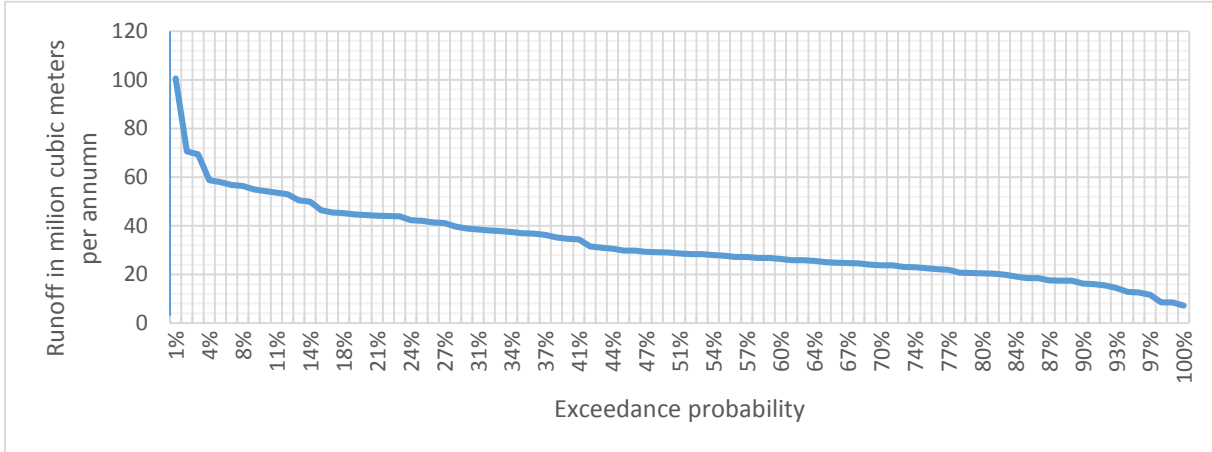


Figure 14: Example of a flow-duration curve

2. **Water System (Evaluating Uses of Water):** The water system is mapped by the consultant. Parts that are taken into account are:

- The infrastructure that is in place to distribute and store the water;
- Other (controllable) sources of water such as a reclamation plant, boreholes or a desalination plant;
- The uses of water by the social and economic system;
- The reserve that is required for basic human use and the ecosystem.

The use of water is mapped by listing the different uses. Most of the uses are based on *existing lawful use* (see paragraph 0). In that case the information from previous years is used as input. Out of this process comes the *listed annual demands for different uses* including what should be used to meet the *reserve*. The *reserve* is an input that comes from the separate *classification process* that is described in paragraph 0. In the text box a short description of the different types of uses in a South African water system is given. There will be an elaboration on this interaction in paragraph 2.4 and 5.3.



**A short description of the largest uses of water in dams in South Africa:**

- **Agriculture (irrigation):** the need for irrigation is seasonally varying. Timing is important, however there are possibilities for a certain degree of flexibility. There are cash crops grown exclusively for profit or subsistence crops that are grown to feed the own farmers livestock and/or family;
- **Bulk storage:** storage in large dams is seen as a use in the National Water Act and is done under the supervision and responsibility of the national and local government. Smaller dams are operated by for example farmers.
- **Forestry:** usually has a passive use of water, since the trees reduce the runoff before it is stored in the dam. Different types of trees use different amounts of water.
- **Industry and mining:** is a diverse group of users that have processes that require water. There are many differences in the impact that the water has on the processes. Usually the impact on the industry is measured in the amount of money that is lost, if a certain threshold is reached the industry can choose to invest in their own water source, such as a reclamation or desalination plant.
- **Power generation:** the power generation in South Africa is performed by Eskom. Since the production, or lack of production of electricity has a very large impact on society, the government provides highest levels of assurance of water for power generating purposes.
- **Recreation:** the fishing, swimming, boating etc. in water resources. This usually has a small impact on the water resource. This will be restricted in case of endangerment of the recreants (caused for example by the water level or water quality) or the impact on for example the fish or bait population.
- **Water services (rural and urban):** water services to rural and urban households is water that is mostly used for drinking, washing, cooking, watering the garden, washing the car etc. It could be delivered to the house by piping (urban), or distributed at for example local pumps (rural). Some, but not all of these water services fall within the basic human reserve. The basic human reserve recognized the water used for drinking, food preparation and personal hygiene. On the other aspects a rationing can be placed.
- **Ecology:** the ecological system, unlike the other uses, is not an actor representing itself. The state of the ecological system could be defined as a common pool resource (CPR). CPR are resources in which exclusion of beneficiaries through physical and institutional means is especially costly, and exploitation by one user reduces resource availability to others (Gardner & Walker, 1994). If water is consumed by other uses the state of the estuary will decline. The state of the estuary is something that most actors benefit from in the form of e.g. higher water availability and higher recreational attractiveness of the region.
- **Dissimilation of waste water:** an important use of water is the dissimilation of waste in water. Dissimilation of waste makes the water unusable for other uses, for example domestic water. Dissimilation of waste can be done by different sectors. For example the mining industry. An impact of providing more water for larger mining can thereby have a double negative effect on the amount of water available for other uses.

3. **Outcomes of Interest:** The outcomes of interest are the objective or goal criteria which the external consultant attempts to optimize using the controllable input factors. Examples of these outcomes of interest include ecosystem goods and services and how these may be impacted; economic effects and associated social developments. The link between the controllable input factors and the outcomes of interest is the object of study in determining the regional water scheme, since it is by controlling the input factors that the water authority attempts to optimize the outcomes of interest.

The outcomes of interest in this case are complex and their dynamics are difficult to understand. The outcomes of interest are the product of interconnected systems within the ecological, economic and social environment on different levels. In the article of Hughes and Mallory (2009) it is argued for a deeper understanding of the level of benefit that each use brings to society. Specifically they consider that marginal added value should be known so that the uses with the lowest marginal added value can be rationed first. This standpoint formed the starting point of this research as from a multi-actor point of view. It simply provides static information on marginal added value of different stakeholders or uses that do not necessarily improve decision-making on regional water schemes.

The link between outcomes of interest and the controllable input factors will be addressed further in the conclusions of this chapter.

4. **Controllable Input Factors (setting of operating rules):** The next step is to use the information that is gained in the previous phases to set the controllable input factors or the operating rules. The previous phases delivered the following information:
- Flow-duration curves;
  - Information on water sources (boreholes, reclamation, recycling, etc.);
  - The amount of water required for the reserve;
  - The amount of water that is required by the various uses.

These pieces of information can be prioritized, with or without rationing, in certain ways that different levels of assurance for the different uses are achieved. Note that in setting the priorities and rationing no actual guarantee can be given, since the flow-duration curve is used as a probabilistic tool.

**Getting to levels of assurance**

The flow duration curves can be used to calculate levels of assurance for uses if used in combination with a prioritized list of uses (which is similar to how operating rules work). If three uses are introduced with a certain order of priorities, then the levels of assurance of the different uses can be looked up from the example flow-duration curve (Figure 14).

$$\begin{aligned}
 use_1 &= 8 \quad \text{cubic meter per annum} \\
 use_2 &= 12 \quad \text{cubic meter per annum} \\
 use_3 &= 8 \quad \text{cubic meter per annum}
 \end{aligned}$$

We assume that the priorities are as follows  $use_1 > use_2 > use_3$ . In that case  $use_1$  (as we saw before) can be assured with a 97% assurance level, or a 1 in 33 years failure. When looking at  $use_2$  it can be read that it can be assured with an 80% assurance level, or a 1 in 5 years failure. Finally if  $use_3$  is added it would have an assurance level of only 50% or a 1 in 2 years failure. This is summarized in Table 3.

**Table 3: Example of assurance level and failure**

Supply to	Total amount	Assurance level	Failure
$use_1$	$8 \text{ m}^3/\text{annum}$	97%	1 in 33 year
$use_{1+2}$	$20 \text{ m}^3/\text{annum}$	80%	1 in 5 year
$use_{1+2+3}$	$28 \text{ m}^3/\text{annum}$	50%	1 in 2 year

If rationing were included the assurance levels would rise, since the total demand for water then decreases and has a higher probability of being met.

With this information the consultant can create sets of operating rules. The outcomes of this process are the sets of operating rules, which specify at which dam levels which users should be rationed and to what extent. Associated with these operating rules are expected levels of assurance for the different users. These levels of assurance provides no guarantees to the users, but indicate probabilities of security of supply.

The water system surrounding the dam(s) has been studied by the consultant and sets of operating rules have been created. The consultant now choses a set of operating rules and forms his findings into a regional water scheme. The final two steps (as presented in Figure 12) are the approval of the RWS and the RWS being in operation. This will be described in more detail by means of the case in the next paragraph.

The process that was described in this paragraph is based on the findings during the empirical research phase in South Africa. In the research different cases of setting RWSs have been investigated and the professionals performing these type of studies have been interviewed. From these specific cases and interviews this, more general, process has been constructed. Conclusions that can be drawn from this paragraph are:

- The regional water scheme can be seen as the *rule in use* regarding the allocation and rationing of water coming from large dams. During the empirical research phase no clear *rules in form* are found on the RWS. The legislation on rationing however requires a motivated and published decision before rationing can be enforced. This, combined with the lack of ratification in the classification process, could explain why RWS is the current *rules in use*.
- The regional water scheme is tendered by DWAS and executed by an external consultant who has to bring together uncertain input, the water system and its sub-models, the outcomes of interest and the controllable input factors.
- There are several issues at play in this process:
  - The uncontrollable input is inherently uncertain;
  - The interactions sub-models in the water system are not taken into account. Only separated interactions between the consultant and different expert groups take place;
  - The optimum in outcomes of interest is value dependent (and difficult to, for example, monetize).
- Consultants that perform RWS studies provide a signal in scientific literature that there is a need for more information to be able to make informed decisions on the controllable input factors.

The next paragraph will provide the case of the setting of the RWS for the Mossel Bay region.

## 2.3 INTERMEZZO: AN EXAMPLE OF THE PROCESS FOR SETTING OPERATING RULES IN PRACTICE

To get more insight into how operating rules typically are formed, this paragraph will go into a specific case. First the study into the RWS and the operating rules are examined. Secondly a response by the municipality of Mossel Bay is investigated. The example is illustrative to the described process in general and provides practical insights into how an RWS is determined and operating rules are set.

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### 2.3.1 MOSSEL BAY REGIONAL WATER SUPPLY SCHEMES REPORT

In the report set up by IWR Water Resources on demand of the DWA (Mallory et al., 2013) first the cause for the development of the operating rules is given. DWAS ordered the RWS to be developed, since the Wolwedans dam is seen as a crucial dam that required attention. The dam did not go full for the last five years and recently reached an all-time low level of 14%.

The *water system* is reviewed by assessing the current water requirements of the different users in the system. These are recorded into a static amount of water that is required per year. In this case the uses are the municipality of Mossel Bay, PetroSA (a gas to liquid refinery), irrigation, forestry and ecological water requirements. These requirements added are matched to the mean annual runoff (MAR).

The *uncontrollable input* is investigated using the duration flow, or exceedance curves. The exceedance curve for the Wolwedans dam is copied into Figure 15. These curves are made for each of the four dams in the system and then combined into a single graph. Besides the long-term yield curves, short-term yield curves are also created. These are based on years of stochastic data and provide a prediction for the yield that can be gained from the dam depending on the current level of water in the dam.

## 2 Analysis of the Current Decision-Making Process

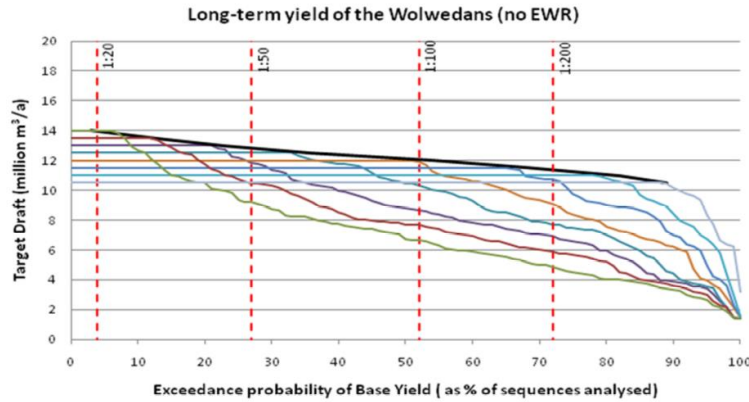


Figure 15: Illustration from the RWS report for the Mossel Bay region (Mallory et al., 2013, pp. 5–2)

For the *controllable input factors* the study goes into other sources of water such as boreholes, reclamation plants and desalination plants. For these it is important who has the ownership, who has been using them the last years, what is the capacity and how much is the water costing from each source. The current plans and practices for managing water are also considered. These are aspects such as what source is presently supplying which users.

The proposed operating strategy is presented using the concept of assurance of supply. As was described in the previous paragraph the controllable input factors are used to achieve an optimum for the outcomes of interest. In this case the outcomes of interest are the assurance of supply levels of different uses. The researchers provide four different scenarios of controllable inputs and review them over the outcomes of interest. The following scenarios are reviewed:

1. Current water requirements and 1 million m<sup>3</sup>/annum release for the Reserve
2. Future water requirements and full EWR implemented
3. MBLM (Mossel Bay Local Municipality) rule with optimization, no EWR imposed on the Moordkuil River
4. MBLM (Mossel Bay Local Municipality) rule with optimization, with the EWR imposed on the Moordkuil River

The different variables and strategies that are varied in the scenarios are: (no) rise in water demand, (not) meeting the ecological requirements and the meeting of requirements from different sources (dams, desalination and reclamation). The scenarios with the MBLM rule have been added after correspondence with the local municipality of Mossel Bay. The study makes this note:

*“Based on comments received from MBLM on this proposed operating rule, an alternative rule (proposed by MBLM), in which the water use from the Klipheuwel Dam was maximized, has been recommended and is reported on in this section” (Mallory et al., 2013, pp. 7–4).*

The outcomes on the different scenarios are presented in the manner as presented in Figure 16. In this graph the multiple lines represent different runoff scenarios. From the 50<sup>th</sup> percentile runoff downward restrictions need to be applied to ensure the water supply. For the minimum and 99<sup>th</sup> percentile runoff serious shortages occur. The rationing takes place when the line gets below a certain threshold (50%, 20% and 10% of the water down dam capacity in this case). The rationing will reduce the steepness of the lines in this graph.

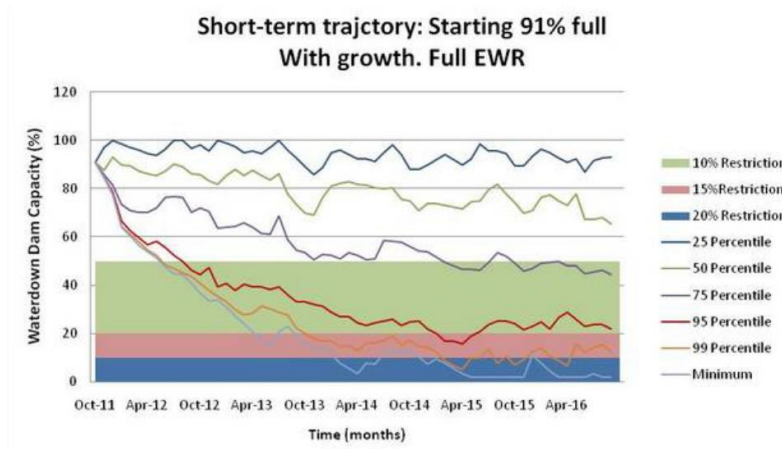


Figure 16: Presentation of outcomes of interest over the second scenario (Mallory et al., 2013, pp. 7–3)

The report concludes with a recommendation for operating rules. The recommendation entails which users to supply from which source (Figure 17).



Other interesting observations from the report are that four moments of contact with experts or stakeholders have been recorded in the study: a field visit in March 2010; a meeting about Robertson dam on the 10<sup>th</sup> of March 2010; a project initiation meeting on the 30<sup>th</sup> of August 2010 and a field visit in March 2011. Also an appendix is added that goes into the requests for information and whether this information was received. What is remarkable is that only 5 out of 28 requests for information were met by the authorities.

### 2.3.2 RESPONSE OF THE MOSSEL BAY MUNICIPALITY TO PROPOSED WATER SUPPLY SCHEME

The municipality of Mossel Bay wrote a response to the proposed water scheme. The most important comments and recommendations being (Mossel Bay Municipality, 2012):

1. Further consultative process should be followed with all stakeholders before any final decisions are taken in this regard;

## 2 Analysis of the Current Decision-Making Process

2. The financial implications of augmenting the water supply with water from the recycling plant and desalination plant have not been taken into account;
3. The distribution of the financial burden between the various users that would benefit has not been considered;
4. The region has recently survived a severe drought, the levels of security are too high in this proposal;
5. It is unfair that upstream farmers use water at a very low price, while this causes the desalination plant to operate at an extended period;
6. It is unacceptable to have the EWR for the estuary to increase from 1 to 4

This response provides insight to the observed process of setting a regional water scheme and can be linked to the more general observations that have been made in this chapter. The first comment argues for a more deliberate decision making process in which more or all stakeholders are consulted. The second, third, fourth and fifth comment are on the cost and the distribution of cost. In the view of the municipality the cost of executing the Regional Water Scheme is too high and is distributed in an unfair manner. The sixth point is on the determination of the reserve for the estuary. In their opinion the allocation is too high.

What this shows is that there is no clear optimal set of operating rules and different sets of operating rules might be valued differently for various motivations by dissimilar groups of stakeholders. The objectives for the RWS cannot be determined by a single consultant, but is the product of many interactions in a policy arena. In the current process there is little actual interaction with the stakeholders in this policy arena.

In the currently observed decision-making for an RWS however, the consultant attempts to remain politically neutral and find an objective optimum. The response by the Mossel Bay municipality is an illustration of the difficulty, or impossibility, to find such an objective optimum.

The next paragraph will go into the interactions between the process for setting operating rules and the policy arena in which this process takes place.

## 2.4 THE PROCESS FOR SETTING AN RWS WITHIN A MULTI-ACTOR SYSTEM

In the previous paragraphs a field of tension was detected between the outcomes of the current decision-making process and the affected stakeholders. This paragraph will go into this tension between the system analysis that is performed in the decision-making process and the multi-actor system in which it is situated.

In paragraph 2.2 the systems view (Figure 18) was introduced to help understand the current process for determining and RWS. The link between the controllable input factors and the outcomes of interest was described.

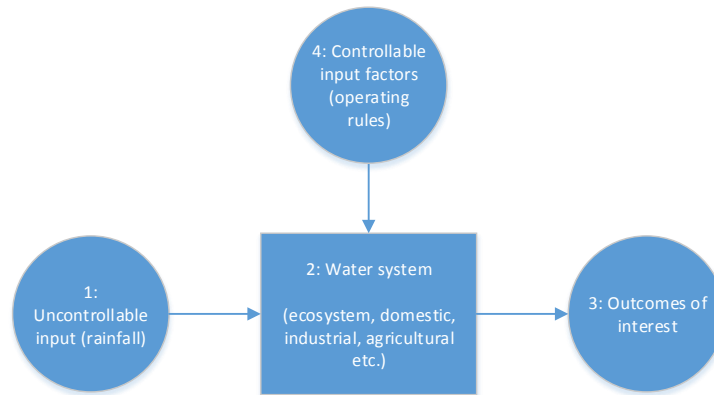


Figure 18: Systems view of the water system with its inputs and output

To understand how the multi-actor system interacts with the systems view model literature from the field of Policy Analysis (PA) can be used. PA recognizes actors as a person or a group of persons or organizations that is capable of making decisions and acting in a more or less coordinated way (Burns et al. 1985). These actors have perceptions, values and resources. Perceptions is how the actor views the world and is subjective and different for every actor. Values are the directions in which the actor wants the system to move. These could also be seen as the objectives of the actor. The resources are the practical means that the actor has to achieve his values or objectives (Hermans, 2008). In the South African water system actors that can be identified are: different communities, farmers, industries, different fields of experts etc.

Figure 19 provides a graphical representation of the systems view that was used to describe the current process of determining an RWS which is embedded in a multi actor system. The policy analysis is represented by a network of actors that have their own perceptions, resources and values. The actors, or stakeholders, in the policy arena are affected by the outcomes of interest and (want to) have an influence on the controllable input factors or policies.

## 2 Analysis of the Current Decision-Making Process

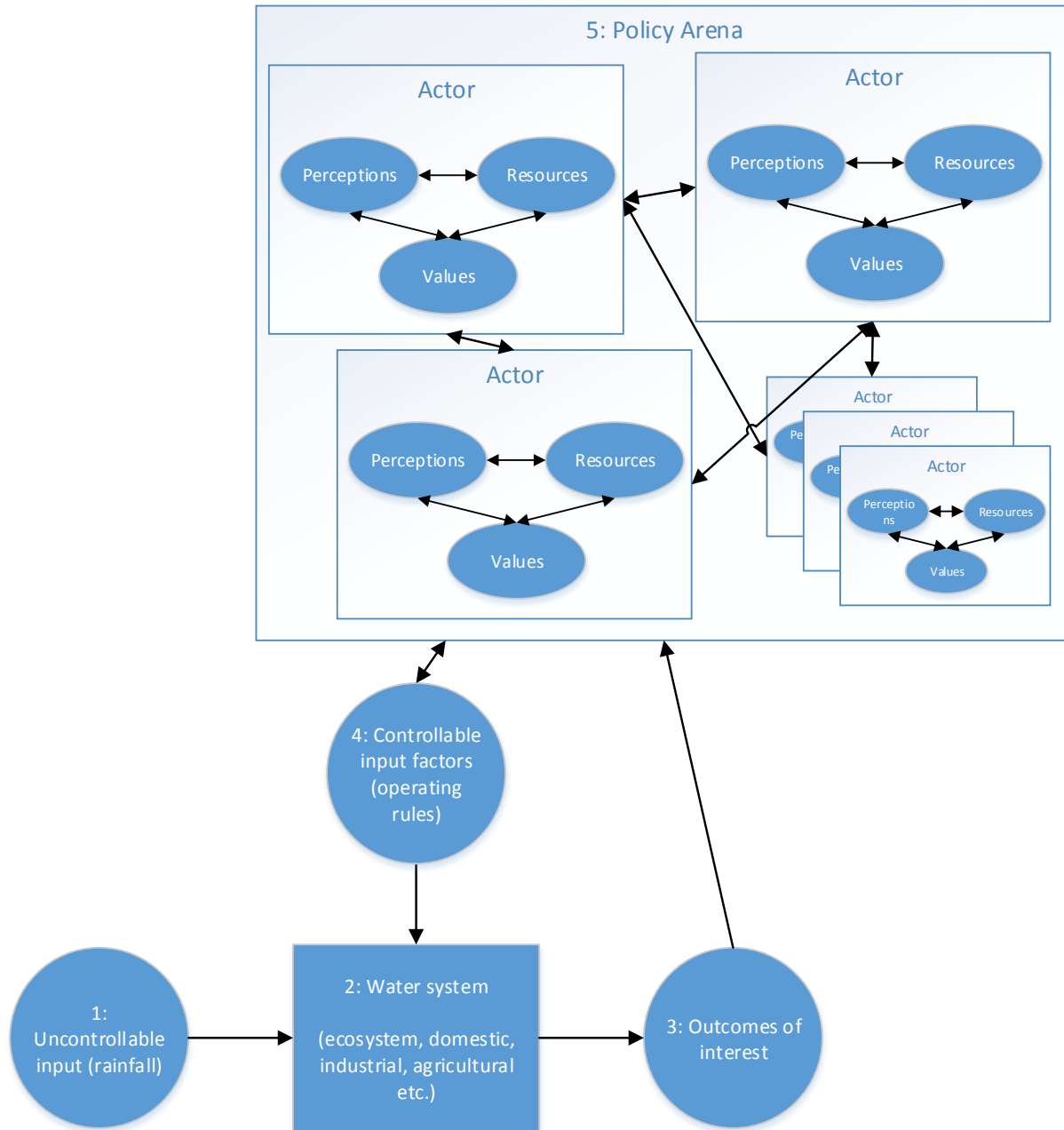


Figure 19: The Policy Analysis System View Embedded in a Multi-Actor System (adapted from (Hermans, 2008))

The problem could be identified seeing the current decision-making process embedded in the multi-actor environment. The interactions between the consultant determining the RWS and the actors in the policy arena is difficult because of two reasons (amongst others). Firstly, the consultant has little insight in perceptions and values of the actors. Secondly, the actors have little insight in how the policies affect the outcomes of interest, what trade-offs are being made and into the dynamic aspects of the system in combination with the uncertainty of input.

The design should enable interaction and learning between the water system under study and the multi-actor environment in which it is in.



## 2.5 CONCLUSIONS ON THE CURRENT-DECISION MAKING PROCESS: ANSWERING RESEARCH QUESTION 1

This final paragraph will summarize the findings of the deepened analysis of the current decision-making process, add an analysis on public participation in South Africa and will answer the first research question.

The South African law has been under large reform since the democratic elections of 1994. The National Water Act (NWA) of 1998 has the most impact on the water system as scoped for this research. The NWA prescribes the formal institutions and processes.

It was found that new *rules in form* have yet to be converted into *rules in use*. There seems to be a lack of progress in the processes that are currently prescribed in legislation. For example:

- The decentralized Catchment Management Agencies have not been set up for most of the Water Management Areas. Only two out of nine agencies are operating to this date.
- To balance between utilizing and protecting the natural resources the NWA prescribes the Classification process. Currently the Classification process fails to complete its lifecycle into legal ratification of reserve setting.
- No Resource Quality Objective or reserve setting has been ratified and published in the Government Gazette by the minister of DWAS yet.
- There are big delays reported in the licensing process (Gore & Dagut, 2013).

The current *rules in use* are a combination of preexisting institutions, together with the efforts of practitioners in the water sector to best adhere to the (new) 1998 National Water Act. These *rules in use* are currently performing the functions of the *rules in form*. The practitioners use their discretionary leeway to cope with this discordance between *rules in use* and *rules in form*.

In these *rules in use* reserve settings are taken into account, although unratified by the minister. The regional water scheme could be seen as an artifact of the institutional transition. A combination of old and new, trying to cope. The RWS is not currently explicitly mentioned in legislation, however it is still being used and evolves with the water system. Within the scope of the research the Regional Water Scheme and the Operating Rules are most intriguing and interesting for study.

The interactions in the process of determining a Regional Water Scheme are limited to mostly information exchanges between experts. There are activities for taking stakeholders into account, however these activities are often informative or reactionary to stakeholders instead of there being two-way interactions. The actors in the system are not asked to provide information into their perceptions and values. These perceptions and values are assumed for the actors.

### **Deliberative Democracy**

In another system, like for example the Dutch representative democracy this would not give lead to problems. The Dutch '*Waterakkoord Kleinschalige Wateraanvoorzieningen Midden-Holland*' (KWA) can be compared with the Regional Water Scheme in South Africa (Hoogheemraadschap van Rijnland, 2014). The KWA is determined in the '*Peilbesluit*' which is determined in a similar process as sketched for South Africa. External studies are performed and chosen citizen representatives ratify measures on their behalf. Stakeholders or citizens can be aware of the process taking place and can object in case of disagreement, but are not directly involved.

## 2 Analysis of the Current Decision-Making Process

It is 20 years since South Africa has had their first democratic elections and the abolition of institutional apartheid. South Africa has set out to be a **deliberative** democracy. Deliberative democracy can be defined in multiple manners and there are different frameworks for assessing government. For the purpose of this argument in the thesis the definition of deliberation and democratic legitimacy of Joshua Cohen are used (1989). A rough definition which Cohen works with is that a deliberative democracy is: “*an association whose affairs are governed by the public deliberation of its members*” (Cohen, 1989).

The process would suffice in the system of the Dutch representative democracy, however does not align with the intention that South Africa has for being a deliberative democracy. The issue of the decision-making to be less deliberative is added to the issue that Hughes and Mallory indicated (see chapter 1) on the interaction between different expert groups in performing the Regional Water Scheme study.

### **Answering Research Question 1: What are the rules in form and the rules in use in South African water management?**

With the knowledge gathered in this chapter the first research question can be answered and the first section concluded. The rules in form in South Africa have been established in 1998. In these rules decentralization is important and the classification process mainly determines the balance between protecting and utilizing the resources. However, these rules in form have not been converted to rules in use. Rules in use are the Regional Water Scheme and Operating Rules. Therefore the research will focus on the process for determining the Regional Water Scheme. In the current process the interactions between expert groups and the deliberative process with citizens and stakeholders have been identified as key issues.

## SECTION II: THEORETICAL FRAMEWORK

### 3 THEORETICAL LENSES

Unconventionally, this chapter starts by answering the second research question:

**Research Question 2: What theoretical lenses can be used in designing an improved decision-making process for water management?**

The lenses that will be used in this research are: *Policy Analysis*, *Citizen Participation*, *Participatory Systems Design*, *Social-Ecological Systems* and *Boundary Objects*.

For storyline purpose the question is answered at the start of this chapter. The rest of the chapter will go into the specifics of these lenses and how they are adopted. The problem of addressing the process for determining a Regional Water Scheme has characteristics many different theoretical lenses can improve understanding over. However it is not possible to take all lenses into account. Therefore the choice of lenses is an incomplete choice. The lenses that have been chosen were chosen on the basis of a combination of their ability to add to the understanding and my personal affinity with the theories.

My personal affinity is partly induced by my studies at the Technique, Policy and Management faculty at the Technical University of Delft. During my bachelor degree I have been introduced to the concepts to solving multi-actor systems involving a technical component. The domain of my interest has been energy, water and industry, to which a large amount of my subjects was oriented. During my masters System Engineering, Policy Analysis and Management a clear design of systems component was added to my toolbox and I chose to specialize in Modeling, Simulation and Gaming, with which I have had affinity since the start of my studies. Some of the lenses used came natural to me because of my background. Others, such as *Citizen Participation*, *Social Ecological Systems* and *Boundary Objects*, I had to adopt and learn about in the course of this research.

Other angles of approach could have been economic (cost-benefit of water), anthropologic (the social impacts), civic engineering (infrastructure oriented) or many other. With the current scope of this study the lenses would fit less in my perception, since they provide less of a helicopter view.

The following paragraphs provide a short introduction into the state-of-the-art of the lenses; how the lens will be adopted in this study and how the lens correlates with the problem aspects and research objectives mentioned in chapter one.

#### 3.1 POLICY ANALYSIS LENS

This research will use a Policy Analysis lens. Since PA is a large multi-faceted field with different schools enrooted into operations research (OR) and system analysis (SA) it will be further specified what will be used in this research. As a basis for defining the methodology mostly the recent publications bundled by W.A.H. Thissen and W.E. Walker will be used for reference (2014).

Enserink, Koppenjan & Mayer (2013) developed a view on policy analysis in which they place Policy Analysis in a historic perspective. PA developed in the 1970s and its roots go back to Operations Research which dates back to the 1940s and was mainly used to develop optimal solutions for well-structured problems. This then evolved into System Analysis which took a broader socio-technical perspective and attempts to capture complex behavior by analysis the interactions between different components. PA takes this a step further by broadening its view and allowing the policy analyst to take on different views on the policy making process. These different views allow the analyst to see policymaking through different lenses and not discard the richness and variety of theories on policymaking. The five most common models for policy making as described by Enserink et. al. (2013) are policymaking as: rational decision-

making, a political game, a discourse, a garbage can, an institutional process. During this research these models are used alternately, since not one is correct. By doing this the complexity of the research problem is not discarded.

Mayer, van Daalen & Bots (2004) have developed a conceptual model for contributing to the design of new policy analysis projects. The model identifies six activities and translates these into six PA styles. This research will probably use multiple activities and styles during its course. Mayer et. al. (2004) propose the identified activities in a hexagon model presented in Figure 20. Research and analyze activities are about establishing facts and causes and effects while design and recommend activities are design and solution oriented. Clarification of values and argument activities searches for values and arguments that underlie the debate; advice strategically activities aim to advise a client on how to achieve their goals given a certain political constellation and democratize activities have an ethical normative objective to “further equal access to and influence on the policy process for all stakeholders.” mediate activities help in designing rules and procedures for negotiating in the policymaking or decision-making process.

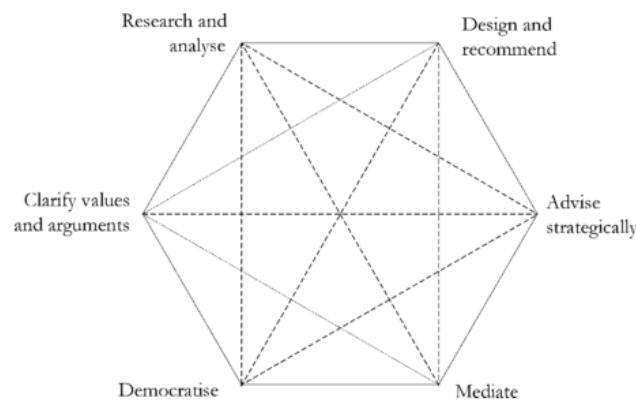


Figure 20: Hexagon model of PA activities (Mayer et al., 2004, p. 11)

There will be dominant and subordinate activities in this research project, meaning that all activities will probably have a role. However, a dominant activity will likely be clarify values and arguments, since the research maps the socio-technical system (this will be elaborated on in the paragraph on social-ecological systems) and therewith identify the clashes in opinions between supporters and opponents of different alternatives. This will then be input or inflow to democratize the stakeholders and enabling or empowering them to take part in the debate on operating rules. Ultimately this will lead to mediating activities, in which the democratized stakeholders can participate in the negotiations on operating rules using clarified values and arguments to support their negotiation.

These activities are according to Mayer et al. (2004) linked to the participatory and interactive PA styles. The participatory style looks at society critically and assumes not all sections of the population have ready access to policy systems (Fischer, 1990, 2000). It assumes the public to be capable of having a voice and aims to achieve their goals (this will be elaborated on specifically in the paragraph on citizen participation). The interactive style assumes that the involved stakeholders, experts and analysts have differing views on a policy problem. Insight can be obtained by bringing about confrontation and interaction of different views (Mayer et al., 2004). Stakeholders and experts could be invited to participate in structured meetings to structure problems or devise solutions. These interactions allow the participants to learn from this and confront and refine their views.

### 3 Theoretical lenses

The framework of Mayer et. al. concludes with an overview of the hexagon model of policy analysis in which the activities, styles and criteria for evaluation are summarized (Figure 21). This will be used to design the methodology and help in setting up the objectives for the design in chapter five.

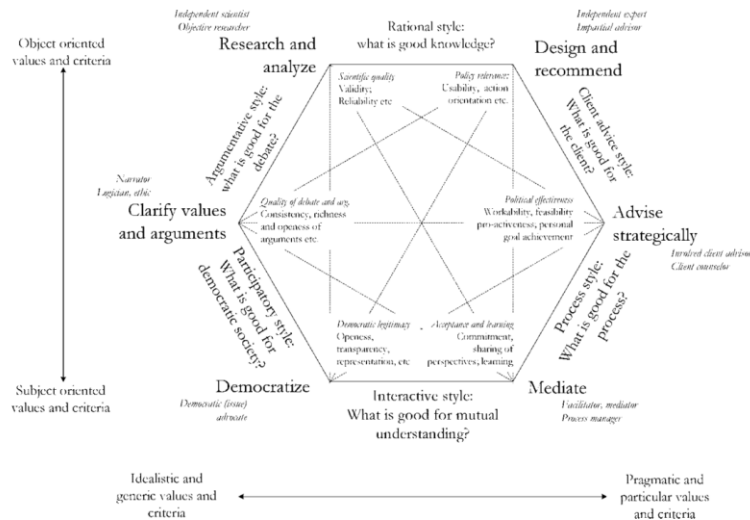


Figure 21: overview of the hexagon model (Mayer et al., 2004, p. 18)

### 3.2 SOCIAL-ECOLOGICAL SYSTEMS LENS

In my personal backgrounds being educated as a systems engineer and policy analyst in the Netherlands where socio-technical systems are often discussed. These type of systems are a combination of technically engineered subsystems together with social, actor based subsystems (Trist, 1981). The behavior of the system as a whole is not a sum of the individual behaviors of the subsystems. The difficulty is that there is a dichotomy in studying the technical and the social part, since there are incompatible differences in methodology (de Bruijn & Herder, 2009). In my studies I have been taught to consciously switch between the system engineering and actor perspective to be able to study socio-technical systems.

Social-ecological systems are different from socio-technical systems, since it includes an ecological component. In this paragraph the theoretical concepts or lens that will be used in this research will shortly be described.

Social-ecological systems can, according to Redman et. al. (2004) to be defined as:

1. "A coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner;
2. A system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked;
3. A set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and
4. A perpetually dynamic, complex system with continuous adaptation" (Redman et al., 2004, p. 163)

SES have both designed as well as self-organizing subcomponents which contribute to a high degree of uncertainty (Anderies, Janssen, & Ostrom, 2004). Another major difference with socio-technical systems is that the end-use in the system has an influence on the health of the resource on which it depends (Anderies et al., 2004; Folke, Hahn, Olsson, & Norberg, 2005; Redman et al., 2004). An example of this is that a level of exploitation of the water resource that is too high will bring the ecological resource (e.g. rivers and basins) into a different stable state, making it deliver less water resources for human use. The wording 'stable state' in SESs comes from the fact that SESs tend to be

resilient to change (Anderies et al., 2004). More on this is found in the article of Walker, Holling, Carpenter & Kinzig (2004) in which they define the concepts of resilience and adaptability.

**Resilience** is defined in by Walker, Holling, Carpenter and Kinzig as follows:

*“the capacity of a system to absorb disturbances and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks” (2004, p. 2).*

In their article four crucial aspects of resilience are defined.

- **Latitude**: the amount of change a system can undergo and still recover;
- **Resistance**: how easy the system can be changed;
- **Precariousness**: how close the system is to its limit (linked to the latitude);
- **Panarchy**: the resilience of a system at a certain level is dependent on the cross scale interactions with higher and lower levels (Walker et al., 2004).

The aspects of resilience are illustrated in Figure 22 as valleys of attraction. The system is resilient to change its stable state like it is to cross from valley to valley. This is determined by the width of the valley (**latitude**) the depth of the valley, or height of the hill (**resistance**) and the current location in the valley (**precariousness**). Walker et al. define these valleys as basins of attraction. The Y axis or slope signifies the natural attraction of the system. The X-axis can be different indicators for the system, in fact there could be many axes added on which the whole state of the system is determined.

**Adaptability** is defined in by Walker et al. as: “the capacity of actors in a system to influence resilience” (2004, p. 3). Complex adaptive systems have the characteristic of self-organization without intent (Levin, 1998). It is noted that although actors act in the SES with certain intentions, the social system as a whole does not exhibit intent. The actors in the system can exert influence in the following manners (applied to keeping a system in a current state, actions could be reversed if the intention is to get a system out of its state): moving the **latitude** thresholds further away from the current state, altering the **precariousness** by moving the current state of the system away from the threshold, heightening the **resistance**, so the threshold is more difficult to reach. The actors could also decouple layers to have less negative effects from **panarchy** if a system would collapse (Walker et al., 2004).

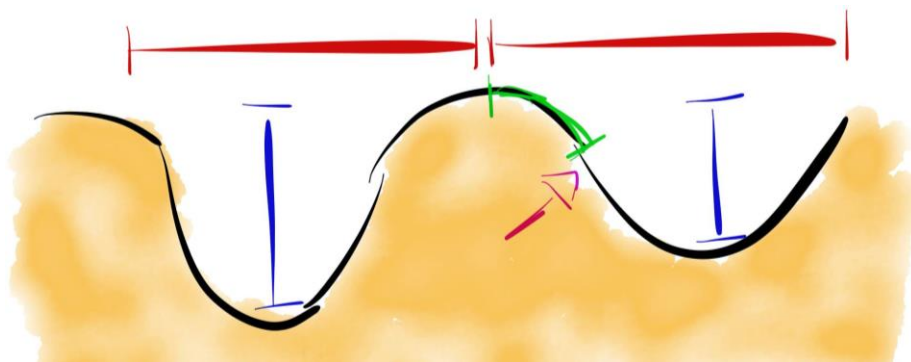


Figure 22: Personal illustration of resilience of SESs.

Legend: **Latitude**, **Resistance**, **Precariousness**. The arrow would represent the current state.

Walker et al. discusses transformation aspects in their article, how can SESs be transformed from one stable state to

### 3 Theoretical lenses

another. For this research that is not added to the theoretical lenses, since the research is not aimed at purposely transforming the SESs into another state.

#### **Adaptive Cycles and Cross Scale Effects:**

SESs can be analyzed using a cycle that passes through four phases: a growth and exploitation phase ( $r$ ) merging into a conservation phase ( $K$ ), this phase is followed by an inevitable chaotic collapse and release phase ( $\Omega$ ), which is rapidly followed by a phase of reorganization ( $\alpha$ ). After this phase the system can get into the  $r$  phase again. This can resemble the  $r$  phase the system went through before or be significantly different. The phases do not need to follow up on each other and alternative pathways are possible. For example a system could go from  $K$  into  $r$  as well. Finally the cycle and its phases occur on multiple levels and have interactions across scales (Walker et al., 2004). Figure 23 presents an illustration of the adaptive cycle and the paths that it can follow.

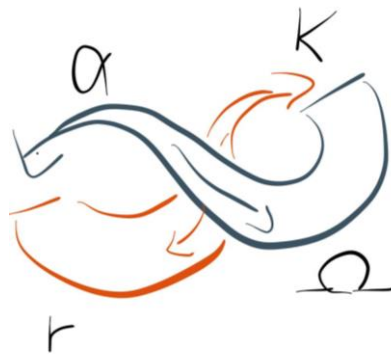


Figure 23: Illustration of the Adaptive Cycle

Legend:  $r$  = exploitation,  $K$  = conservation,  $\Omega$  = release,  $\alpha$  = reorganization

#### **Conclusion**

The addition of the concepts of SESs to the knowledge of socio-economical systems is valuable for the study, since it provides insights in the behavior and characteristics of the system that is being studied. The design requirements that will be used in designing should take into account these behaviors and characteristics.



### 3.3 CITIZEN PARTICIPATION LENS

Citizen or public participation has been the subject of study since Arnstein (1969) presented her Ladder of Citizen Participation. This ladder is a normative framework of assessing the level and/or quality of citizen participation in decision making processes. The Ladder of Citizen Participation is shown in Figure 24. The bottom two rungs on the ladder, nonparticipation, signify the lowest levels of citizen participation. The top three rungs, degrees of citizen power, signify the highest levels of citizen participation. Since its introduction, the Ladder of Citizen Participation has often been used and adapted in scientific literature, however no clear consensus exists on a single interpretation for present day use. Therefore this paragraph will set forth how this concept will be used in this thesis.

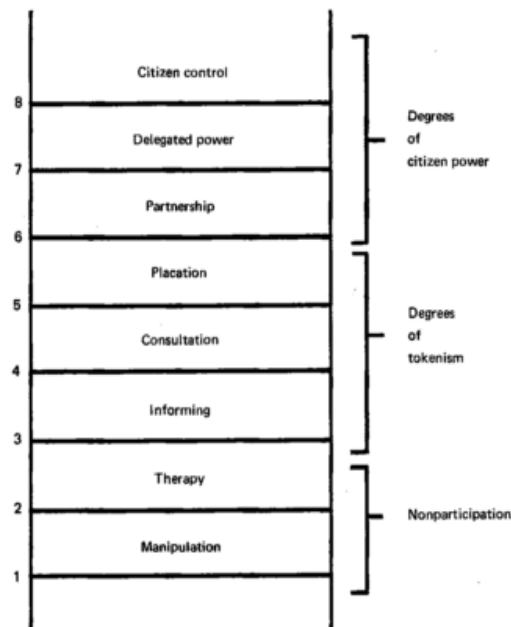


Figure 24: The Ladder of Citizen Participation (Arnstein, 1969, p. 216)

Arnstein defines citizen participation as follows:

*“.. a categorical term for citizen power. It is the redistribution of power that enables the have-not citizens, presently excluded from the political and economic processes, to be deliberately included in the future. It is the strategy by which the have-nots join in determining how information is shared, goals and policies are set, tax resources are allocated, programs are operated, and benefits like contracts and patronage are parceled out. In short, it is the means by which they can induce signification social reform which enables them to share in the benefits of the affluent society”* (Arnstein, 1969, p. 216).

Arnstein focusses her attention on the have-nots and processes of citizen participation that are an empty ritual rather than to be of actual benefit to the community. The Ladder of Citizen Participation can be used to categorize different decision-making processes, however it does not speak of achieving the genuine levels of participation, or what is rung on the ladder is appropriate for the process in question.

### 3 Theoretical lenses

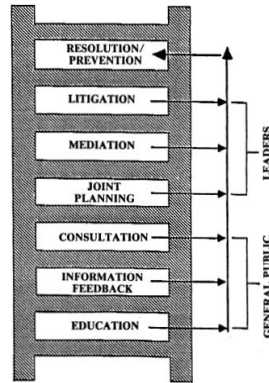


Figure 25: The New Ladder of Citizen Participation (Connor, 1988, p. 252)

Connor (1988) suggested progression from rung to rung on the ladder. He describes the process of moving from his lowest rung: education, to his highest rung resolution/prevention (Figure 25). In his article Connor adds the process that is required to go from step to step. Not all steps are required and a description of when to skip which step is included (Connor, 1988). Connor concludes the following:

*“there is no one best way to design and manage a public participation program”* (Connor, 1988, p. 275) and *“a complex economic, social and political issue will not be resolved by a news release and a public meeting a systematic process appropriate for the specific situation must be designed and implemented”* (Connor, 1988, p. 257).

Choguill (1996) wrote on the application of the Ladder of Citizen Participation applied to underdeveloped countries. South Africa is mostly categorized as a newly industrialized country (IMF, 2014), (Bożyk, 2006), (Guillen, 2000). These countries have yet to make the transition to a developed country. Therefore it is interesting to have a look at the differences in application of the ladder for underdeveloped countries. Choguill argues the following:

*“Existing models of community participation, such as Arnstein’s ladder of citizen participation, although adequate for analysis in developed countries, provide misleading results within a development context”* (Choguill, 1996, p. 431).



Figure 26: A Ladder of Community Participation for Underdeveloped Countries (Choguill, 1996, p. 433)

Her main adjustment to the original ladder is that in developing countries the participation is not only aimed at influencing the decision-making, but it also serves as a means to obtain basic needs. In the lowest two rungs: self-management and conspiracy the community is neglected or rejected, a situation in which the government doesn’t concern itself with the community (Figure 26).

Irvin & Stansbury (2004) bring forth a more design oriented aspect in citizen participation by providing trade-offs. Their question is: *is it worth the effort?* And: *should you always strive for maximum participation?* To assess that they have listed the advantages and disadvantages of citizen participation for both the government and the citizens on the process and the outcomes of the process. Table 4 presents a compilation of these advantages and disadvantages.

Irvin & Stansbury also identify indicators for low or high costs to realize the citizen participation and indicators for low or high benefits of the citizen participation. This can help in the process of designing a more participatory system, since it brings insights into the tradeoffs concerning the introduction of such a system.

Another interesting addition to the citizen participation lens that will be used in this research is by André in collaboration with Enserink, Connor & Croal (2006). This article sets out best practices in public participation and starts with a definition of public participation:

*“The involvement of individuals and groups that are positively or negatively affected by, or that are interested in, a proposed project, program, plan or policy that is subject to a decision-making process”* (André et al., 2006, p. 1).

**Table 4: Advantages and disadvantages of citizen participation, compiled from (Irvin & Stansbury, 2004)**

	Advantages of citizen participation		Disadvantages of citizen participation	
	To Citizens	To Government	To Citizens	To Government
<b>Process</b>	Education; Persuade and enlighten the government; Gain skills for activist citizenship.	Education; Build trust alloy anxiety and hostility; Build strategic alliances; Gain legitimacy.	Time consuming; Pointless if ignored.	Time consuming; May backfire.
<b>Outcome</b>	Break gridlock; Achieve outcomes; Gain control; Better policy and implementation decisions.	Break gridlock; Achieve outcomes; Avoid litigation; Better policy and implementation decisions.	Worse decision if heavily influenced by opposing interest groups.	Loss of decision making power; Possible unavoidable bad decision; Less budget for actual implementation.

In their article they set out objectives of public participation which can be used to see if there is enough alignment with the objectives that are pursued with the newly proposed process for setting operating rules. Shortened these objectives are as follows: foster justice, equity and collaboration; inform and educate stakeholders on the intervention and its consequences; gather data and information from the public; seek input from the public; better analysis of proposals and contribute to mutual learning.

**Conclusion**

The different ladders of citizen participation can be used to frame the current and proposed system in and help in comparing two alternatives. For my purposes the original Arnstein ladder will be good to use. The adaptations by Connor can be used to see how a process can move from one place to another to assist the transition. The adaptations by Choguill for developing countries I deem less fitted for this problem, since the design needs to fit into a system with developed standards. An illustration would be that Choguill puts much emphasis on NGOs to step in where the government fails. In this case it is unwanted to design for a situation in which that is the case.

A shortcoming of many of the ladders is, in my view, the lack of a design perspective in which trade-offs are being taken into account. The ladders seem to have a normative character in which more height on the ladder is better, however there can be situations imaginable for which the desired rung on the ladder is not necessarily the highest rung. Irvin and Stansbury are the first authors to go into that, so their literature together with Enserink, Connor & Croal (2006) is useful for the purpose of designing the system. The next theoretical lens -participatory system design- is added to get more insights into the design process for participatory systems.

#### 3.4 PARTICIPATORY SYSTEMS DESIGN LENS

To accompany the ladder of citizen participation research into participatory systems design is added. This is a relatively new field of research focusing on participatory systems: *“social-technical networked systems for which three levels of structures networks and governance are distinguished that are interdependent and interwoven in the functioning of participatory systems”* (Brazier, 2011).

Brazier & Nevejan (2014) describe their vision for Participatory Systems. These Participatory Systems are described as social-technical networked systems according to three levels: social, distributed ICT and infrastructure.

- *“Social: refers to social, economic, political and cultural dynamics;*
- *Distributed ICT: refers to technologies that enable large-scale distributed self-organizing processes, information exchange, aggregation and clustering;*
- *Infrastructure: refers to physical networks and physical entities like windmills or cars for example that are part of participatory systems”* (Brazier & Nevejan, 2014, p. 2)

Here two differences to the research problem emerge, namely the distributed ICT and infrastructure. ICT is not necessarily a large part of the proposed design, other vessels for communication could be used. And the concept of infrastructure or a social-technical system is inadequate or incomplete when looking at the water system that is being studied. However, there is potential in using the concepts from participatory systems design and applying it in this research if care is taken. The strength of the approach of participatory systems design for this research is in its design oriented approach. Whereas the lens of citizen participation offered little help in designing a system and positioned itself more as a normative framework to assess and compare.

Participatory systems need a mission, vision, purpose and shared values to succeed. It is successful when participants feel that they are getting something out of it and the system is more than the sum of its parts (Brazier & Nevejan, 2014).

In the vision for participatory systems that Brazier & Nevejan sketch, they demand a participatory system to be designed for trust, engagement and empowerment. These values are chosen to support the processes of adaptability, emergence and self-organization:

- *Designing for trust entails designing for transparency, security, integrity, privacy, identifiability, traceability, accessibility, proportionality, reliability, robustness*
- *Designing for engagement entails designing for interaction, presence, enactment, communication, awareness, co-creation*
- *Designing for empowerment entails designing for autonomy, self-regulation for human actors and automated systems, emergence* (2014, p. 3)

The final part of the vision is on the design process of participatory systems and can be most relevant to this research project.

*“Current insight is that participatory systems are driven by co-design and co-creation of social, technical and ecological systems”*

Stakeholders participate throughout the design process, which starts at the creation of a mission and shared values (A), then three design spaces are defined: the requirement, artifact and process design spaces (B). Thereafter the phases of conceptual design (C), testing (D) and finally the roll out of the system (E). Throughout these necessary

steps learning occurs and re-thinking of previous steps is often required. In Figure 27 the different methodologies associated with the different phases of the design are listed by the authors Brazier & Nevejan.

**Inventory of design methodologies for participatory systems design in different phases of the iterative design process**

**A. Mission**  
Design process: KPI's and metrics  
Design process: scenarios  
Design process: norms and values  
Design process: orchestration of commitment, rules and decision making of design process  
Design process: research design  
Design process: exit strategies and systems ending

**B. Identifying design spaces**  
Systems design spaces  
Value sensitive design  
Presence Design  
Design of trade-offs (YUTPA framework among others)  
Design process: design for re-design (meta-design)  
Design process: poly-centricity  
Design process: artistic research  
Design process: new technology

**C. Conceptual Design**  
Design process: visualization  
Design process: Interaction design  
Design process: self-organization, coordination principles  
Design process: participatory design  
Design process: serious games  
Design process: governance  
Design process: business plan  
Design process: define rules of engagement and decision making of participatory system

**D. Simulation, Emulation, Distributed ICT**  
Design process: distributed ICT  
Design process: simulation  
Design process: emulation  
Design process: testing

**E: Rolling out Participatory System**  
Design process: orchestration engagement  
Design process: governance  
Design process: structure continuous redesign  
Design process: exit strategy and system's end

Figure 27: ABCDE Design process for participatory systems design (Brazier & Nevejan, 2014, p. 5)

## Conclusion

The vision for participatory systems design adds some interesting concepts to the theoretical lenses that will be used in this research. The concepts are mostly aimed at the processes of designing and offer a starting point for those processes. Unfortunately the research into the participatory systems design is still at a very high level of description.

3.5 BOUNDARY OBJECT LENS

Leigh Star and Griesemer (1989) introduce the concept of *boundary objects* when dealing with heterogeneous work from many different actors with different viewpoints. In their article they present an example of how one group of actors (at the Museum of Vertebrate Zoology at the University of California, Berkeley) coped with that phenomena (Leigh Star & Griesemer, 1989). More important is the concept that is distilled from that. A boundary object helps in generalizing findings, so it is sensible to other viewpoints.

*“Boundary objects are both adaptable to multiple viewpoints and robust enough to maintain identity across them”* (Leigh Star & Griesemer, 1989, p. 387)

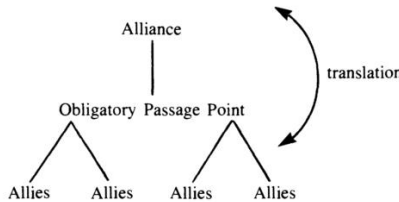


Figure 28: Traditional network represented in the article of Leigh Star & Griesemer (1989, p. 390)

The authors also provide a visual representation of how they view a boundary object. In Figure 28 a traditional network of information flows is represented by the authors. It depicts the funneling of information upwards towards the highest level. The structure that they propose is different from the traditional network, since it has a many-to-many structure and the several Passage Points are negotiated with several kinds of allies. In Figure 29 the structure is presented. The Boundary Objects at the top of the structure “.. have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation” (Leigh Star & Griesemer, 1989, p. 393). A boundary object could for example be a scale model of a skyscraper that is going to be build. Every person looking at this will recognize some common features of the skyscraper, however an architect will have different views on usability, an engineer will look at it from a construction perspective and a member of the local community could have another view. Passage Points underneath could be a construction drawing in which the architect and the engineer meet; or a vision on what the building is meant to express, which could be a translation for the public and the architect.

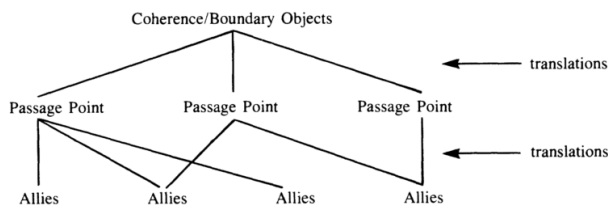


Figure 29: The structure that Leigh Star and Griesemer propose (1989, p. 390)

Recently Leigh Star (2010) reviewed her initial contribution of the Boundary Object with an article named *This is Not a Boundary Object: Reflections on the Origin of a Concept*. In this article she again states what is, and what is not, a boundary object. She addresses three attributes: *interpretive flexibility; material/organizational structure of different types of boundary objects and; the question of scale/granularity* (Star, 2010). In her view:

*“Boundary Objects are a sort of arrangement that allow different groups to work together without consensus”* (Star, 2010, p. 602).

## Conclusion

In this thesis I choose to adopt the lens of a Boundary Object in the sense of the articles cited above. It should be overlapping the border of multiple views or disciplines. It should provide the views or disciplines the ability to communicate on the subject whilst recognizing their own knowledge or views in the Boundary Object.

### 3.6 RECAPPING THE THEORETICAL LENSES AND THE ANSWER TO RESEARCH QUESTION 2

The different theoretical lenses will be used during the research to gain more insight into the system that is being studied and help in the design of a process that will serve the goals of the South African Water Act better. In the report this chapter will be used in order to keep to definitions and keep confusion to a minimum. An applicable quote that applies to the use of most of the concepts and theories that have been introduced in this chapter is found in the article by Walker et al. on SESs:

*An inherent difficulty in the application of these concepts [of resilience, adaptability and transformability] is that, by their nature, they are rather imprecise. They fall into the same sort of category as “justice” or “wellbeing,” and it can be counterproductive to seek definitions that are too narrow. Because different groups adopt different interpretations to fit their understanding and purpose, however, there is confusion in their use (Walker et al., 2004, p. 1).*

Besides the concepts that Walker et al. are referring to, this chapter introduces concepts from Policy Analysis (*openness, transparency, representation, commitment, learning etc.*), Citizen Participation (*legitimacy, trust, education etc.*), Participatory Systems Design (*autonomy, engagement, merging realities, emergence, self-organization, trust, empowerment etc.*) and Boundary Object (*consensus, allies, points of passage etc.*). All of these theoretical lenses have definitions that are also inherently difficult to apply just like resilience, adaptability and transformability. Therefore care needs to be taken to ensure that any confusion in the use of these concepts is minimized. This chapter introduced the interpretation of each theoretical lens and introduces how it will be used in the course of the thesis.

The application of the theoretical lenses will become clear in the next chapter, methodology in which choices are being made on how the different lenses are going to be combined into the research methodology.

## 4 METHODOLOGY

In this chapter the activities and methods that will be used during the research project will be set out. This answers research question 3: How can an improved decision-making process for water management be designed and validated?

Firstly the overarching approach is presented. Secondly the design for a Participatory System with a Boundary Object is presented. This design will go into the process that will be followed, will choose a modeling technique with which the Boundary Object will be modeled and goes into the process for coming to the simulation model. Thirdly the case study area in South Africa is presented and discussed. Finally the methodology can go into the validation of the design and conclude by answering the research question.

### 4.1 DESIGN SCIENCE APPROACH

The Design Science approach will be adopted as described by Hevner (2007) using the Three Cycle View on Design Science. Hevner aims at developing a clear and consistent body of knowledge that helps in the design and execution of high quality design science projects. Figure 30 is a visual illustration of the Three Cycle View of Design Science<sup>10</sup>.

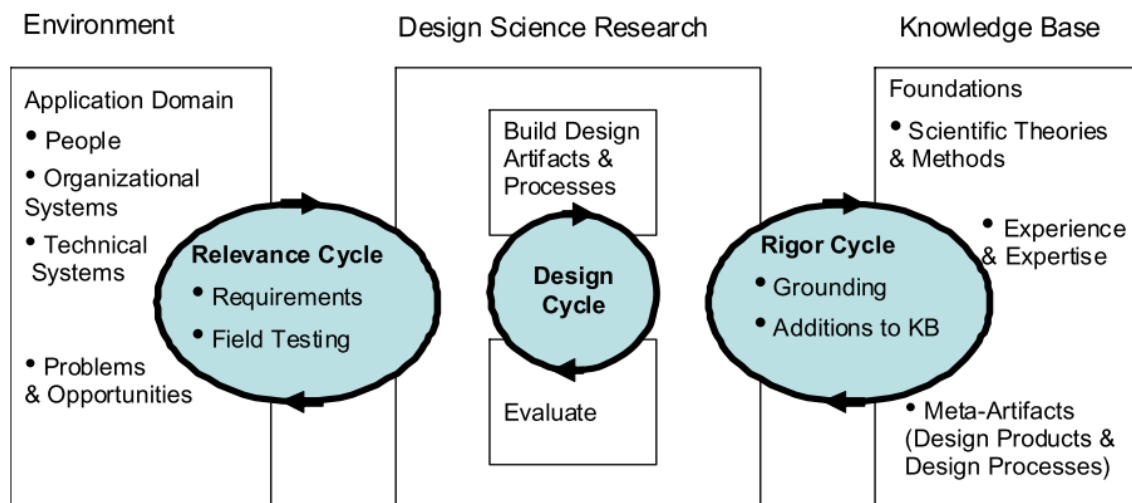


Figure 30: Three Cycle View on Design Science (Hevner, 2007, p. 88)

**The Relevance Cycle:** the motivation for Design Science comes from the desire to improve the environment by creating new artifacts (Simon, 1996). Good design science starts by identifying problems in an actual application environment. The cycle between the Design Science Research and the environment provides the research with requirements and acceptance criteria and the research will provide the environment with its outputs, namely implementations of the artifacts. There is a cycle, since the 'field testing' of the artifacts determine whether more iterations are required and/or requirements need to be updated.

<sup>10</sup> To prevent plagiarism: the following text in this paragraph mostly summarizes the work of Hevner (2007). Rephrasing and interpretation takes place and personal observations will be made from the first person perspective (using 'I').



**The Rigor Cycle:** the research draws from the state-of-the-art knowledge base in the application domain of the research and uses existing artifacts and processes from the application domain. The research adds to the knowledge by adding experiences and designed artifacts and processes. Hevner (2007, p. 90) argues that to ground all design research in kernel theories is unrealistic and even harmful. He prefers to include rich opportunities and problem from the relevance cycle; existing artifacts; analogies and theories.

**The Design Cycle:** is the core of Design Science and consists of generating alternatives and evaluating these over requirements iteratively until a satisfactory design is achieved. The requirements come from the *relevance cycle* and the design and evaluation theories come from the *rigor cycle*. There should be a balance between constructing and evaluating the evolving design artifact.

Hevner concludes with the fact that Design Science can be seen as a Pragmatic Science (*pragmatism considers practical consequences or real effects to be vital components of both meaning and truth (Hevner, 2007, p. 91)*), since it has an emphasis on relevance and making a clear contribution to the application domain. However a good Design Science research is defined by the *synergy between relevance and rigor and the contributions along both the relevance cycle and the rigor cycle*.

---

#### 4.1.1 IMPLICATIONS OF THIS SPECIFIC RESEARCH ON THE DESIGN SCIENCE APPROACH

The Design Science Approach as described with the Three Cycle View by Hevner is adopted in the execution of this research. The research will design artifacts which draw on the requirements that come from the environment in which it is deployed iteratively during the research phase. Scientific theories and experiences are used in the evaluation of the design. The artifacts that are developed and new experience gained during the research will be added to the knowledge base by means of the thesis and a scientific article.

There are however implications that the nature of this research imposes on the Design Science approach since the environment for the design is in South Africa, a country that is foreign to me. The *relevance cycle* draws from the people, organizational systems, technical systems and problems & opportunities in the application domain. This environment was only first introduced to me during the three month exchange period in South Africa. The *design cycle* will therefore be limited until I gained a high enough insight into the environment to abstract requirements from it. From that point on the iterative process between the *relevance cycle* and the *design cycle* starts working. The *rigor cycle* however is likely to be impaired by the process of integration of the researcher with the environment of South Africa. The iterative process between the *design cycle* and the *rigor cycle* is therefore likely to only become more prevalent in the period after the exchange. Figure 31 displays the geographical discordance or difficulties that is introduced when performing a design research while having only a short period of three months to embed yourself and the research within the foreign environment.

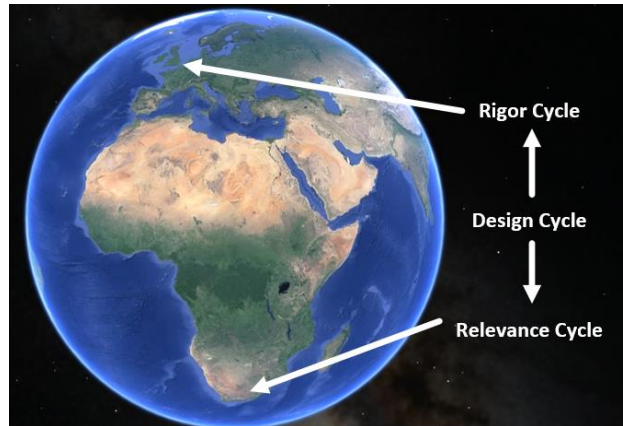


Figure 31: Geographical discordance between Rigor and Relevance Cycle

Despite the identified difficulties that the Design Science Approach has on the research, the method is adopted. It can be used to contribute to the application domain in a meaningful and relevant manner as well as adding experiences and artifacts to the current body of knowledge.

#### 4.2 DESIGNING A PARTICIPATORY SYSTEM WITH A BOUNDARY OBJECT

The approach of Hevner has been adopted. In section I the relevance cycle was most prevalent. The issues in the coping with dry spells in South Africa have been scoped down to the process of determining a Regional Water Scheme. In the first part of section II the rigor cycle has introduced theories from Policy Analysis, Citizen Participation, Participatory Systems Design, Social Ecological Systems and Boundary Objects. In section III the design cycle will form the link between those by redesigning the current process as a Participatory System using a Boundary Object in communication between groups.

In this paragraph the method and activity choices will be made that will be followed during the design phase in section III. The design process followed in this section III corresponds to the first four steps in a participatory systems design process<sup>11</sup>:

- A. Defining the mission/objectives
- B. Defining the design space and
- C. Conceptual design.
- D. Simulation and Testing

The conceptual design (step C) is divided into the design of the boundary object: the System Dynamics model of the water system and the process in which the boundary object is to be used. The functioning of the model as a boundary object will be tested through interaction with multiple experts (step D).

The overall process in Participatory Systems Design has been adopted, however thus far the more specific methods for performing the steps is found in literature on Participatory Systems Design. In Policy Analysis methods and activities have been developed to gain insight into varied policy-related situations or problems. Since PA has developed from its rational origins to also address messy policy problem situations (Enserink et al., 2013) it provides a complementary basis to Participatory Systems Design thinking. For instance, in Policy Analysis methods such as

<sup>11</sup> All five steps (ABCDE) are described on page 38

objectives trees, means-ends diagrams and causal diagrams are analysis tools that can be used in Participatory Systems Design. These methods are only a small selection of minor methods in PA to indicate the nestedness of PA in the design science approach.

The next sub-paragraph 4.2.1 will go into using a model as a Boundary Object. Followed by 4.2.2 that will go into the choice of modeling method.

---

#### 4.2.1 USING A MODEL AS BOUNDARY OBJECT ACROSS DISCIPLINES

The design will use a model to serve as a Boundary Object across disciplines. In the chapter 2 we have established that Regional Water Scheme affects many different systems and insight into these systems is required to make an informed decisions. The systems however are divided over different disciplines of experts which struggle to communicate across the boundaries of their discipline. Additionally South Africa aims to be a deliberative democracy, to make the allocation choices truly deliberative the actors and stakeholders in the policy arena should be able to understand and participate in the process.

*A Boundary Object can be used for dealing with heterogeneous work from many different actors with different viewpoints and boundary objects helping in generalizing findings, so it is sensible to other viewpoints (Leigh Star & Griesemer, 1989).*

In this case the use of a model as a boundary object can best be described with the diagram presented in Figure 32. In this figure two domains are presented that have a slight overlap. The model will be over the boundaries of the two domains and allows both the domains to contribute to it on a high level. The domain knowledge will have to be brought to a higher abstraction level, so that it can go with the high level knowledge on the other domain. In this manner a translation across disciplines is create with which the different domains can both relate. It is important that the knowledge added to the boundary object is on a high abstraction level, however still found valid by the experts within the domain.

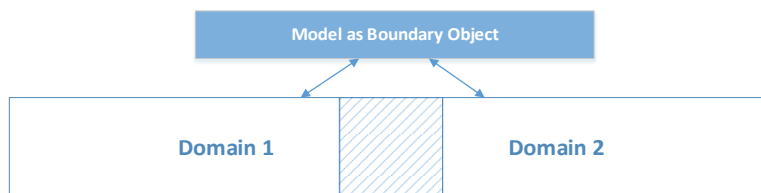


Figure 32: Model as a Boundary Object across Two Domains

The Boundary Object in communication is illustrated in Figure 33. The experts on different domains can add and gain knowledge from the boundary object model. Besides the experts on the domains that are currently involved, such as ecology and hydrology it now becomes possible to add other disciplines into the boundary object, such as disciplines within economic and social studies.

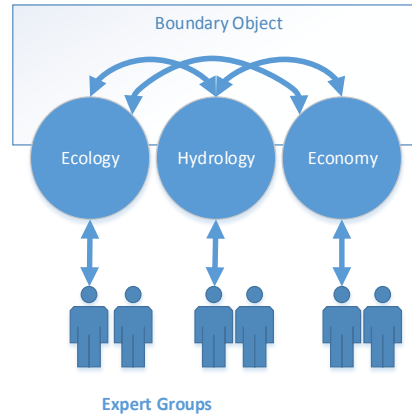


Figure 33: Model as a boundary object

To make the model in a Boundary Object fashion experts are to be involved as much as possible. Modeling will be as much interview or discussion based. Rather than gathering information and modeling separately.

### 4.2.2 CHOOSING A MODELING TECHNIQUE

The first step in building a model to be used as a boundary object is to determine what kind of model this should be. To make a grounded choice for the type of modeling the functions of the model, characteristics of the problem being modelled and the availability of data are going to be matched with the different available techniques. The functions and characteristics that are listed are specifically related to the modeling process. What aspects to assess in choosing a modeling technique are skills that have been learned over the course of my studies and specialization Modeling, Simulation and Gaming (courses given by Els van Daalen, Jill Slinger, Erik Pruyt, Jan Kwakkel, Igor Nikolic and Alexander Verbreack)

The following **functions** can be identified for the model. The model should:

- Cross the boundaries of different disciplines at a high (strategic) level;
- Serve as a means of communication;
- Provide insight into the working of the system (the model should be transparent box, rather than black box);
- The model should provide insight into the processes over a longer time period of 5-10 years;
- The model should provide have common denominators across disciplines and therefore be using quantitative measures, rather than qualitative mechanisms. The model outcomes can still be interpreted on a qualitative level regardless.
- Take into account different perceptions of different actors and provide possibilities to deal with mismatches in perceptions and values over the system.

The **problem** that is being modeled can be described with the following characteristics:

- The problem has both continuous aspects, such as the flows of water and the population and economic growth. However it also has discrete aspects, such as the functioning of the operating rules.
- The system is dynamic, with inherent memory and feedback loops. The modeling technique should therefore be able to deal with dynamic problems.

- At this level of scope and abstraction the issue is mostly of temporal nature. The spatial aspect can be left out of scope. Knowledge and information from other models can be added as constraints in the model.
- There is a mix between deterministic and stochastic characteristics, since there is both the question of why certain effects occur as well as what if question, coming from the uncertainty in runoff into the system.

The final aspect that will be used to describe the problem is the **availability of data**:

- The system can be regarded as data rich, since there have been many reports and many more in progress on the (ecological) state of the natural resources and the hydrological characteristics of the natural resources. However looking at the practical examples of the studies into RWS it is identified that a lot of the practical knowledge is not available or not given to the researcher.
- White box vs. black box: the system is relatively knowledge rich in regard to the level of scope that is chosen and the amount of research that is being conducted at that level. Even though the social-ecological system is complex there is a lot of knowledge on the general causation in the system (aspects in which there is disagreement can be modelled as such in the model).

To now match the problem to be modeled with a modeling technique we can determine what kind of model typology characteristics are matching with the problem descriptors. Table 5 shows the problem descriptors and the model typologies related to the descriptors.

Table 5: Problem descriptors linked to model typology

Problem descriptor	Model Typology
Long time horizon, strategic issues and crossing boundaries of disciplines	→ High level modeling
The model should have common denominators across disciplines	→ Quantitative modeling
Changes are both ongoing (continuous) and intermittent (discrete)	→ Capable of dealing with both continuous and discrete behavior
Inherent system memory and feedback loops	→ Dynamic modeling
The when is more important than the where	→ Temporal modeling
There are why and if questions	→ Deterministic and stochastic
Data is available	→ Data rich modeling possible
Knowledge on system-level is available	→ White box modeling is possible

The next step is to compare the required model typologies with different modeling techniques that are available. In Table 6 this is done. The color coding represents the fit that the technique has with the requirement, red being the lowest and green being the highest. In the table System Dynamics, Discrete-Event Simulation and Agent-Based Modeling exhibit the highest level of fit with the required model typology, since most other modeling techniques do not support capturing the dynamic behavior in the system. Physical system modelling takes place within the different disciplines such as hydrology, however given the operational characteristics of this type of modeling it would struggle in serving as a boundary object across different disciplines.

Table 6: Matching between modeling techniques and required typologies

Modeling technique	High level	Quantitative	Continuous & Discrete	Dynamic	Temporal	Deterministic & Stochastic	Data rich	White box modeling
Physical system modelling	Red	Green	Red	Yellow	Green	D <sup>12</sup>	Green	Green
System Dynamics	Green	Green	C <sup>13</sup>	Green	Green	D <sup>12</sup>	Green	Green
Discrete-Event Simulation	Red	Green	D <sup>14</sup>	Green	Green	Green	Green	Green
Agent-Based Modeling	Yellow	Green	D <sup>14</sup>	Green	Green	Green	Green	Green
Statistical modelling	Yellow	Green	Red	Red	Green	D <sup>12</sup>	Green	Red
GIS modelling	Yellow	Green	Red	Red	Red	D <sup>12</sup>	Green	Green
Spreadsheet modelling	Green	Green	Red	Red	Green	D <sup>12</sup>	Green	Green
Expert systems	Green	Red	Yellow	Red	Yellow	D <sup>12</sup>	Yellow	Green

#### Explanation of the color coding used in Table 6:

- Physical system modeling: is the classification of the hydrological models that are being used in the current decision-making process. The hydrological models are operational models with a higher level of detail, accuracy and shorter time horizon. The main critique on these models is that they are at a very detailed and operational level. This limits them to stay mostly within the boundaries of the hydrological system and struggle to cross it to the ecological and social system.
- System Dynamics models: has many aspects that fit the problem characteristics well. However the problem was identified to have both continuous as well as discrete aspects. System Dynamics struggles to deal with discrete aspects in modeling a system.
- Discrete-event models have a large degree of fit with the problem characteristics, however it would struggle to deal with the continuous aspects of the water system, such as the flows of water and ecosystem dynamics. Also the level of modeling is operational and it would therefore struggle to overarch boundaries between different disciplines.
- Agent-based modeling has a very large degree of fit with the problem characteristics. An issue is that the discrete attributes of the system make it difficult for ABM to model the large flows of water. Otherwise it can deal with both deterministic as well as stochastic issues, and is
- Statistical models are not fit for dynamic systems; GIS models are not fit for dynamic systems and focus on the spatial aspect rather than the temporal; spreadsheet models do not fit dynamics systems;
- Expert systems could be used, the direction of change can be indicated. The boundaries over different disciplines can be overarched by means of debate between the experts. However the complex nature of the system puts boundaries on the degree to which the experts can make sense of this.

Discrete-Event Simulation and System Dynamics are both forms of top-down modeling (Siebers, Macal, Garnett, Buxton, & Pidd, 2010) in which you model the system rather than the entities. Discrete-Event Modeling is oriented at the middle abstraction-, meso- or tactical level and focusses on processes, queues and discrete resources, using flowcharts (Borshchev & Filippov, 2004). System Dynamics is oriented at a high abstraction-, macro- or strategic level and focusses levels and feedback loops, using stock-and-flow diagrams (Borshchev & Filippov, 2004). Discrete-Event

<sup>12</sup> Deterministic

<sup>13</sup> Continuous modeling

<sup>14</sup> Discrete modeling

Simulation would struggle coping with continuous flows, whereas System Dynamics struggles with intermittent, or discrete signals.

An agent-based model would also fit with the problem characteristics: it can deal with issues at a both a high and a low level and it can deal with ongoing and intermittent changes in the system. It's capabilities to deal with discrete events in the model would make it more fit to model the decision made at the dam level. ABM builds the model bottom-up, requiring detailed knowledge, or building blocks from each discipline. ABM has a very graphical interface in running the model, however lacks the causal interface that is found in System Dynamics modeling.

Therefore, for the scope of this research and the aim of the model as a Boundary Object, System Dynamics is the most suited modeling technique for use as a Boundary Object for its fit with the problem being modelled, communicability, ease of modeling and graphical interface.

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#### 4.2.3 ENGAGED MODELING PROCESS

For building the System Dynamics model different approaches can be adopted. Two extremes are the expert desk-modeler that models the system from his own perspective as an expert, and Group Model Building in which the modeler is merely a facilitator and a group of stakeholders or experts provides the input for the modeling in a session. The first is most suited for a rational style research and advice and the second is more mediating and aims at mutual learning and gaining negotiated knowledge.

The modeling process will be approached by means of an engaged process with experts on the problem. The modeling will be based on interviews with one or more experts from the different groups that are sought to be combined by the model. Appendix B provides a table with an oversight of the different stakeholders and experts that have been involved in the modeling process.

The next paragraph will go into the choice for a case area to perform the design on and to serve as a proof-of-concept.

### 4.3 INTRODUCTION TO THE CASE STUDY AREA

A case study area is used specifically for the research to develop the boundary object and process. The designed objects will be generalized to be applicable for other areas in South Africa as well. Therefore the case study area should be representative for South Africa and lend itself for a three-month study from a Dutch master student.

For this the region of Mossel Bay, in the Western Cape province was chosen. This region is supplied by multiple dams, with the Wolwedans dam being the biggest. It has an estuarine ecosystem, a large industrial user and agricultural use besides the domestic use of Mossel Bay and smaller towns and villages.

The Wolwedans dam is a concrete dam near Mossel Bay, South-Africa. It collects water from the Great Brak river and has a catchment area of 192 km<sup>2</sup> (Mallory, Ballim, Pashkin, & Ntuli, 2012) and can hold up to 25,5 million cubic meters of water. It mostly serves domestic and industrial users. Besides that the estuary houses a valued ecosystem which requires a certain amount of water.



Figure 34: Wolwedans dam in perspective to South-Africa (picture: Piet Huizinga)

The average yield of the dam is enough to satisfy the needs of the ecosystem and the users together. However the region has to cope with floods and droughts. The water level has been recorded since the construction of the dam in 1990 and is presented in Figure 35. The graph shows the scarcity of water that has occurred in 2010 very well.

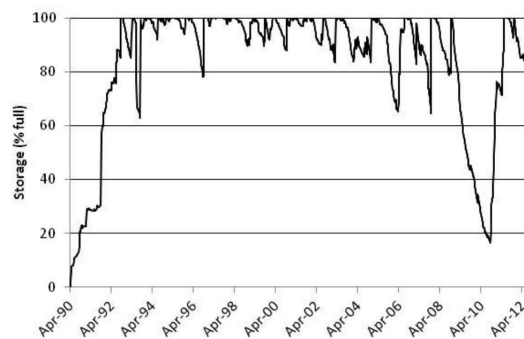


Figure 35: Historic water level in the Wolwedans reservoir (Mallory et al., 2012)

The region of Mossel Bay is chosen since it has the following characteristics:

Firstly, because it is an exemplar for many water regions in South Africa, since it has an ecosystem, social system and economical system represented in it. The estuarine ecosystem is characterized by the temporarily opening and closing of the mouth. 70% of the South African estuaries are temporary open/closed estuaries (Snow & Taljaard, 2007). There are different stakeholders represented in the system: large industrial users, agricultural users, a larger town and smaller villages. Although there is no mining or forestry, the other actors can serve to test working with the policy arena.

Secondly, there is a lot of data available for the region. The Great Brak estuary has been in the focal point of ecological studies for a long time, but also the multi-actor environment has been under study. This is uncommon in South Africa and therefore a unique feature of the Mossel Bay region. The studies that have been undertaken within the South African Netherlands Partnership for Alternatives in Development (SANPAD) and have been documented in the booklet: The Story of the Great Brak: Water and Society (Slinger et al., 2012). There is data on the hydrological system as is found in the study into the Regional Water Scheme (RWS) that has recently been executed (Mallory et al., 2013).



Since it is the interface between the water system and its subsystems and the multi-actor policy arena that are of interest. This representable case area of which a lot of data is available is selected to perform the study and the design on.

#### 4.4 ANSWERING RESEARCH QUESTION 3

Now that the methodology is set out, research question 3 can be answered:

##### **How can an improved decision-making process for water management be designed and validated?**

The question has two parts a design part and a validation part. For the design part the methodology has provided us with an operationalized combination of participatory systems design, boundary objects and citizen participation. Using Policy Analysis and modeling techniques to give meaning to the activities found in the different lenses.

To answer the validation part of the question some further analysis is required and will take place here. The validation will be set up in this paragraph and performed in the validation chapter that follows the design chapter.

Validation of the design can happen at different levels or from different perspectives. In their article Slinger & Kwakkel (2008) present a figure used in reflecting on modeling efforts (Figure 36). This figure can be adapted to fit the purpose of this thesis and illustrate the different levels at which validation and reflection can take place.

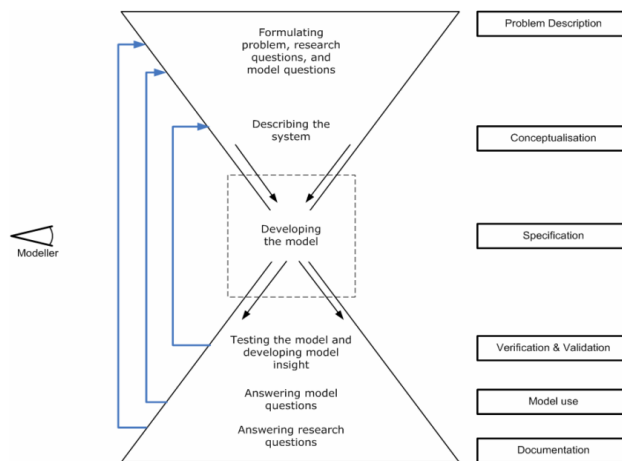


Figure 36: Reflective positions (Slinger & Kwakkel, 2008)

The figure has been adapted for purpose of this research in Figure 37. Validation levels one to three have been labeled ascending in level of scope. The research project first descended in scope. Starting with the highest level of scope: a problem in the decision-making regarding regional water scheme. This issue was then scoped down to designing a process entailing an SD model as a boundary object using selected theoretical concepts. Scoped down further is the conceptualization, specification and use of the SD model. The validation of the project will be in ascending, reversed manner. So first the model, then the concepts and finally the validation towards the end goal. The questions that can be asked then are as follows:

Validation 1: Can the specified System Dynamics model be validated?

Validation 2: Can the model be validated to function as a Boundary Object?

Validation 3: Can the design improve the decision-making process for determining a Regional Water Scheme?

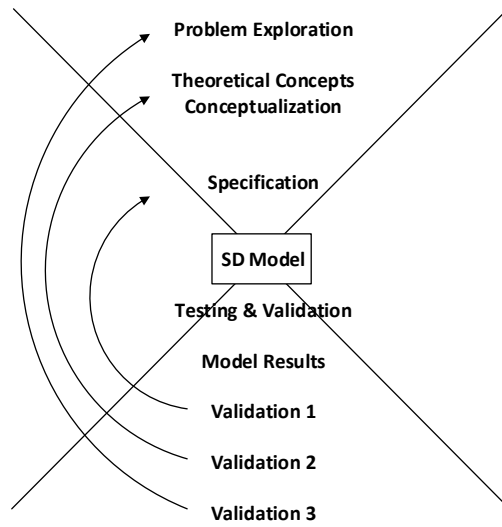


Figure 37: Hourglass structure and Validation of Design

The validation has now been set out to be performed at these three levels of scope. The reflection on the thesis will be performed in a similar way, only then the point of view of the researcher going through the research process will also be taken. This is illustrated in Figure 36 as the modeler's eye on the left side.

# SECTION III: DESIGN AND APPLICATION IN CONTEXT

## 5 DESIGN OF INTERVENTION

This chapter describes the design process of the intervention that is conducted in this research and presents the design itself. A design science approach is adopted representing a combination between policy analysis, participatory systems design and systems engineering. First the objectives for the intervention are defined and the design space is specified. This provides information on what the intervention should achieve and the boundaries within which it should operate. Secondly the conceptual design is presented within the design space, aiming to satisfy the objectives as far as possible. The chapter will be concluded with the conclusions and insights gained during the design process. Validation and discussion is situated in the next chapter.

### 5.1 DEFINING THE MISSION/OBJECTIVES

The process that is developed must meet objectives and requirements. In section I it became apparent that there is a need to serve the three pillars of the National Water Act better, namely: sustainability, equity and efficiency. The regional water scheme (RWS) in place has the goals to support sustainability, equity and efficiency. The objectives that the design in this research tries to achieve are related to the decision-making process. More specifically the design should improve aspects in the decision-making process to achieve RWSs that better meet their goals: sustainability, equity and efficiency. So, from now on, for the purpose of clarity a distinction is made between the goals of the RWS and the objectives regarding the design for the decision-making process leading up to an RWS. The intervention is a design of the process to determine an RWS. This chapter will mostly go in to the objectives of the process, rather than the goals of an RWS.

At the highest level the objective for the design would be: support the decision-making regarding regional water schemes and their operating rules. This objective is too general and immeasurable. Therefore it has to be deepened another level, by asking what does support decision-making entail.

For this the literature from Policy Analysis in combination with Citizen Participation and Participatory Systems Design can be used:

- In Policy Analysis objectives from the *democratize* activities can be related to support decision-making. The following objectives should be pursued: more openness, a higher transparency, higher representation and more validity (Mayer et al., 2004, p. 17).
- Citizen Participation literature examines the power citizens have in the process, whether the citizens are merely informed in for them ungraspable terms, or citizens enabled to be deliberately included into the decision-making process (Arnstein, 1969). These concepts can be used to deepen the previously identified objectives that came from PA. So openness should now include citizens from all layers and groups in society. This goes for transparency as well. All citizens should understand the information that is made transparent. In Citizen Participation literature disadvantages are also identified: the process can be *more time consuming*, there can be *loss of decision making power* and the *cost of decision-making* can rise (Irvin & Stansbury, 2004). These factors can be reframed to the objectives more progress and low cost of the decision-making process.
- In Participatory Systems Design there are three principles central: designing for trust, engagement and empowerment (see text box for more details). These design principles however, are less applicable to the

objectives for the design in this research. Note is taken of these principles in case an application is found.

- *“Designing for trust entails designing for transparency, security, integrity, privacy, identifiability, traceability, accessibility, proportionality, reliability, robustness*
- *Designing for engagement entails designing for interaction, presence, enactment, communication, awareness, co-creation*
- *Designing for empowerment entails designing for autonomy, self-regulation for human actors and automated systems, emergence” (Brazier & Nevejan, 2014, p. 3).*

The highest level objective is can now be specified to be of more use in the design process. Figure 38 shows the objective tree that can be used for designing the intervention.

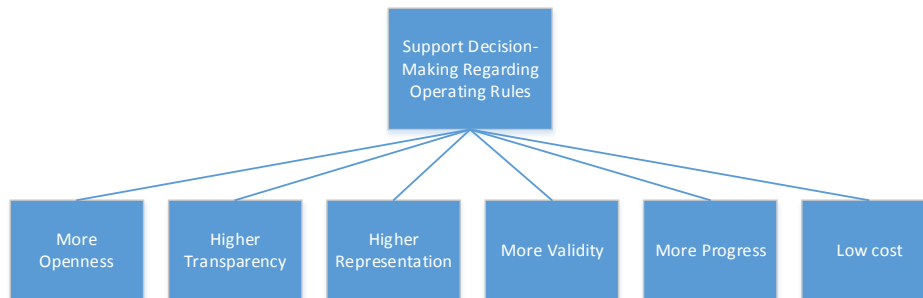


Figure 38: Objective tree for the design

The objective of the design would then be as follows:

***Support decision-making regarding regional water schemes and their operating rules by adding higher transparency and representation, making it more valid and ensuring progress without excessive costs***

It is now of interest and necessary to see whether the different branches in this objective tree can be translated into understandable and fairly measurable factors. The following table provides more insight into the different objectives by specifying to one level deeper.

Table 7: Objectives and specification

Objective	Direction	Specification
Openness	Maximize	Openness would be low if only a small number of selected participants can join the process and would rise by lowering the restrictions or barriers to join into the process. Ideally any person or organization would be able to join the process.  Trade-off: putting the process open for anyone will slow process.
Transparency	Maximize	Transparency in the process would be low if only resulting operating rules are published. Transparency rises by providing more insight into assumptions, scenarios, expected impacts on outcomes of interest and intermediate decision-making in the process. Ideally all these factors would be open to the public. Some processes don't lend itself to be transparent. E.g. if decisions are made based on mental models, then providing transparency is difficult. For the sake of transparency these processes should be avoided.

		Trade-off: high transparency could raise cost or make the process more sluggish, which can endanger progress.
Representation	Maximize	This would be low if only a small group of stakeholders feel or are represented in the decision-making process. To represent more groups in the decision-making process these groups need to be enabled to participate. This links to the literature on citizen participation. Manipulation (stakeholders are kept uninformed) is the lowest level of representation. Higher levels of representation are achieved when stakeholders are given mean to interpret information and power in the decision making process (Arnstein, 1969).  Trade-off: high levels of participation endanger progress and raise cost (Irvin & Stansbury, 2004)
Validity	Maximize	Validity in the process would be low if the decisions (in the complex, dynamic setting) are based on unconnected sets of tacit mental models. Ideally the decisions would be based on scientifically proven, integrated models.  Trade-off: between the validity and the simplicity of the model. A highly valid model might be more complicated and lose the ability of the model to function over the boundaries of different disciplines, or to serve as a boundary object.
Progress	Maximize	Progress is about the decision-making process being finished within a certain amount of time. Adding or complicating steps in the decision-making process will slow the progress of the decision-making process. Ideally the process would finish in the shortest amount of time possible, yet satisfying the other objectives.  Trade-off: in the worst case the decision-making process would be very sophisticated, however unable to finish <sup>15</sup> .
Cost	Minimize	The costs of the process should remain limited. The authorities assigns a certain budget to the decision-making process. This can come from water or general taxations. Extra costs shall only be approved if the benefit is clear.  Trade-off: this has trade-offs with nearly any of the objectives, since we live in a highly monetized world.

The objectives have been specified a level deeper and trade-offs have been sketched for each of the objectives. Only the main trade-offs have been given, as the list is inexhaustible. Trade-offs do not apply to every specific design choice, but as general rules of thumb<sup>16</sup>.

The objectives that have been identified in this paragraph, except for the costs, cannot be directly measured and can at best be put on an ordinal scale. It is out of scope for this research to attempt to accurately measure or compare different designs against the objectives as a scale. Therefore the trade-offs will need to be used as general rules of thumb to decide on different design variables and design choices and trade-offs taken into account will be explained as explicitly as possible.

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<sup>15</sup> This is what could be argued for some aspects of the South African water law. For example the classification process, which is highly advanced and sophisticated, however has not or seldom executed itself to completion for any of the water resources (page 13).

<sup>16</sup> E.g. not all design options that raise transparency will also raise costs. Case in point: the decision to make a report public on the authorities' website doesn't need to involve significant higher costs, yet raises transparency.

To be able to compare the design with the current decision-making process pairwise comparison of the estimated effects on the different objectives will be used.

## 5.2 DESIGN OF THE SYSTEM DYNAMICS MODEL

This paragraph will go into the conceptual design that has been made during the empirical research phase in South Africa. The design was made in a cooperative and iterative manner, involving experts to participate in the modeling to share their knowledge on the system and processes. The paragraph will be divided into a part that goes into the System Dynamics model as a boundary object and a part that goes into the process in which the boundary object can be embedded.

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### 5.2.1 CONCEPTUALISATION

In this sub-paragraph the developed System Dynamics model will be elaborated on. In this research the System Dynamics model is used to assess whether a model can be used to simulate the actual behavior of the water system characterized by a large dam and whether this model can serve as a boundary object. Therefore the model that was created is made at the highest level possible, while still being valid and recognizable enough for the experts and stakeholders to accept it as a representation of the actual water system.

The System Dynamics models was constructed in South Africa by means of an engaged process with experts on the different sub-models (see Appendix B). The role of the System Dynamics modeler was to translate the knowledge that is held by the experts into a single, connected model. The sub-models that have been created are connected as is shown in Figure 39. As an illustration

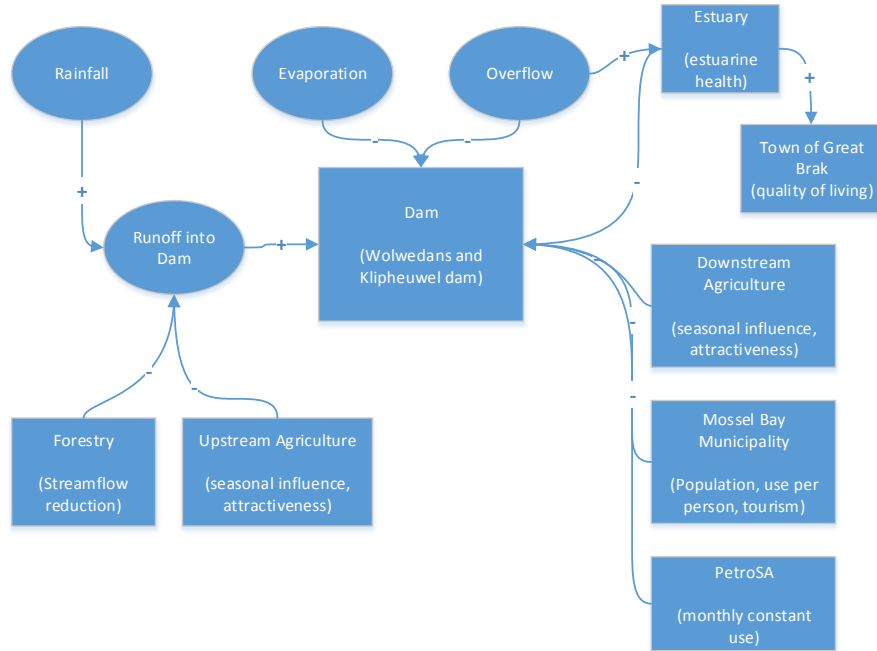


Figure 39: Connected Sub-Models in Dam Operation Model

### 5.2.2 SPECIFICATION

The **dam operation model** specified for the Wolwedans Dam has multiple subsections. The seven most important subsections will be specified in detail: the Wolwedans dam subsection, the Great Brak estuary subsection, the Mossel Bay municipality subsection, the local Great Brak community subsection, the PetroSA subsection and the upstream agricultural subsection. Sections that are left out of this specification, but are found in the System Dynamics model are the Klipheuwel dam subsection and the downstream agriculture subsection. These are adaptations of the Wolwedans dam and upstream agricultural subsections and follow a structure so similar that it would be mostly a repetition of previously introduced specifications.

#### The Wolwedans dam subsection

The volume of freshwater in the Wolwedans dam ( $x_1$ ) is influenced by the runoff into the dam from the Great Brak river ( $x_{11}$ ), the rainfall directly onto the surface of the Wolwedans Dam ( $x_{12}$ ), evaporation from the Wolwedans Dam ( $x_{13}$ ), overflow of the Wolwedans Dam ( $x_{14}$ ) and extraction of water from the Wolwedans dam ( $x_{15}$ ) for different uses downstream. This results in the following equation:

$$\frac{d}{dt} x_1 = x_{11} + x_{12} - x_{13} - x_{14} - x_{15}$$

The runoff into the dam from the Great Brak river ( $x_{11}$ ) uses a time dependent runoff function ( $runoffWDf(t)$ ) and is affected by the upstream use of water for agriculture ( $use_{agriculture\ upstream}$ ) and the streamflow reduction by plants and trees ( $streamfl_{forrest}$ ). The streamflow reduction is calculated by making a simplified streamflow reduction per square kilometer of forest and calibrating this to the data used in the RWS study (Mallory et al., 2013). The rainfall directly onto the surface of the Wolwedans Dam ( $x_{12}$ ) is determined by a time dependent rain



function ( $rainWDf(t)$ ) which is based on hydrological data (Appendix E). The evaporation of water from the dam ( $x_{13}$ ) is determined by a time dependent evaporation function  $evapWDf(t)$ . The overflow of the dam ( $x_{14}$ ) occurs when the current volume of water in the dam ( $x_1$ ) exceeds the capacity of the Wolwedans dam ( $cap_{WD}$ ) and more water comes in than the sum of water extracted for use ( $x_{15}$ ) out and evaporates ( $x_{13}$ ) at that moment in time. The extraction of water from the Wolwedans dam ( $x_{15}$ ) is the sum of use by the estuary ( $use_{estuary}$ ), water used by the Mossel Bay municipality ( $use_{mosselbay}$ ), water used by PetroSA ( $use_{petrosa}$ ) and water used by downstream irrigation ( $use_{agriculture\ downstream}$ ).

$$\begin{aligned}x_{11} &= runoffWDf(t) - use_{agriculture\ upstream} - (Surface_{forrest} * sfr_{forrest}) \\x_{12} &= rainWDf(t) \\x_{13} &= evapWDf(t) \\x_{14} &= \max(x_{11} - (x_{13} + x_{14}) \text{ if } x_1 > cap_{WD} \text{ and } 0 \text{ otherwise} \\x_{15} &= use_{estuary} + use_{mosselbay} + use_{petrosa} + use_{agriculture\ downstream}\end{aligned}$$

### The Mossel Bay municipality subsection

The population of the Mossel Bay municipality ( $x_2$ ) changes by the amount of births in Mossel Bay ( $x_{21}$ ), the deaths in Mossel Bay ( $x_{22}$ ) and the net amount of people migrating to Mossel Bay ( $x_{23}$ ). The equation for the population of Mossel Bay would then be:

$$\frac{d}{dt} x_2 = x_{21} + x_{23} - x_{22}$$

The amount of births ( $x_{21}$ ) and deaths ( $x_{22}$ ) are calculated by multiplying the population of Mossel Bay ( $x_2$ ) with the birth rate ( $br_{mb}$ ) and the death rate ( $dr_{mb}$ ) of Mossel Bay. The amount of people migrating to and from Mossel Bay has been put in a single net migration that is calculated by multiplying the population of Mossel Bay with a net migration rate ( $mr_{mb}$ ).

$$\begin{aligned}x_{21} &= x_2 * br_{mb} \\x_{22} &= x_2 * dr_{mb} \\x_{23} &= x_2 * mr_{mb}\end{aligned}$$

The total number of tourists residing in Mossel Bay ( $x_3$ ) changes by the arriving of tourists in Mossel Bay ( $x_{31}$ ) and tourists leaving Mossel Bay ( $x_{32}$ ).

$$\frac{d}{dt} x_3 = x_{31} - x_{32}$$

The arrival of tourists in Mossel Bay ( $x_{31}$ ) is calculated by multiplying an average number of tourists ( $at_{mb}$ ) with a seasonally oscillating function ( $touristf(t)$ ). The departure of tourists is dependent on the average staying time for tourists ( $astt$ ) and the number of tourists that are currently in Mossel Bay ( $x_3$ ).

$$\begin{aligned}x_{31} &= at_{mb} * touristf(t) \\x_{32} &= \frac{x_3}{astt}\end{aligned}$$

The domestic demand coming from the Mossel Bay municipality ( $demand_{mb}$ ) is then calculated by multiplying the amount of people in Mossel Bay with a demand for water per person per month ( $dpp$ ).

$$demand_{mb} = (x_2 + x_3) * dpp$$

### The Great Brak estuary subsection

The Great Brak estuary subsection is based around the estuary with an indicator that represents the estuarine health ( $x_4$ ). The health can either increase ( $x_{41}$ ) at a certain pace, or deteriorate at a certain pace ( $x_{42}$ ). This estuarine health is an abstract number in the case of this model. It has a range between zero and two, zero representing a dead estuary, two representing a very healthy estuary and one representing the estuary in its present state.

$$\frac{d}{dt} x_4 = x_{41} - x_{42}$$

The increase and decrease are both dependent upon the fraction of water that is supplied ( $x_{43}$ ) and the current level of health ( $x_4$ ). The fraction of water supplied ( $x_{43}$ ) equals the water that is supplied ( $averagesupplied_{estuary}$ ) as a running average over twelve months divided by the water that is required to retain health ( $x_{44}$ ). The amount of water that is required is calculated with a function that is dependent on the current health of the ecosystem ( $waterrequiredf(x_4)$ ). The effect of supplying enough water is larger if the estuary is further away from its maximum health ( $health_{max}$ ). And the increase effect is spread over several months by the delay in health increase ( $delay_{healthincrease}$ ). Analogously, for the decrease of health, supplying less water than required will make the health decrease more strongly and if the health comes closer to zero, the decrease will become less. This effect occurs over some time, the delay in health decrease ( $delay_{healthdecrease}$ ).

$$\begin{aligned} x_{41} &= \max\left(0, \frac{x_{43} * (health_{max} - x_4)}{delay_{healthincrease}}\right) \\ x_{42} &= \max\left(0, \frac{(1 - x_{43}) * x_4}{delay_{healthdecrease}}\right) \\ x_{43} &= \frac{averagesupplied_{estuary}}{x_{44}} \\ x_{44} &= waterrequiredf(x_4) \end{aligned}$$

### The local Great Brak community subsection

The quality of living conditions for the people in Great Brak ( $LQ_{gb}$ ) is included as an index in the model.

$$LQ_{gb} = \frac{x_5 + (1 - x_6) + \frac{x_4}{2}}{3}$$

The living qualities are determined by the attractiveness of Great Brak to tourists ( $x_5$ ), the effect that a flood has on the area ( $x_6$ ) and the health of the estuary ( $x_4$ ). The attractiveness to tourists ( $x_5$ ) is modeled as a stock which restores ( $x_{51}$ ) to a certain level after it has been decreased by the effects of a low water quality ( $x_{52}$ ) or a flood ( $x_{53}$ ). A flood also has a direct effect on the quality of living conditions ( $x_6$ ) this effect goes up after a flood occurred ( $x_{61}$ ) and slowly dies out if time passes after a flood ( $x_{62}$ ). The check to whether a flood occurs is based on the amount of water that is spilling over the dam. This is a simplification, since in reality it would depend on the water level in the estuary. There is a strong connection to the spillover and the water level of the estuary, however tide and timely breaching also play a role.

$$\begin{aligned} \frac{d}{dt} x_5 &= x_{51} - x_{52} - x_{53} \\ \frac{d}{dt} x_6 &= x_{61} - x_{62} \\ x_{51} &= \frac{1 - x_5}{delay_{ragb}} \\ x_{52} &= x_5 * (1 - effect_{wqtf}(x_4)) \end{aligned}$$

$$\begin{aligned}
 x_{53} &= x_5 \text{ if 'flood} = \text{yes' and 0 otherwise} \\
 x_{61} &= \max(0, 1 - x_6 + x_{62}) \text{ if 'flood} = \text{yes' and 0 otherwise} \\
 x_{62} &= \frac{x_6}{\text{duration}_{\text{flood}}} \\
 \text{flood} &= \text{yes if } x_{14} > \text{flood}_{\text{overflow}}
 \end{aligned}$$

### The PetroSA subsection

The PetroSA subsection is modeled relatively simple, since the processes in the plant have not been modeled, but a constant operation, requiring a constant monthly amount of water is assumed ( $\text{demand}_{\text{petrosa}}$ ). This demand can be met or not resulting in a certain utilization of the PetroSA plant ( $x_7$ ). This is a running average of the fraction that the plant is in use ( $\text{operating}_{\text{petrosa}}$ ) over a year. How much the plant is in use at a certain moment is a function of the amount of water that is supplied to the plant ( $\text{operating}_{\text{petrosa}}f(x_7)$ ). PetroSA also uses  $1.000 \frac{\text{m}^3}{\text{day}}$  from Reverse Osmosis plant that runs on Mossel Bay effluent.

### The upstream agriculture subsection

Agriculture is practiced both upstream as well as downstream of the Wolwedans dam, however mostly upstream. It therefore is difficult to ration in practice, since it abstracts water before it is inside the dam. There is also some agriculture downstream which is included in the model. Only the upstream agriculture is specified in this thesis, since the structure is very similar.

Central in the agricultural subsection is the total area of land in use ( $x_8$ ). This changes when new land is taken in use ( $x_{81}$ ) or land is reduced for other uses ( $x_{82}$ ).

$$\frac{d}{dt}x_8 = x_{81} - x_{82}$$

New land is taken in use for agriculture when there is an attractiveness for agriculture ( $x_9$ ) and there is area available for the construction ( $\text{ta}_{\text{argi}}$ ). A certain period is taken into account for the construction and abolishment of agricultural land ( $\text{delay}_{\text{agri}}$ ).

$$\begin{aligned}
 x_{81} &= \max\left(0, \frac{(x_9 - 1)(\text{ta}_{\text{au}} - x_8)}{\text{delay}_{\text{agri}}}\right) \\
 x_{82} &= \max\left(0, \frac{(1 - x_9)(x_8)}{\text{delay}_{\text{agri}}}\right)
 \end{aligned}$$

The monthly demand that the agriculture has ( $\text{demand}_{\text{au}}$ ) is determined by an average for water consumption of the crops that are grown ( $\text{consumption}_{\text{crops}}$ ), together with a seasonal factor for irrigation ( $\text{irrigation}f(t)$ ) multiplied by the amount of land on which agriculture is practiced ( $x_8$ ). The attractiveness of agriculture upstream ( $x_9$ ) can rise ( $x_{91}$ ) or fall ( $x_{92}$ ) due mostly by the amount of water that is supplied compared to the desired amount of water ( $x_{91}$ ). The attractiveness has a ceiling ( $\text{maxattr}_{\text{au}}$ ) and a tipping point ( $\text{tippingpointattr}_{\text{au}}$ ) at which level of rationing it becomes unattractive for farmers to have more agricultural land. The fraction that is supplied to farmers ( $\text{fractionsupplied}_{\text{au}}$ ) is calculated over the period of the last twelve months. The model uses the following formulas for this:

$$\begin{aligned}
 \text{demand}_{\text{au}} &= x_8 * \text{consumption}_{\text{crops}} * \text{irrigation}f(t) \\
 \frac{d}{dt}x_9 &= x_{91} - x_{92} \\
 x_{91} &= \max\left(0, ((\text{fractionsupplied}_{\text{au}} - \text{tippingpointattr}_{\text{au}}) * (\text{maxattr}_{\text{au}} - x_9))\right)
 \end{aligned}$$

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$$x_{92} = \max(0, ((tippingpointattr_{au} - fractionssupplied_{au}) * maxattr_{au}))$$

$$fractionssupplied_{au} = \frac{\int_{t-12}^t demand_{au}}{\int_{t-12}^t use_{au}}$$

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### 5.2.3 APPENDIX REFERRAL FOR OTHER SD MODEL RELATED INFORMATION

More on the model and modeling process is found in the appendixes. For a table of the variables, units and uncertainty ranges that have been used can be found in Appendix D. Related to that some table functions have been used to specify certain relations with or simulate input into the model. These have been specified in Appendix E. The structure of the different sub-models in the Vensim simulator is provided in Appendix F and some examples of model runs over time for certain variables is found in Appendix G.

### 5.3 DESIGN OF THE INTERVENTION PROCESS: USING THE MODEL AS A BOUNDARY OBJECT

Using the SD model as a boundary object will have implications for the process in which an RWS is determined. This paragraph will go into the implications that adding a model as a boundary object add to the process that is followed in determining an RWS. Since the scope of this research is exploratory the process will be described at a high level. More specific design choices need to be made when the process is further developed outside of this research.

In the current process for determining an RWS there are interactions with the consultant that is performing the study and other disciplines or actors. For example, the consultant and the ecologists come to understanding about the amount of water available and the consequences that providing a certain amount of water might have on the ecosystem. Another example is the communication that was observed between the consultant and the municipality. In that case the provisional scheme was published, the municipality had remarks to it and the scheme was revised including an extra scenario that was brought to table by the municipality. Therefore we can see that there is a two way interaction between actors in the system and the consultant performing the study. This interaction however is narrowed down to a single action at a time. The ecologist will talk about ecological water requirements and not about economic impacts. This process is illustrated in Figure 40. The interactions with (parts of) the Policy Arena happen only after the study is conducted and could cause the study to be evaluated again by the consultant or have no effect in which case the study is approved.

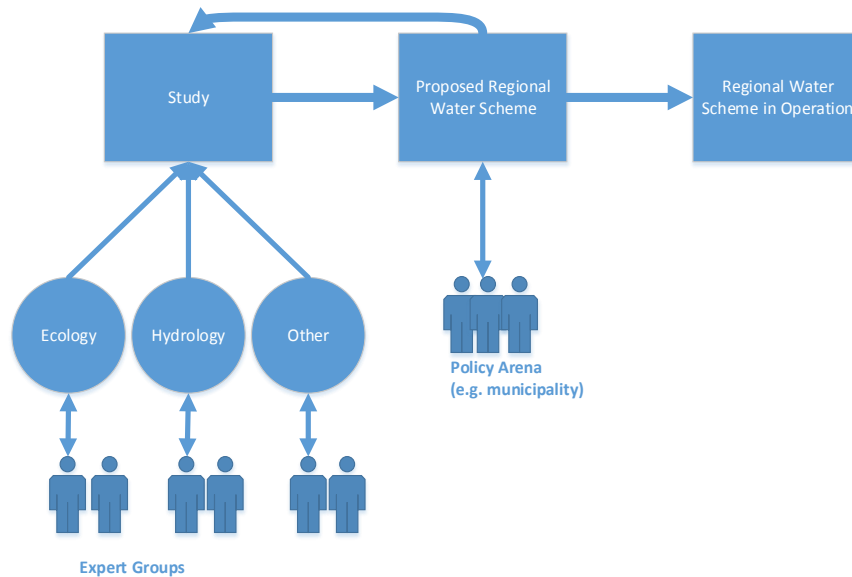


Figure 40: Information flows in the observed process

The next sub-paragraphs go into how the process that is designed in this research could be shaped.

#### 5.3.1 USING THE BOUNDARY OBJECT CHARACTERISTICS TO BUILT THE MODEL

In a proposed process using a model as a boundary object the flow of information can be broader. The different experts will express their views on their discipline as input for the model, but will also be able to gain insight the high level knowledge of the other disciplines and the effect of their proposed policies on the outcomes of interest. This allows the different disciplines to adjust their perspectives according to their values. Figure 41 provides an illustration.

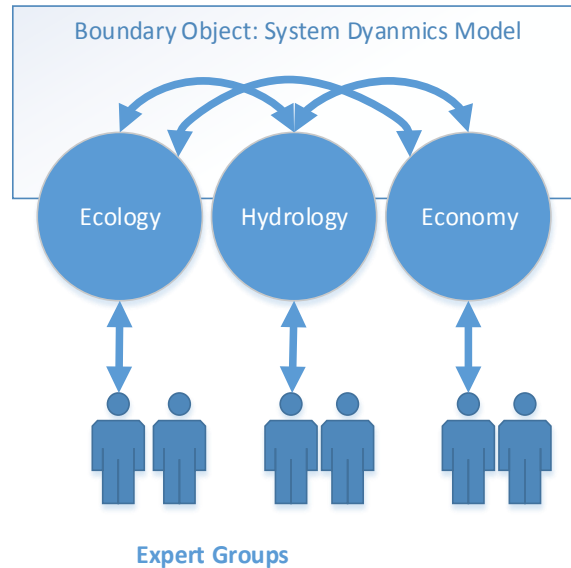


Figure 41: Added interactions with SD model as Boundary Object

The figure shows that the high level knowledge from the different expert groups is included in the model. In the model it can interact with high level knowledge from other disciplines and provide feedback to the specific actor groups on how their sub-model is in coherence with the other sub-models in the water system.

**Structural and parametrical uncertainty**

The model building will require insight into the causal relations in the water sector. Since the water system is a complex system there is likely to not be consensus on both the different relations as well as the parameter values. This can be divided into structural uncertainty and parametrical uncertainty. Both can be dealt with in the SD modeling. In the case of structural uncertainty multiple structures can be modeled and simulated over many runs to compare the effect of the structural uncertainty on the outcomes of interest. For the parametrical uncertainty an upper and lower boundaries can be chosen from which a large number of scenarios can be generated.

Before the model can be simulated and provide outcomes over different scenarios and operating rules these scenario's and operating rules need to be set. The scenarios are created by assessing the structural and parametrical uncertainty in the model (as explained in the text box above) and by varying the uncontrollable input. For the uncontrollable input both historical data as well as simulated scenarios can be used.

- Structural uncertainty: acquire different structures in interviews with experts, build multiple structures that can be switched on and off by means of switching variables that can assume the values 0 or 1.
- Parametrical uncertainty: acquire upper and lower bounds for the parameters.
- Uncontrollable input: use historical and simulated data to create runoff scenarios.
  - There should be long term runoff scenarios to assess the operating rules over a 15 year period
  - There should be short term runoff scenarios to assess how the operating rules function over resource stressed periods of five years.

Also the consultant should gather different sets of possible operating rules. This set should be as varied as possible, since after this phase selection can still be done. The selection can be better argued for after the simulation process than before the simulation process.

Now that the uncertainty space over the variables and uncontrollable input is sketched a more difficult part follows which requires knowledge and insight in modeling and simulation. Since the uncertainty space is now very large the simulation model cannot run all possible settings. There are statistical sampling methods that can assist in representatively sampling an uncertainty space, whilst keeping the amount of experiments required limited. There are different sampling methods available. In this case an efficient and uniform distribution sampling (e.g. Monte Carlo or Latin Hypercube) would be interesting to answer questions such as “under what circumstances would the operating perform well or poor?” and to see what uncertainties are of most impact on the system (and should be further investigated) or what uncertainties have little impact on the system (and the differences can be accepted). The recently developed Exploratory System Dynamics Modeling Analysis (ESDMA) can provide more insight in possibilities for dealing with the uncertainty space (Kwakkel & Pruyt, 2013).

**Important tradeoff: validity versus progress**

In the next phase other actors and stakeholders should participate. This phase can be entered when the different expert groups have had their input in the model and the model is considered valid. The decision on when the model is valid is critical for the progress of the project as a whole and there is a large risk that this decision will be the bottleneck for the process to find progress into the next phase. Here we are confronted with the trade-off between validity and progress. Given the lack of progress that was identified in the previous chapter, in combination with the fact that this process is repeatable priority is given to progress. There should be a party in this process that guards the process and takes the decision to move ahead into stakeholder participation.

5.3.2 ACTOR/STAKEHOLDER/CITIZEN PARTICIPATION

In this phase the model and the model outcomes are presented to the actors to start the process of citizen participation and deliberation over the model outcomes and policy options. This phase was designed keeping in mind the knowledge on Citizen Participation. In the literature on Citizen Participation (see paragraph 3.3) the following advantages and disadvantages have been identified:

Table 8: Advantages and disadvantages of citizen participation, compiled from (Irvin & Stansbury, 2004)

	Advantages of citizen participation		Disadvantages of citizen participation	
	To Citizens	To Government	To Citizens	To Government
Process	Education; Persuade and enlighten the government; Gain skills for activist citizenship.	Education; Build trust alloy anxiety and hostility; Build strategic alliances; Gain legitimacy.	Time consuming; Pointless if ignored.	Time consuming; May backfire.

Combining this table with the objectives that are created for the designed process we can roughly say that a higher level of citizen participation will have the following effects on the objectives:

- Higher openness: boundaries for accessing the process are lowered;
- Higher representation: a larger and more representative share of the population contributes to the process;
- Lower progress: can be time consuming (especially if voting or veto is included);
- Higher costs: citizen participation requires the citizens to be reimbursed and have resources to gain (external) expertise.

It is challenging to find a balance in the trade-off between these different objectives for the process and determine an optimal level of citizen participation. The appropriate level can differ depending on the priorities or values that are attached to openness, representation, progress and cost.

For the purposes of this research the focus is for a large part on progress, for the following reasons:

- In the present state an elaborate system is identified, which lacks progress;
- The proposed process includes new elements into the system, for example system modeling;
- These new elements could endanger progress even more.

Therefore safeguards need to be built to ensure that progress can and will be made in the proposed process. The decision-making will not improve by implementing another elaborate process that lacks the progress to be finished.

Taking back the figure of the water system embedded in the multi-actor setting, which is illustrated again in Figure 42 on the next page. The following steps need to be executed:

1. Identify the Policy Arena and transform the data (model outcomes);
2. Interact with the actors in the policy arena;
3. Process the information gained on the perceptions, values and resources of actors in the policy arena.



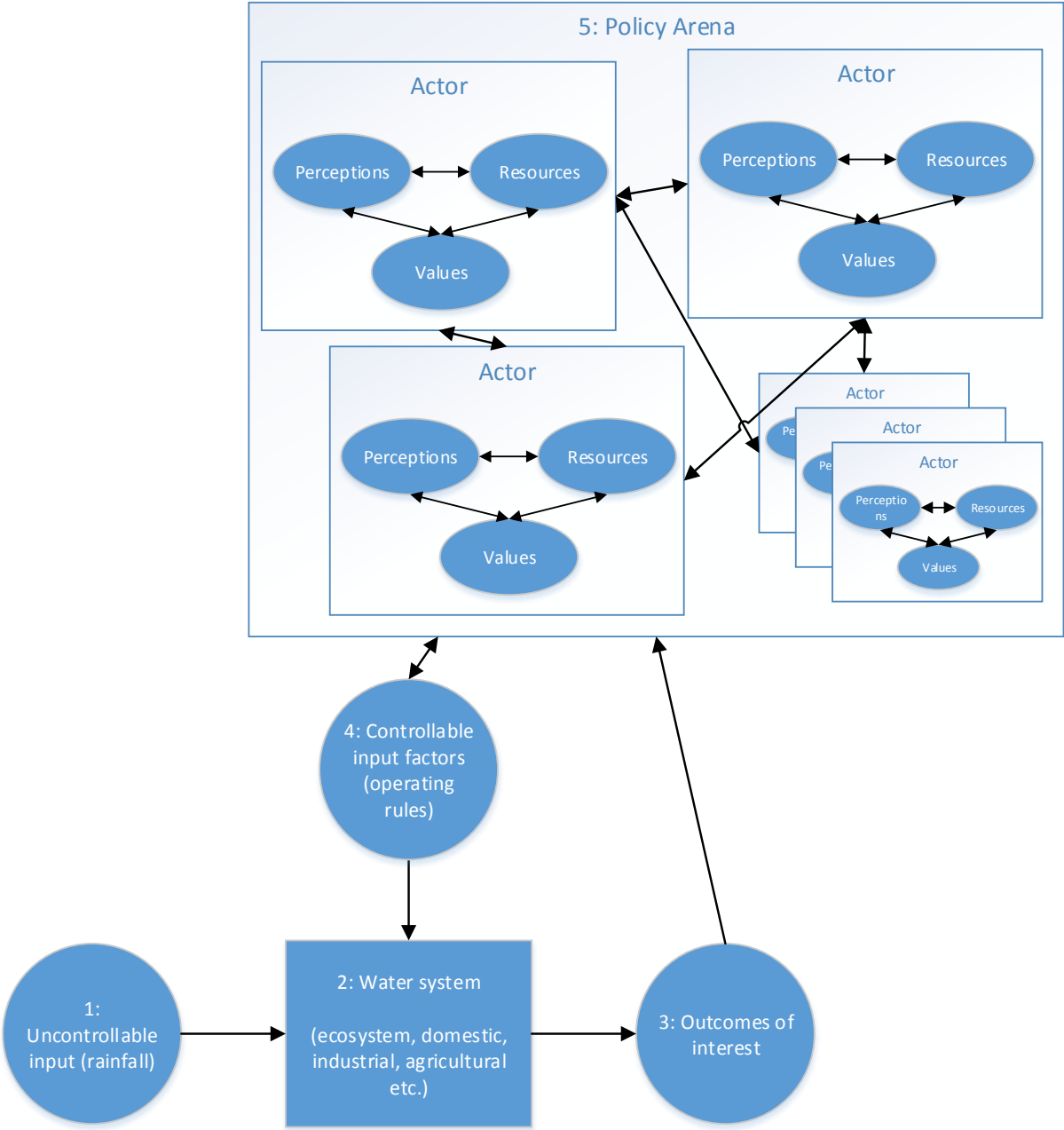


Figure 42: The Policy Analysis System View Embedded in a Multi-Actor System (adapted from (Hermans, 2008))

These further steps that need to be taken will be discussed in the following paragraphs.

5.3.2.1 IDENTIFY THE POLICY ARENA (AND IDENTIFY WHOM TO INCLUDE)

An essential step in the process is to identify whom to include into the process. Figure 43 illustrates what this process entails. The four illustrations should be seen from left to right. The first illustration is the Policy Arena before it is mapped. We know it is there and it is half transparent, since we do not know something about it. The second illustration is the Policy Arena after the actors in the Policy Arena have been identified. It should be noted that the perceptions, resources and values are still black boxes. In the third illustration a selection has been made on which actors to include in the interactions. It is difficult to say anything about this selection process from this level of study, however it could be made in interest of progress however so that representation and openness remain ensured. The fourth illustration shows the participation actors with their perceptions, resources and values. This would represent the situation after the interaction between the boundary object and stakeholders has been completed and insight gained.

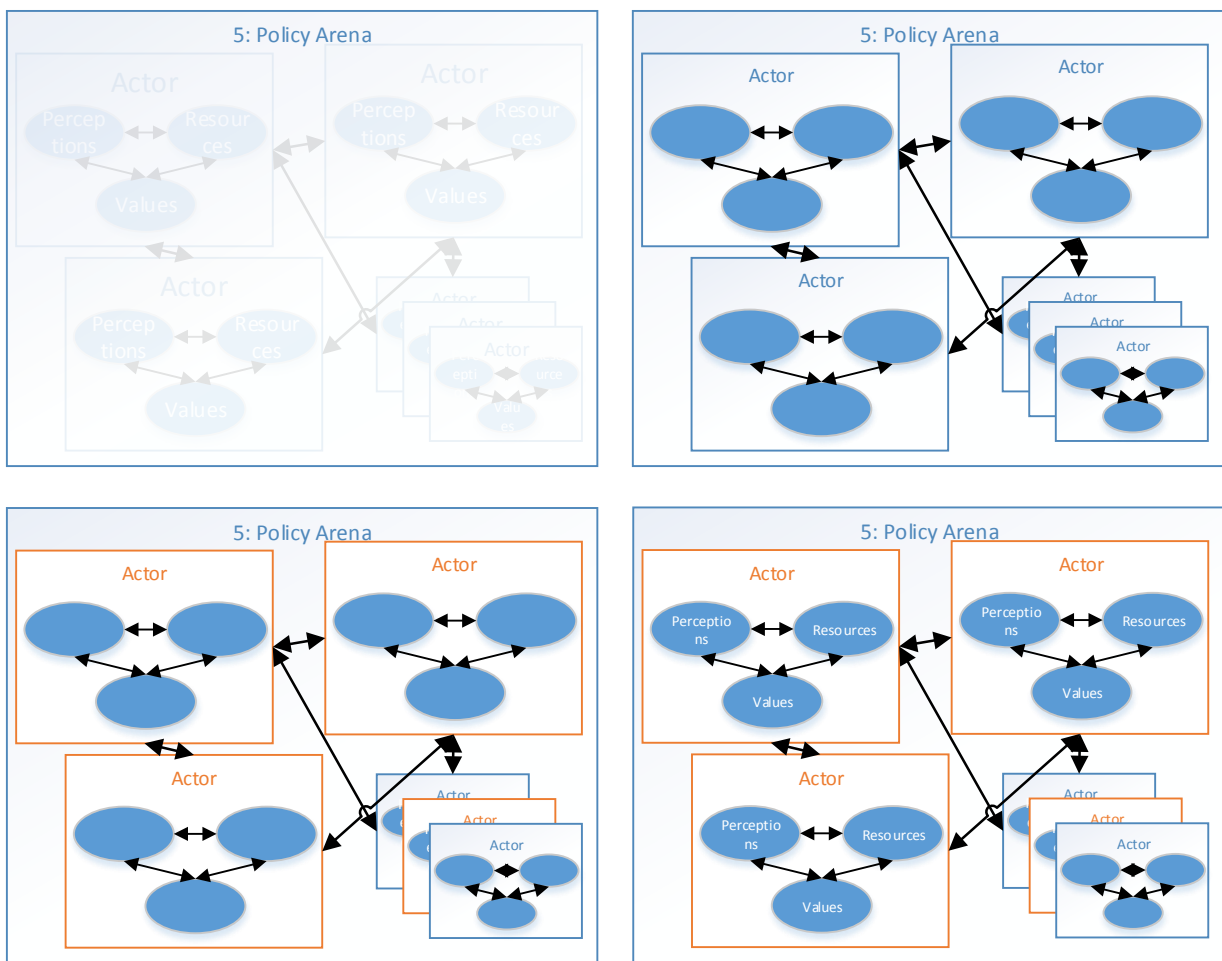


Figure 43: Identifying Policy Arena and Selecting Participants

The fact that actors have no perceptions, resources and values in the first three situations does not mean that they are not there, it just indicates that no process took place in which the consultant gained insight in to these factors. They become more visible in the last picture, since then the consultant has more understanding coming from the communication in the process.

5.3.2.2 TRANSFORM DATA

In order to allow a variety of actors to interact with the boundary object a transformation of the model data into more accessible information should be made. For this, scorecards can be used. The scorecards contain information on the outcomes of interest over different scenarios and polices. The outcomes of interest can be color coded to ensure a maximum accessibility of all groups in South Africa.

South Africa has a literacy rate of 93%, however numeracy numbers are lower (CIA, 2011). Recently the math and science education has been heavily criticized in the 2014 World Economic Forum benchmark (Bilbao-Osorio, Dutta, & Lanvin, 2014, p. 287). Ranking South African math education lowest out of 148 countries surveyed.

The color scaling should be kept transparent and be openly accessible and discussable to prevent manipulation of outcomes. Figure 44 illustrated the conversion from the system view to the scorecards.

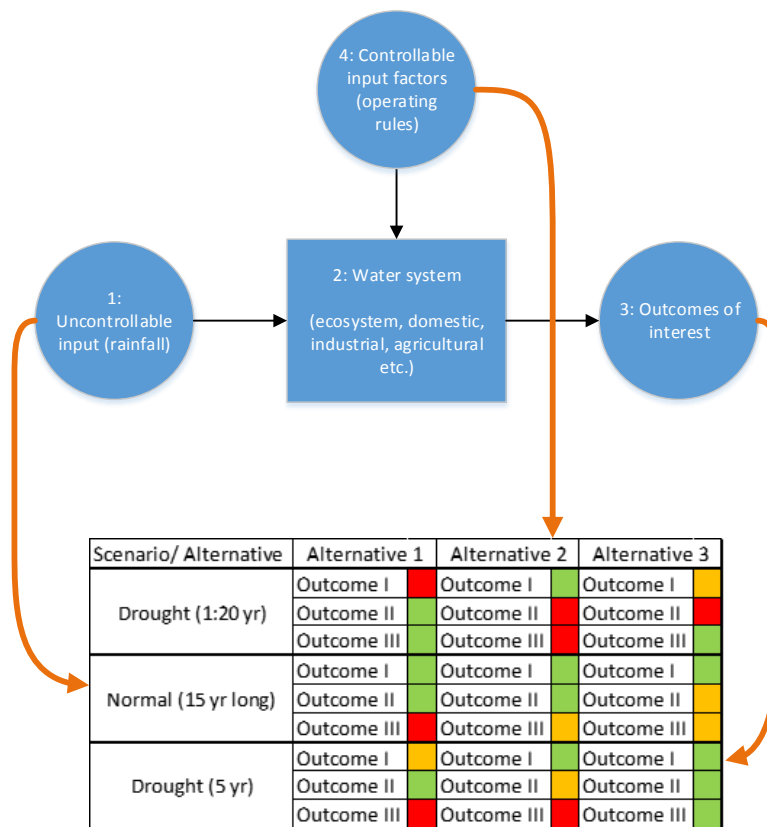


Figure 44: Transforming the data into scorecards

If during the modeling phase no consensus is formed on *structural uncertainty* and this uncertainty has a large impact on the outcomes of interest. The choice can be made to agree to disagree and create scorecards for both structures. Then the progress is ensured and interaction can take place. Because of the interaction there is more insight into the Policy Arena and the structural uncertainty can be addressed as an issue on its own, without holding up the process.

5.3.2.3 INTERACTIONS

The next step is the actual interactions with the actors. In Figure 45 this step is illustrated. On the left side the interactions are placed in the multi-actor perspective, it is the interaction between the policies and outcomes of

## 5 Design of intervention

interest with the actors in the Policy Arena. The right side of the image illustrates how the actual interaction takes place between the different actors and the scorecards. The actors can be engaged separately and be introduced to the process and water system (to a certain degree). The main interaction will be by means of ranking the different alternatives based on the outcomes of interest.

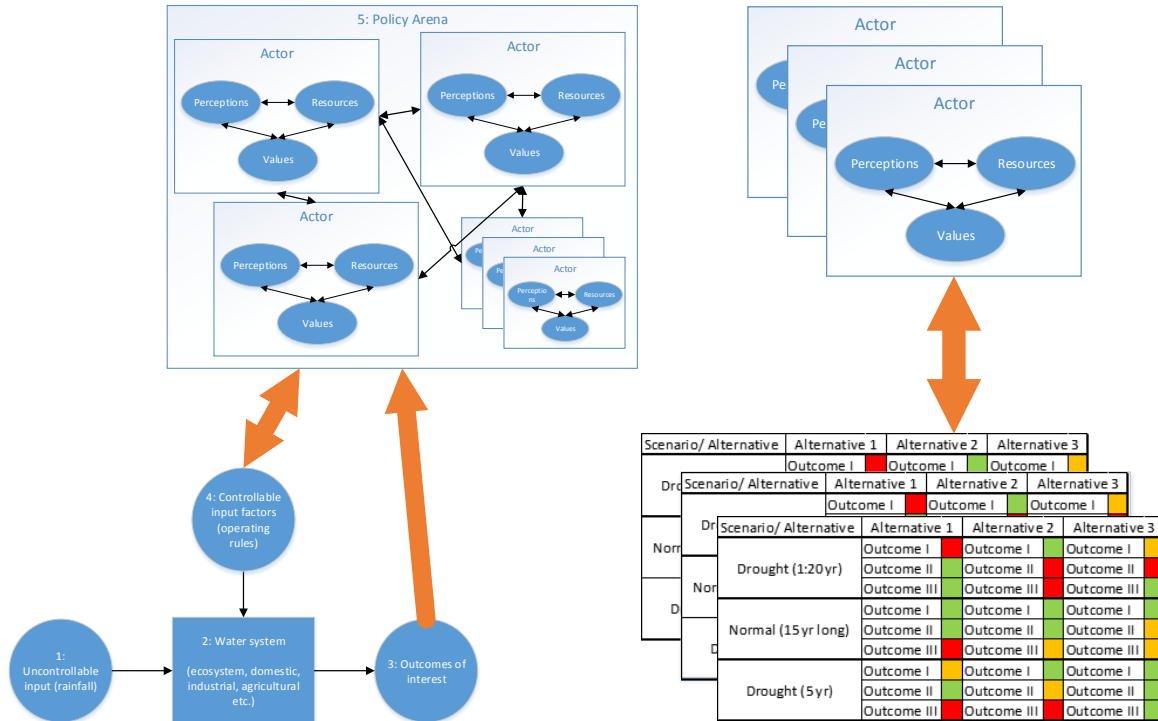


Figure 45: Where the interaction takes place (left) and how the interaction takes place (right)

The ranking will provide information about how the actors are valued. The interaction around the ranking process provides the actor with information on the water system, and the researcher on how the actor perceives the water system.

### 5.3.3 DETERMINING THE RWS AND SETTING THE OPERATING RULES

It is now up to the consultant or researchers to conclude the process by making use of the extra information that is acquired on the system. By using the knowledge of the different actors combined with the inputs from the Policy Arena and the extra insight that the modeling and simulation process has brought.

Although in this design I choose to keep the decision discretion at the hands of the consultant, I do think that the added information into the decision process will add on the objectives that have been set out at the beginning of this chapter.

### 5.3.4 REPEATING THE PROCESS

Adaptability in SESs is defined by Walker et al. as the capacity of actors in a system to influence the resilience of the SES (2004). The actors as a group generally act unintentional towards the SES, the basic resilience of the system will absorb most disturbances and the adaptability will be limited. In a ceteris paribus situation a clear limit to the

resilience can be identified. However, the process design makes use of changes in the adaptability that the precariousness can cause. By repeating the process of setting the operating rules based on the values of the actors in the system links the changing willingness to increase or decrease adaptability with the actual decisions on adaptability. Figure 46 shows the negative feedback loop that makes use of the link between the state of the ecosystem and willingness to change adaptability. The repeated process of assessing values of the stakeholders therefore raises the resilience of the ecosystem.

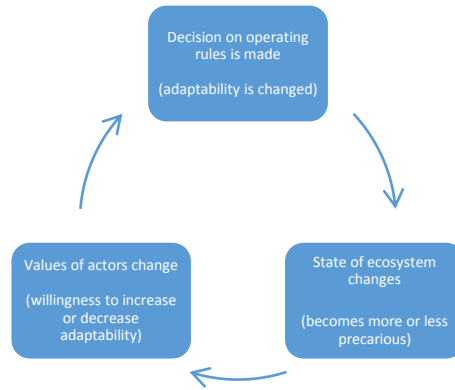


Figure 46: Link between setting of operating rules, state of ecosystem and willingness to change the adaptability

#### 5.4 CONCLUSIONS ON DESIGN OF THE INTERVENTION

To summarize the conclusions on the designing of the intervention are the following:

- There is a distinction between the goals of the RWS and the objectives for the process of setting the operating rules.
- The goals of an RWS are to support sustainability, equity and efficiency.
- The objectives for the process of setting operating rule is to help in the determination of RWSs that serve their goals better. These objectives therefore relates to improving the process for determining an RWS.

Using the literature of Policy Analysis, Citizen Participation and Participatory Systems Design the following objective for the process for determining an RWS is formulated:

*Support decision-making regarding regional water schemes and their operating rules by adding higher transparency and representation, making it more valid and ensuring progress without excessive costs*

The terms in the objectives have been elaborated on in this chapter and first trade-offs have been made clear. Unfortunately most of the objectives are not directly measurable and therefore estimations and pairwise comparison on the different objectives shall be used to evaluate the design to the current situation.

- It is chosen to use a model as a boundary object, since boundary objects can be used for dealing with heterogeneous work from many different actors with different viewpoints and boundary objects help in generalizing findings, so it is sensible to other viewpoints (Leigh Star & Griesemer, 1989).
- It was chosen to use System Dynamics as a modeling technique. Functional requirements, problem characteristics and availability of data have been taken into account. ABM did show very promising applicability, this however is not chosen, since at this stage the System Dynamics modeling technique models with more ease at a high abstraction level.
- It was chosen to adopt an interview based modeling approach. The individual interviews will provide insight and will allow me as a researcher to see the different expert groups at their convenience and in their own environment.

The current process for determining an RWS has been mapped into the information flows and is illustrated in Figure 47. There is limited interaction between the Policy Arena and the process for determining the water scheme. Mainly because the information isn't accessible and difficult to comprehend for all actors.

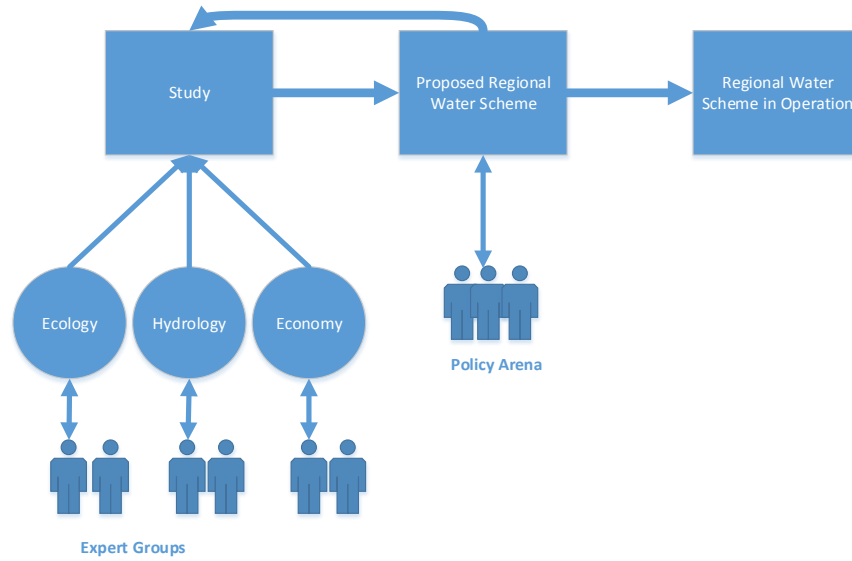


Figure 47: Current Process for determining an RWS

Therefore the proposed process in Figure 48 includes interactions between the higher abstraction level knowledge of the experts and engages the actors in the Policy Arena by means of translation into scorecards. The process supports the decision-making process by adding onto the following aspects:

- Transparency: the model assumptions, variables and outcomes can be made public for insight.
- Representation: more actors within the Policy are enabled to voice their values.
- Valid: the model includes interactions between disciplines and can be validated by the domain experts.
- Progress: in the design of the process progress was important and therefore safeguards have been built in. However it is difficult to say whether progress can be ensured.
- Cost: this process is unfortunately more expensive than the current decision-making process. An experiment will help in assessing how much higher the cost would be. The costs and benefits for the environment and actors in the Policy Arena is even more difficult to assess.

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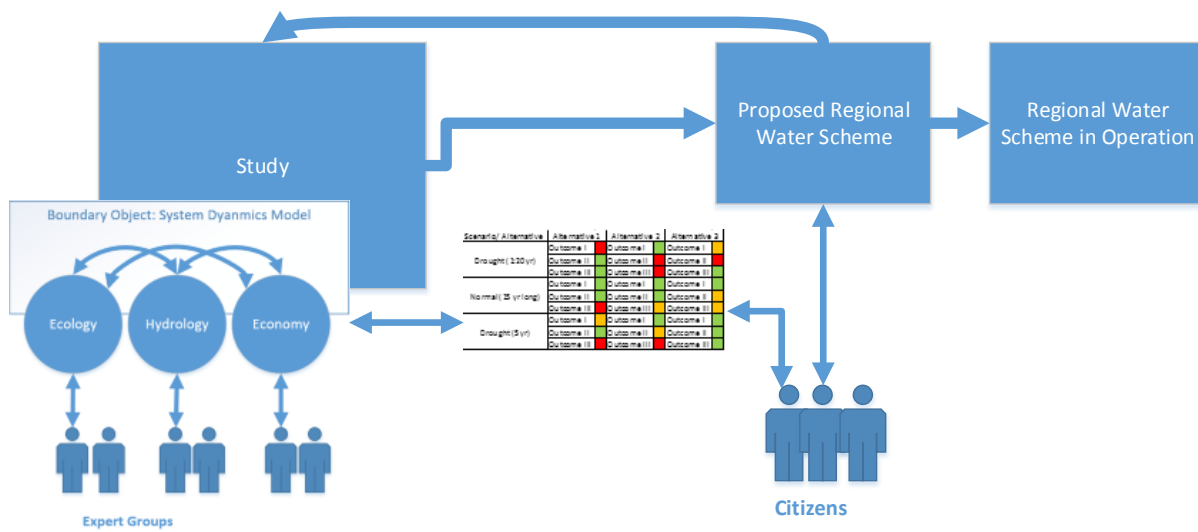


Figure 48: Process Design including the Boundary Object

This chapter can be concluded with the answering of **research question 4: Which design can improve the decision-making on water management in South Africa?**

The design of a System Dynamics model used as a Boundary Object to facilitate communication amongst different groups can improve the decision making in South Africa.

This is yet to be validated in the next chapter by answering the next research question.



## 6 VALIDATION

This chapter concerns the validation of the designed intervention. This will be done according to the validation steps that have been set out in the methodology as part of answering research question three. In the methodology the following three validation questions were raised:

Validation 1: Can the specified System Dynamics model be validated?

Validation 2: Can the model be validated to function as a Boundary Object?

Validation 3: Can the design improve the decision-making process for determining a Regional Water Scheme?

The following paragraphs will answer each of the three levels of validation in the above order.

### 6.1 CAN THE SPECIFIED SYSTEM DYNAMICS MODEL BE VALIDATED?

The validation of a System Dynamics model is answering the following question: is the model adequate, acceptable, sufficient representation of the real system with respect to the problem purpose?

*“No model can claim absolute objectivity, for every model carries in it the modeler’s worldview. **Models are not true or false, but lie in a continuum of usefulness**” (Barlas & Carpenter, 1990).*

There is therefore the validity of an SD model is different for different uses of the model, since the validity depends on the purpose for which the model is used. In the case for this thesis the purpose of the model could be formulated as: to provide insight into the system by integrating knowledge of sub-systems into a common quantitative simulation model retaining the characteristics and behavior of the different sub-systems. The created model should be adequate, acceptable and sufficient with respect to that purpose.

Both the model **structure** as well as the model **behavior** will be subject to several validity tests. With the structural validity is tested whether the structure of the model together with the model equations are adequate representations of the real world system. The equations are compared to available (expert) knowledge and theories on the real system. The validity of the model behavior is validated by looking at the model output. Whether the model generated behavior patterns are close enough to the real system behavior patterns and whether this behavior is caused for the right reasons.

First the different expert validation sessions will be presented and then validity tests done by the modeler self are summarized in the following table:

Date	First Name	Last Name	Field	Validation information
9-5-2014	Louis	Celliers	Ecologist	The model can be valid for cities the size of Mossel Bay, but less for the large cities such as Cape Town, or Durban, since these differ in their approach for water management.
29-5-2014	Stephen	Mallory	Hydrologist	The model can still be valid for its high level purpose even when the pipelines and canals are not explicitly modeled.
13-6-2014	Nick	Fourie	Government	The actions of the regional agricultural board do not seem to hurt the validity of the high level model, which only gives monthly water distribution factors.
23-6-2014	Stephen	Mallory	Hydrologist	The evaporation and rainfall functions would add to the model. They (almost) cancel each other out on a yearly basis, however can make a difference on a monthly scale. If they are not in the model Stephen Mallory argues it does not hurt the models validity on the current level of modeling.
27-6-2014	Barry	Clark	Ecologist	The non-linear effects are essential to the models validity (and they are included). The models that Barry Clark develops go into more detail on the

## 6 Validation

				ecological scale, however take a lot of time and expertise to develop and are (thus far) not being simulated on a continuous base.
30-6-2014	Piet	Huizinga		<p>The flooding of the estuary is of great importance to the people living in the estuary mouth. Piet Huizinga studied the estuary of Great Brak extensively and argues that the flooding is very difficult to implement in the model, since prevention is based on strategic breaching and water outlets based on tacit knowledge and weather predictions. The occurrence of flooding can be seen as exogenous to the problem that is being modeled and therefore the exclusion of flooding does not harm the validity of the model.</p> <p>There was a session on the breaching of the mouth of the estuary and a valid mental model of the breaching was constructed. However it depended too much on discrete choices by the operators to be included into the model. To mitigate this a function is derived from the yearly water supplied to the estuary to predict a percentage of time that the mouth is opened, assuming good estuarine management.</p> <p>The structure that was chosen by the modeler is of lower detail than Piet Huizinga would have liked, however the parts that are put in can be seen as valid for this purpose.</p>
30-6-2014	Susan	Taljaard	Water Quality	<p>The estuarine ecology and water quality parameters are amongst others dependent on the opening and closing of the mouth and the timing of opening. The session resulted into model structures that would validly represent the fish population and water quality. The model structures were mostly based on the mouth opening and closing.</p> <p>During the session it became apparent that fish and water quality in the model for the experts to consider it as a valid representation of the ecosystem.</p>
30-6-2014	Lara	van Niekerk	Ecologist	
3-7-2014	Dick	Naidoo	Government	Validated the sources of water that the municipality of Mossel Bay has access to. The boreholes, desalination plant and reclamation plant. The water coming from these sources is currently only being used for municipal use and consumption by PetroSA, which is consistent with the model.

During the sessions with stakeholders and experts it was validated that the model boundaries result in a valid representation of the modeled problem for the Great Brak. No essential loops or sub-models seem to have been left out. A provision is made to include the rainfall and evaporation functions when data becomes available. Without rainfall and evaporation included the model can however still be regarded as valid in its boundaries.

The conformation of the different variables, functions and parameters can be found in Appendix D. Most variables and stocks have real world units as dimensions and have ranges of values that have been derived from theories or estimations, which are referenced to. A scan for numerical errors is presented in Appendix H. In this scan no numerical errors have been found present.

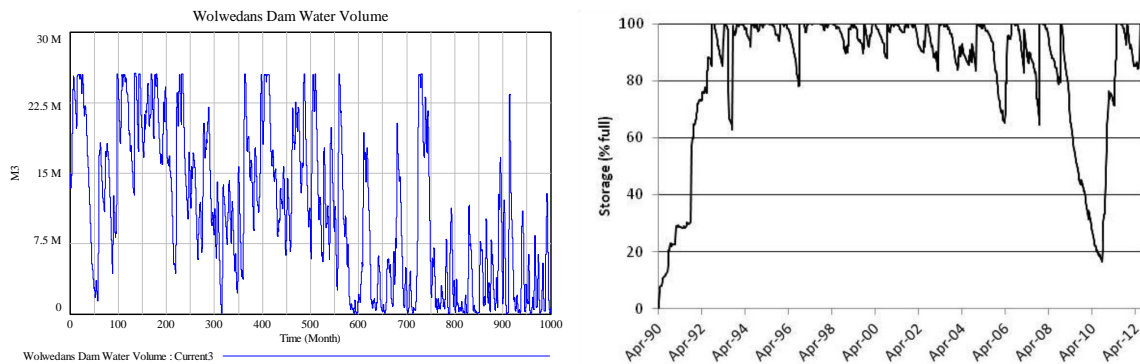


Figure 49: Model outcome dam water level (left) compared to historical dam water level (right)

The model behavioral outcomes can be validated by comparing the model generated dam level over time with the historically available data. Figure 49 shows this comparison. The behavior can be considered valid, as we see comparable dam behavior. For example the dam level cannot exceed the capacity of the dam, since the dam would overflow at this point. In the model it is validated that when the dam level exceeds the dam capacity an overflow into the estuary occurs. The mass balance of water is maintained over the simulated time period.

The specified System Dynamics model can be concluded to be valid for most of its purpose. It produced universally identifiable outcomes by combining high level knowledge from different disciplines. For the ecosystem in the estuary and the dynamics of the opening and closing of the mouth it can be argued that the level of detail at which the model produces outcomes is insufficient. During workshop sessions it became clear that the experts in question would like to have that included. However, for the sake of correctness of the model behavior this is purposefully kept out at this point of model development. The ecosystem is represented by a function that increases and decreases its health responding to the water that is supplied and its demand for water, which is determined by its current state of health. In my view the model still fulfills its purpose at this abstraction level for the ecosystem. Therewith the model can be regarded as valid. In the most basic sense of its purpose that is.

**6.2 CAN THE MODEL BE VALIDATED TO FUNCTION AS A BOUNDARY OBJECT?**

To validate whether the model can function as a boundary object, first is referred to how the boundary object is used in terms of the theoretical lenses paragraph on boundary objects (page 50). This leads me to three questions that could validate whether the model did function as a boundary object:

1. Is the model both adaptable to multiple viewpoints and robust enough to maintain identity across them? (Leigh Star & Griesemer, 1989, p. 387)
2. Is the model capable of having different meanings in different social worlds but is its structure common enough in more than one world to make it recognizable; a means of translation (Leigh Star & Griesemer, 1989, p. 393)
3. Does the model allow different groups to work together without consensus? (Star, 2010, p. 602)

To answer the first two questions: the System Dynamics model makes use of causal structures and maps these by using differential equations via a visual modeling interface. If the model is run it produces data over time for each of the variables in the model. The data can then be presented in any of the many ways the modeler finds fit. The reason why I'm mentioning these aspects is to illustrate the adaptability of the interactions with the user. In the most extreme cases:

- The expert is a modeler as well, then the interactions could take place modeling in Vensim;
- The actor is not numeric, then the data can be transformed a color coded to let the actor express its values by ranking the different alternatives (Figure 50).

Scenario/ Alternative	Alternative 1	Alternative 2	Alternative 3
Drought (1:20yr)	Outcome I	Outcome I	Outcome I
	Outcome II	Outcome II	Outcome II
	Outcome III	Outcome III	Outcome III
Normal (15yr long)	Outcome I	Outcome I	Outcome I
	Outcome II	Outcome II	Outcome II
	Outcome III	Outcome III	Outcome III
Drought (5yr)	Outcome I	Outcome I	Outcome I
	Outcome II	Outcome II	Outcome II
	Outcome III	Outcome III	Outcome III

Figure 50: Adaptation of model to be non-numeric

## 6 Validation

There are many different possibilities in between, an example is the modeling sessions that has been done at CSIR Stellenbosch on the 30<sup>th</sup> of June with Piet Huizinga, Susan Taljaard and Lara van Niekerk. They are experts on the estuarine system on the water management practices, water quality and ecosystem. Although they had little experience in modeling a quantitative dynamic system, they did know all about the causal structure that is the basis for the model (Figure 51). The model as a boundary object adapted, took shape of causal structures to enable different viewpoint to contribute, whilst retaining identity across them (it remained a water system model).

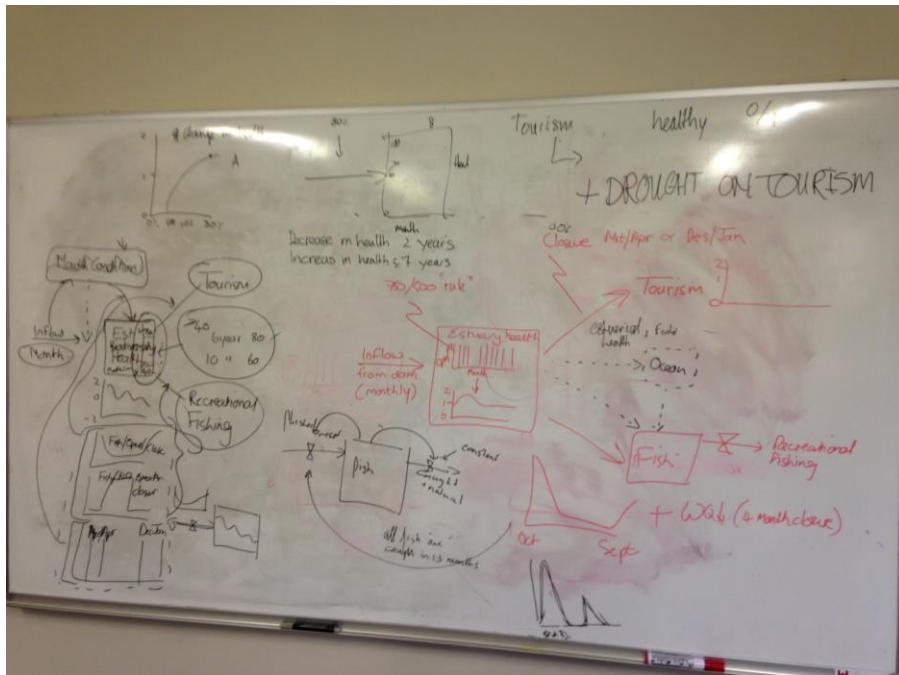


Figure 51: Whiteboard used during the collaborative modeling session with Huizinga, Taljaard and van Niekerk

The third characteristic of a boundary object is: it allows different groups to work together without consensus. There are manners in which the model can work together without consensus.

Most importantly, there does not have to be consensus on the value that is attached to the prioritizing of the water demands. This might seem trivial, since the process is aimed at getting these values from the citizens, however it therefore is important that the boundary object is least affected by these values as possible. The actual ranking occurs outside of the model, based on model outcomes that are not affected by the valuing.

However there can also be a lack of consensus on the structure of the model (and this could even be value related). In the previous chapter this was described as structural uncertainty (paragraph 5.3.1 on page 73). If such a disagreement occurs the model is able to deal with this. First it should be explored whether the structural uncertainty significantly influences model outcomes. If not the disagreement does not hinder the objectivity of the model and it does not require consensus to function. If the structural uncertainty does influence the model outcomes significantly then outcomes can be produced for the different structures. The process can continue and the disagreement can be upheld. There are several options with multiple structures in place: the modeler can try to identify robust solutions, having a good effect on both the structures; the ranking can be performed over a combined outcome space (ranking on the robustness) or multiple outcome spaces. The latter one can be done if the dispute has potential to be solved (by for example a research).

The model does provide options to allow different groups to work together without consensus. It doesn't sweep the consensus under the carpet, but it exposes it and provides different options to dealing with it. In my view both the exposing and the dealing with it are important in allowing groups to work without consensus.

The three characteristics of a Boundary Object have been fulfilled. Therewith for this research the model can be seen as a valid option for use as a boundary object in the South African water sector.

### 6.3 CAN THE DESIGN IMPROVE THE DECISION-MAKING PROCESS FOR DETERMINING A REGIONAL WATER SCHEME?

To validate that the design improves the decision-making process the cycle of determining a regional water scheme should be walked through completely. At this point the first steps of the process have been carried out successfully, adding knowledge over the boundaries of different expertise groups. This has been elucidated in the previous paragraphs. The System Dynamics model can be seen as valid and the model was functioning as a boundary object over the boundaries of multiple disciplines.

There are indications that the design improves the decision-making process. Firstly, the interactions between different expert groups can be improved by the design. Secondly, the dynamic quantitative modeling assists in gaining insight in the behavior of the system over time and over an uncertainty space. Thirdly, it is expected that the design will improve the interactions with citizen, allowing the citizens to contribute their values on the different alternatives by means of ranking based on understandable outcomes of interest.

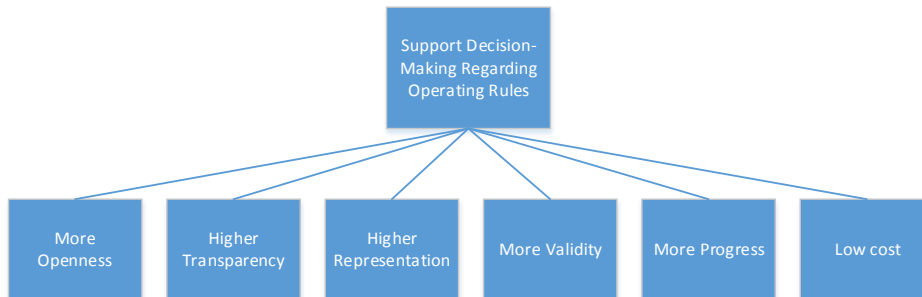


Figure 52: Objective tree for the design

The design of the intervention started by defining the mission/objectives for the design to fulfill. Figure 52 is a reprint of the objectives that have been defined at the start of the design. The objectives have been used to design the intervention towards. Taking into account that only the first steps of the decision-making cycle have been completed only validity and transparency are able to be validated that the design has a positive effect on these objectives. For the objectives openness, representation, progress and cost further testing is required.

This can already be seen as an improvement of the decision-making process. The ambition of the design however, is formulated over the whole decision-making process rather than just the first part. It could be that the proposed design is ineffective at further stages of the process and it is undesirable to implement.

For example, the interactions with citizens to express their beliefs and values on model outcomes. Has not been carried out in the course of this research. It is untested whether the participation in this process is genuinely well-informed, open and accessible to all layers and groups in society. The main pillars that are still to be validated are the following:

## 6 Validation

- The translation of the model outcomes into a non-numerical colored scale is proposed. However this conversion and the scale is yet to be validated. Questions are whether it is a valid representation of the data and whether the citizens can make a sensible choice that represents their values by using the translation.
- The experience that the citizens have in interacting with the scorecards. Questions that should be answered is: are the users able to recognize the system and express their values by using the scorecards? Do the citizens feel heard or recognize the deliberative process when engaged via this process?
- The usefulness of the gathered information on the system (via the simulation study) and the values of the stakeholders in the system (via the deliberation and interactions) for the decision-maker or the decision-making process. This should be validated with the persons that normally would be managing the process.

Therefore it is concluded that the impact of the design on the decision-making process cannot be validated at this stage. The research that is required to validate this is outside of the scope of this research project. In the next chapter, conclusions and recommendations this limited validation is discussed further, both in terms of implications as well as recommended future research.

### 6.4 ANSWERING RESEARCH QUESTION 5

Research question 5 can now be answered: Can the design be validated enough to speak of a proof-of-concept?

The System Dynamics model that has been developed in the course of this research project is found to be a valid model for its purpose. The concept of using a System Dynamics model as a boundary object in the South African context has been found to be a valid (working) concept. Finally, the impact on the decision-making process to Regional Water Schemes in South Africa is not validated within this research project. The design can improve the first steps of the process and for the further steps further validation is required. The further validation should focus on the translation of model outcomes, user experience and usefulness to the decision-makers.

## SECTION IV: CONCLUSIONS, RECOMMENDATIONS AND REFLECTION

## 7 CONCLUSIONS AND RECOMMENDATIONS

During this research the problem of coping with varying water supply in South Africa was explored. Research questions have been formulated and the sub-research questions have been answered. This chapter will summarize the main conclusions of made in the research, answer the main research question and provide recommendations for both future research and more general on the decision-making process to a Regional Water Scheme.

The following main research question will be answered by going through the conclusions on the sub-research questions:

### ***How does water management work in South Africa? And how can decision-making on water management be improved?***

1. What are the rules in form and the rules in use in South African water management?
2. What theoretical lenses can be used in designing an improved decision-making process for water management?
3. How can an improved decision-making process for water management be designed and validated?
4. Which design can improve the decision-making on water management in South Africa?
5. Can the design be validated enough to speak of a proof-of-concept?

Insight into the problem situation was enlarged by answering **sub-research question 1**: '*what are the rules in form and the rules in use in South African water management?*' In the analysis it is concluded that the rules in from have been under large reform since the democratic elections of 1994. The National Water Act (NWA) of 1998 has the most impact on the water system as scoped for this research. The NWA prescribes the formal institutions and processes.

It was found that new *rules in form* have yet to be converted into *rules in use*. This could be caused by the fact that the new processes and (the forming of) institutions that have been described in legislation lack progress. Practitioners use their discretionary leeway to cope with this discordance between *rules in use* and *rules in form*. Therefore a mixture between old and new rules exist.

It was found that the rule in use that is most related to the problem of coping with varying waters supply is the Regional Water Scheme. This brings together the human use, ecosystem use and resource availability by allocating water and setting conditional rationing schemes. There is a deep expertise on hydrology, ecology, water demand management and understanding at system level. This understanding is found in the many classification projects that are executed for the chief directorate of resource directed measures and have been reviewed during this research. However, the interactions that occur during the making of a Regional Water Scheme (RWS) are limited to mostly information exchanges between experts. There are many activities for taking stakeholders into account, however these activities are often informative or reactionary to stakeholders instead of there being deliberation or debate.

The current process for determining an RWS has been mapped into the information flows and is illustrated in Figure 53. There is limited interaction with the citizens the process for determining the water scheme. Mainly because the information isn't accessible and difficult to comprehend for all actors.



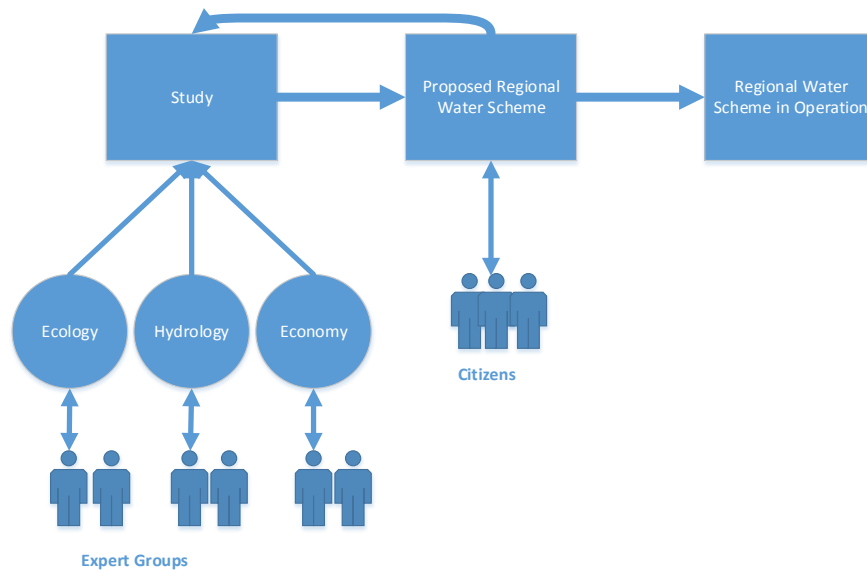


Figure 53: Current Process for determining an RWS

This analysis of the problem situation brought emphasis on the rules in use, specifically the process for setting a Regional Water Scheme. In this process the participation of citizens in a deliberative manner and the cooperation between experts across different disciplines are points that the research should focus on.

For answering **sub-research question 2**: ‘*what theoretical lenses can be used in designing an improved decision-making process for water management?*’ Theoretical lenses have been chosen that will be applied to provide insight in this research project. The theories of Policy Analysis, Social-Ecological Systems, Citizen Participation, Participatory Systems Design and Boundary Objects. The choice of lenses is influenced by both the problem situation and my personal background and experience. The application of the lenses will be made clear in the rest of this chapter.

The first application of the theoretical lenses was in answering **sub-question 3**: ‘*how can an improved decision-making process for water management be designed and validated?*’ For answering this question a design and validation plan is set up for a design of a process using a simulation model functioning as a Boundary Object for a specific, yet representative case. To support methodology the knowledge from Participatory Systems design is used together with methods from Policy Analysis. A validation plan is set up comprising of a three level validation: the level of the decision-making process, the functioning as boundary object and the simulation model.

System Dynamics has been chosen to model the boundary object in. The properties of System Dynamics -modeling quantitative at a high (strategic) level, able to simulate dynamic behavior over time with a white box structure- make System Dynamics the preferred modeling formalism.

The Mossel Bay region is chosen to act as the case study area to develop the boundary object and process specifically for. The designed objects have been designed to be generally applicable for other areas in South Africa as well. The region of Mossel Bay is chosen firstly, because it is an exemplar for many water regions in South Africa and secondly, because there is a lot of data available for the region.

To answer **sub-research question 4**: ‘*which design can improve the decision-making on water management in South Africa?*’ the steps as set out in the methodology are followed. First the objectives of the design are formulated. It is

## 7 Conclusions and recommendations

important to note that this objective is the objective of the design, which is different from the goals of the Regional Water Scheme (sustainability, efficiency and equity). In setting up the objective the theoretical lenses of Public Participation, Policy Analysis and Social-Ecological Systems have contributed. The objective is as follows:

***Support decision-making regarding regional water schemes and their operating rules by adding higher transparency and representation, making it more valid and ensuring progress without excessive costs.***

The design that has been created integrates the knowledge from the different expert groups into the simulation model. This simulation model serves as a means of communicating across disciplines making a basis for deliberation across experts. This is illustrated in Figure 54 below. The simulation model can allow citizens to partake in the deliberation by means of scorecards. The scorecards are composed by transforming the model outcomes into an understandable, non-numerical format for the citizens to express their views on. This allows the citizens to express their views based on outcomes that are generated over uncertainties through the structure set up by the experts together. The decision to select an RWS from the simulated and ranked alternatives remains to be the choice of the minister and will not be a hard outcome from the process. The choice however, can be made on a more informed and deliberated basis.

Having a Social-Ecological Systems lens it is recommended to repeat the decision-making process on a regular basis to increase the resilience of the system. It allows for an extra negative feedback loop that is outside of the Boundary Object, namely the values of the citizens and stakeholders. Based on the state of the ecosystem (precariousness) the willingness to invest in the ecosystem are likely to change (the willingness to increase adaptability). Installing this extra negative feedback loop will heighten the resilience of the Social-Ecological System.

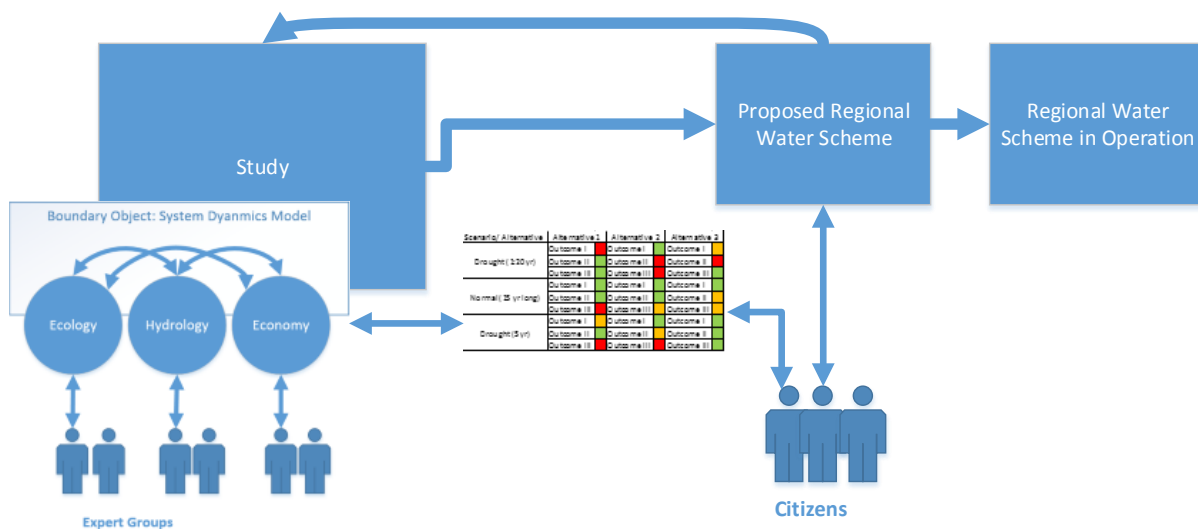


Figure 54: Process Design including the Boundary Object

The individual design choices have been made taking into account trade-offs on the objective criteria. This had to be done with rules of thumb expected effects of different alternatives. More testing will be recommended to gain more insight into the effects of the design choices. Using the rules of thumb and reasoning from the theoretical lenses the following can be said for the different objective criteria:

- Transparency will rise, since the model assumptions, variables and outcomes can be made public for insight. The scorecards and method for transformation will be documented and be public.
- Representation will rise, since the Boundary Object allows more actors within the Policy to voice their views in the decision-making process. The threshold for participation in terms of effort and knowledge is lowered.
- The validity of the decision-making process rises, since the dynamic quantitative modeling of the interacting subsystems is introduced. The model is documented and can be validated by different means and to different degrees of certainty.
- Progress: in the design of the process progress was important and therefore safeguards have been built in. However it is difficult to say whether progress can be ensured.
- Cost: this process is unfortunately more expensive than the current decision-making process. Further piloting will help in help in assessing how much higher the cost would be. The costs and benefits for the environment and actors in the Policy Arena is even more difficult to assess.

In answering **sub-research question 5**: *'can the design be validated enough to speak of a proof-of-concept?'* More is gone into the worth of these expected effects on the objective criteria. Findings from the validation are that firstly the System Dynamics models is found to be valid for the limited purpose it serves in this context. Secondly, the System Dynamics model was able to function as a Boundary Object and Finally that there is an indication that the design can improve the decision-making process. The main conclusions from these validation steps will shortly be elaborated:

**Validity of the model:** the System Dynamics model succeeded in representing the expert's knowledge at a high abstraction level. Experts recognize the causal structures and agree with the model boundaries. The sub-model for which this is questionable is the eco-system sub-model. During the interactions with the experts a discrepancy between the desired level of detail from the expert's point of view and the capabilities to model this into System Dynamics was not resolved. The ecosystem has been modeled in a highly abstract manner. This is valid at the most basic level, however it should be accepted by the expert group to be considered fully valid.

**The model as a Boundary Object:** the System Dynamics model is found to be validly working in functioning as a Boundary Object between expert groups. The model allows different expert groups to integrate their high level knowledge in a single model. It provides options to allow different groups to work together without consensus. It doesn't sweep the consensus under the carpet, but it exposes it and provides different options to dealing with it. In my view both the exposing and the dealing with it are important in allowing groups to work without consensus.

**Improvement to decision-making process:** the validity of the first two steps signify an improvement in the first steps of the decision-making process for a Regional Water Scheme. It could not be validated for the further stages of the process. The research that is required to validate this is outside of the scope of this research project. In recommendations this limited validation is discussed further, both in terms of implications as well as recommended future research.

The **main research question**: *'how does water management work in South Africa? And how can decision-making on water management be improved?'* Can now be answered. It first needs to be made clear that the answer to this research question is not exclusive. There is not one answer to this question.

The answering of this question led the research down a path of problem exploration, linking this with theoretical lenses, designing an intervention to the current situation and validating this design. At every step in the process choices have been made that influenced the direction of the outcome. Each of these choices closed of other paths of research and potential designs, or answers to the research question.

## 7 Conclusions and recommendations

The choices in this research have been motivated by arguments and observations. Criteria in these choices have been the potential for improvement and the fit between theories and the observed problem situation. However the choice is also determined by where is looked and what is asked.

The answer to the research question for this research is: water management in South African works as a network of coping water professionals coping with a difference between rules in use and new rules in form. The Regional Water Scheme is a regional set of agreements on allocation and rationing in droughts that is currently used. The decision-making process is multidisciplinary and should be deliberative. This can be improved by using a System Dynamics model as a Boundary Object in both the expert contribution as well as the citizen deliberation.

### 7.1 RECOMMENDATIONS

The recommendations can be made on three levels:

1. Related to the decision-making process for determining an RWS
2. Related to using a Boundary Object in the process
3. Related to the System Dynamics model or modeling of the specific systems in South Africa

The general recommendations will be mostly on the decision-making process, whereas the recommendations related to using a Boundary Object and the System Dynamics model are more found in the limitations and recommendations for future research.

#### **Value progress over rigor**

The changes to the National Water Act (NWA) in 1998 have been ambitious and set out for a system of water management of high value. In the currently observed system this quality and rigor component is found in the research reports. However the progress of the processes set out in the NWA has been low. In many cases the older processes are still in place to cope with the lack of progress for the new processes. Therefore it is recommended that the department of Water and Sanitation values progress of the processes over rigor in the processes. This implies lowering the standards for the content of the processes temporarily to ensure progress. This can later be heightened to the original ambitions. For now learning by doing might be a better strategy, rather than coping with a combination of old and new institutions.

#### **Invest in knowledge on a system level**

The observed expertise and knowledge was found mostly in the specific expertise groups. Only a limited amount of professionals seem to be involved at a system level. This research is an example of gaining knowledge on a system level that exceeds the boundaries of a single expertise, but rather integrates over boundaries of expertise.

#### **Keep the current level of transparency in research outcomes**

The reports that are made by different authors in the line of the classification projects or regional water schemes are all published and made publicly available online. This has been beneficial for this research and can be for many other projects. It is a recommendation to keep up this transparency in research outcomes

Besides the recommendations at the level of the decision-making process there are also limitations to the research and recommendations for future research. This will follow in the next two paragraphs.

## 7.2 LIMITATIONS

The limitations to the research, its design and the outcomes will be discussed in this paragraph.

### **The research focusses on the Regional Water Schemes**

The deliberate choice was made to embed the research process into the current practices, or the rules in use. However, as was shown in the analysis, the rules in use differ from the rules in form since 1998. The research is therefore focusing on outdated processes. It should therefore evolve with the rules in use that will eventually coincide more with the rules in form. The choice was made deliberately, to ensure that the design and research outcomes are applicable and usable in the real world system. Choosing applicability and fit with the current situation over the limitation of the potential misfit if the rules in use would have a swift shift.

### **The validation process hasn't been completed**

The validation process has not been completed for the decision-making process as a whole. This has been left out of the scope of this research project to keep the project feasible within the constraints of the graduation thesis.

### **Generalizability to non-metropolis regions**

It has only been tested for one specific area. This area has been chosen for several reasons, one of them being that it is a generalizable representative case. However, it is also an area with a lot of data available from previous studies and an area that is geographically very compact (the dam, users and ecosystem are close to each other). This made the specification of the System Dynamics model slightly easier. There are other systems that could be more difficult, such as long rivers with many offtakes, or including for example a mining user.

This however seems to me at this point to be difficulty that can be overcome. The model is able to deal with increased complexity that a longer river or different user group adds by taking with only the essential high level causal structures. Therefore I am confident it can be adapted to fit other regions that are no large cities such as Cape Town, Johannesburg, Pretoria or Durban.

### **Generalizability to large cities**

There are many indications to assume that process created in this research is not generalizable to large cities such as Cape Town, Johannesburg, Pretoria or Durban. The decision-making processes and institutions are different in these cities, than regions such as the Mossel Bay region. Therefore this study cannot be generalized to these regions. However, the concept of using a System Dynamics model as a Boundary Object might be very promising in these areas as well. The model should however be specified for each individual city and embedded in their specific institutions and processes.

## 7.3 FUTURE RESEARCH

The following research can be recommended as future research if interested in developing this design and the use of Boundary Objects in the decision-making process further.

The full validation of the design, including a full test walkthrough was outside of scope of this research project. Therefore the immediate future research would be validation of further steps. This can be divided into different topics that can be investigated in a single or in multiple researches. The following topics have been identified:

### **Translation of model outcomes to scorecards**

The translation of the model outcomes into a non-numerical colored scale is proposed. However this conversion and the scale is yet to be validated. Questions are whether it is a valid representation of the data and whether the citizens can make a sensible choice that represents their values by using the translation. There is experience with these types of translation within the classification projects that are undertaken. The project could benefit from the knowledge that has been gained there.

### **Citizen experience with scorecards**

The experience that the citizens have in interacting with the scorecards should be further researched. Questions that should be answered is: are the users able to recognize the system and express their values by using the scorecards? Do the citizens feel heard or recognize the deliberative process when engaged via this process? That the communication by means of scorecards can be successful is an underlying assumption for the success of the latter (not validated) part of the design. Therefore a future research into this is desirable.

### **The deliberative character of the designed process**

The usefulness of the gathered information on the system (via the simulation study) and the values of the stakeholders in the system (via the deliberation and interactions) for the decision-maker or the decision-making process. Together with the tension between the deliberative process and the decision-maker choosing a scheme. South Africa is striving to have a deliberative democracy, however it is still finding its way into reaching this ambition. Research into what the minister can do with the information gained in the course of the designed decision-making process and to what degree the choice of the minister fits a deliberative democracy remains vague.

### **Agricultural water usage**

During the specification of the System Dynamics model and in the many interviews and discussions that took place in the course of this research project one of the main uncertainties was the water use by upstream farmers. Farmers make use of offtakes that are not always monitored. For purposes of allocating the water it is recommended to research the actual use of farmers. Farmers have the potential to delay their water use for weeks or months with limited impacts to their yield and could therefore be important allies in coping with the varying water supply. It must be noted though that this is a highly political issue that requires sensitive research to not hinder the development of the deliberative decision-making process.

The topics that can be recommended for future research can be a nearly inexhaustible list. Therefore the topics above have been selected for significance and their link directly to this research project. Although the topics have been selected to fit this research will there are realistically some hurdles to be taken before the process as a whole can be tested. Examples of these hurdles are the fact that new researchers will have to take time to get in the problem situation. Research steps need to be reiterated in the follow up studies. For example, the model and process should be adjusted specifically to the case area in which the test will be performed. To partly mitigate this a paragraph on usability of the study has been included in the next paragraph. This paragraph is aimed at carrying the project forward after the master thesis presentation.

## 8 REFLECTIONS

To conclude the thesis this chapter sets out to reflect on different aspects of the research. Subjects that will be addressed are a reflection on the objectives, deliverables and relevance of the project and on the usability of the project outcomes.

### 8.1 REFLECTION ON OBJECTIVES, DELIVERABLES AND RELEVANCE

The main objective of this research is to improve the decision-making process for coping with dry spells in South Africa. This was divided into four parts and related to the four-layer model of Williamson. This model is illustrated once more in Figure 55 to help reflect on the objectives.

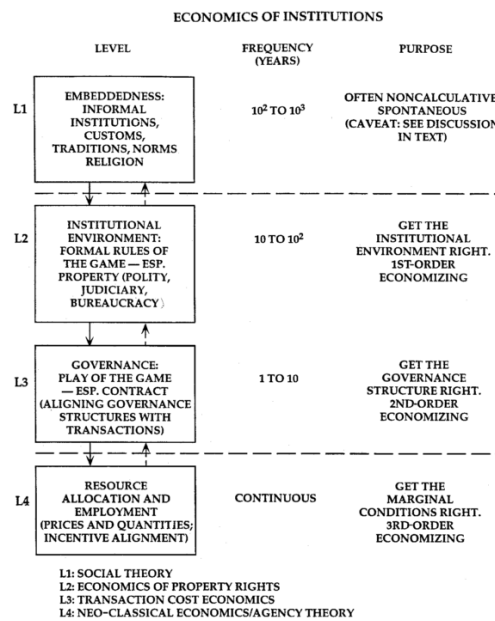


Figure 55: Four Level Model of Institutional Analysis by Williamson (1998, p. 23)

The first objective was to gain insight into the second level, the institutional environment can be seen as attained. It provided the insight that there is a difference between the institutions as rules in form, mainly the National Water Act form 1998 and the rules in use which are the current practices. This difference between rules in use and rules in form is due to a troublesome transition period in which the professionals working in the water sector cope with their best intentions to sustain progress in the decision-making.

The second objective was to gain insight into what the institutions in the second level lead to. This objective is attained by analyzing the concrete case of the decision-making regarding the Regional Water Scheme for the Mossel Bay Region.

The third and fourth objective were finding improvements and providing a proof-of-concept for this. The research has systematically worked towards improvements for the decision-making process and has succeeded in partially providing a proof-of-concept. Future research is required to fully attain this objective, however within the scope of the research project it is attained.

The project has succeeded in delivering the deliverables as set out in chapter one:

1. An analysis of the institutional environment for coping with dry spells.
2. An analysis into the practices for coping with dry spells in South Africa.
3. An analysis on how to improve the current decision-making process. This would be a problem analysis combined with a design space for improving the process.
4. The proof-of-concept for the proposed improvement. This will entail a design of the improvement and a proof-of-concept consisting of a limited amount of validation and testing of the designed improvement.

Noting that, again, the proof-of-concept is limited to the parts that have been tested in the scope of this research.

### Relevance

The dilemmas in allocating water amongst different groups is of great societal relevance in South Africa. Especially the deliberative character that South Africa has set its ambitions for is still developing. The research offers a new method for deliberately coming towards a Regional Water Scheme. This is clearly not the only method, but at this point it is relevant for South Africa to see into different ways of converting the decision-making processes into being in accordance with the ambitions the nation has set for itself.

The use of a model as a Boundary Object is an ongoing research topic in which methods and approaches are not yet developed. This research is relevant since it demonstrated a case of a model that has purposely been used as a Boundary Object.

## 8.2 USABILITY

In this chapter it is chosen to define the validity towards the usefulness of the model. Therefore it is important to reflect on the usability after handing the thesis is presented. This will go mostly into using the model as a Boundary Object, since this is the mostly likely essential part to be picked up.

For the continuation of using a model as a Boundary Object a skilled System Dynamics modeler is required to host the interactions and connect the disciplines through the model. However, in my research in the South African water sector I have not encountered System Dynamics modelers amongst the water sector professionals at for example CSIR. Therefore the development will have to come from an institution with skilled modelers. The TU Delft is an example of such an institution. Given the ongoing collaboration between the TU Delft and the CSIR there are however possibilities for this hurdle to be overcome.

From a Systems Engineering, Policy Analysis and Management point of view an interesting research topic. However, the actors actually in the decision-making process have little conception of System Dynamics or using a model as Boundary Object. Therefore the attention during this research project was largely at conveying the ideas and discussing the concepts.

To achieve this four (larger) presentations have been given and many one-on-one contacts have been aimed at explaining the objectives and the content of the studies. During these meetings interest has been shown in using a modeling approach in the South African context. Sometimes shifts occurred in which an audience of social science oriented water researchers went from having a negative standpoint towards modelers to a relatively positive standpoint.



To involve the South African water professionals more in the research project and make them more susceptible joining the research effort into using a model as a Boundary Object and email has been sent explaining the research that has taken place in South Africa and asking to respond on whether they would like to be further involved. Out of the 38 professionals that have been mailed 10 responded with an e-mail expressing their interest to being kept in the loop on further developments. Beside the e-mail responses 12 persons expressed their interest in to have the master thesis and scientific paper sent to them.

After the presentation of my master thesis these people will be informed by me as a researcher, providing them with a copy of this thesis, the scientific article and the contact details of the project coordinators of the cooperation between the TUDelft and CSIR. The question is now whether the seeds that have been planted across South Africa and the Netherlands will sprout: analyzing the water sector; systematically coming towards a design to improve the decision-making by using a model as a Boundary Object; validating the System Dynamics model; validating the functioning as a Boundary Object; assessing whether it would benefit the decision-making process and finally and perhaps most importantly conveying this to professionals that have the capabilities to further develop this.

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## APPENDIX A WOLWEDANS DAM INFORMATION AND DATA

The Wolwedans dam is a concrete dam near Mossel Bay, South-Africa. It collects water from the Great Brak river and has a catchment area of 192 km<sup>2</sup> (Mallory, Ballim, Pashkin, & Ntuli, 2012) can hold up to 25,5 million cubic meters of water. It mostly serves domestic and industrial users. Besides that the estuary houses a valued ecosystem which requires a certain amount of water.



Figure 56: Wolwedans dam in perspective to South-Africa (picture: Piet Huizinga)

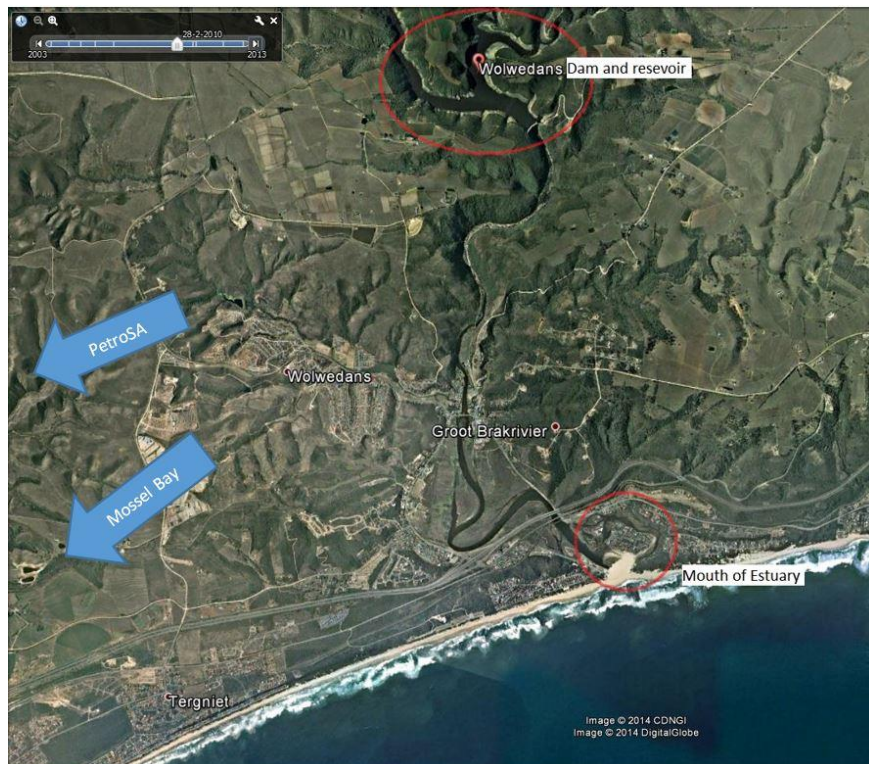


Figure 57: Aerial view of the environment of the Wolwedans dam



The construction of the Wolwedans dam was proposed in 1988 by G.C.D. Claassens, Director-General of Water Affairs with as main purpose to supply the intended Mossref gas processing plant near Mossel Bay with water (DG Water Affairs, 1988). Secondly the dam was also meant to make provisions for the increase in water demand of the Mossel Bay Municipality Area. The investments into the dam were shared between Mossref and the South African government (DG Water Affairs, 1988).

The average yield of the dam is enough to satisfy the needs of the ecosystem and the users together, however the region has to cope with floods and droughts. The water level has been recorded since the construction of the dam in 1990. This shows the scarcity of water that has occurred in 2010.

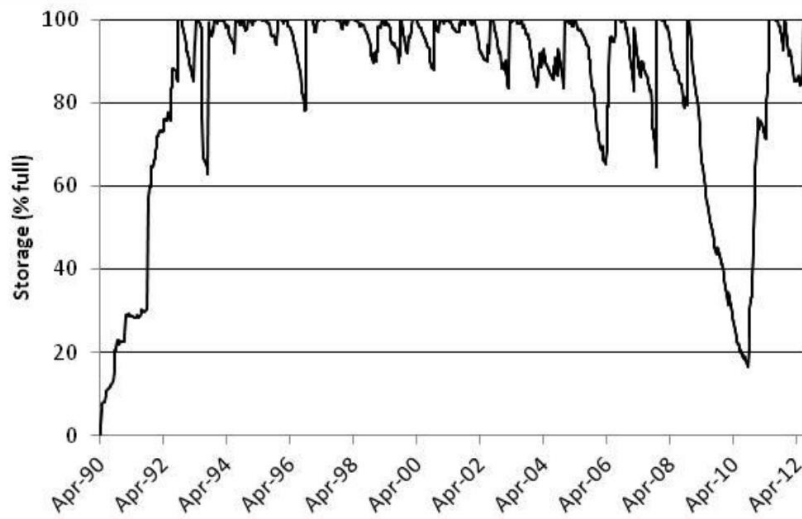


Figure 58: Historic water level in the Wolwedans reservoir (Mallory et al., 2012)

## Appendix B Oversight of Interactions during research in South Africa

## APPENDIX B OVERSIGHT OF INTERACTIONS DURING RESEARCH IN SOUTH AFRICA

Date	First Name	Last Name	Field	Purpose	Type of interaction
13-4-2014	Richard	Meissner	International Relations	Networking	Collegial Talk
13-4-2014	Nikki	Funke	Public Policy	Networking	Collegial Talk
13-4-2014	Elliot	Moyo	Antropologist	Networking	Collegial Talk
13-4-2014	Marius	Claassen	Ecologist	Networking	Collegial Talk
21-4-2014	Karen	Nortje	Antropologist	Networking	Collegial Talk
13-4-2014	Winile	Masangane	Student	Networking	Collegial Talk
22-4-2014	Stephen	Mallory	Hydrologist	Networking	Interview
28-4-2014	Eliot	Eliot	Antropologist	Gaining insight	Excursion
1-5-2014	Stephen	Mallory	Hydrologist	Networking	Interview
5-5-2014	Stephen	Mallory	Hydrologist	Gaining insight	Interview
8-4-2014	Peter	Besnard		Networking	Workshop Session
8-4-2014	Leon	Govender		Networking	Workshop Session
8-4-2014	Dimov	Ilces		Networking	Workshop Session
8-4-2014	Larry	Oellerman		Networking	Workshop Session
8-4-2014	Andrew	Pike	Water Law	Networking	Workshop Session
8-4-2014	Vijay	Reddy		Networking	Workshop Session
8-4-2014	Shaun	Ruggunan		Networking	Workshop Session
8-4-2014	Mariam	Khan		Networking	Workshop Session
8-4-2014	Ivan	Skoryk		Networking	Workshop Session
8-4-2014	Gavin	van der Meu		Networking	Workshop Session
8-4-2014	Vincent	Zulu		Networking	Workshop Session
8-4-2014	Brideggete	Zwane		Networking	Workshop Session
8-4-2014	Monoli	Mbele		Networking	Workshop Session
8-4-2014	Suren	Singh		Networking	Workshop Session
8-4-2014	S.	Ali		Networking	Workshop Session
9-5-2014	Louis	Celliers	Ecologist	Gaining insight	Introduction Meeting
22-5-2014			System Engineering	Networking	INCOSE South Africa
25-5-2014	Kyle	Harris	Ecologist	Gaining insight	Brunch
25-5-2014	Nicole	Kranz	Water Stewardship Advisor Germany	Gaining insight	Brunch
29-5-2014	Stephen	Mallory	Hydrologist	Gaining insight	Interview
2-6-2014	Hubert	Thompson	Water Law	Gaining insight	Interview
7-6-2014	Richard	Meissner	International Relations	Gaining insight	Excursion
13-6-2014	Nick	Fourie	Government	Gaining insight and Validation	Interview / excursion
19-6-2014	Hildrene	Venter	Citizen	Gaining insight	Interview
19-6-2014	Denise	de Wet	Citizen	Gaining insight	Interview
20-6-2014			Wolwedans Dam visit	Gaining insight	Excursion
23-6-2014	Stephen	Mallory	Hydrologist	Modeling	Interview
24-6-2014	Pierre	de Villier		Gaining insight	Interview

24-6-2014	Piet	Huizinga		Gaining insight	Interview
25-6-2014	Susan	Taljaard	Water Quality	Gaining insight	Interview
25-6-2014	Lara	van Niekerk	Ecologist	Gaining insight	Interview
27-6-2014	Barry	Clark	Ecologist	Gaining insight	Interview
27-6-2014	Erwin	Weidemann	Government	Gaining insight	Interview
30-6-2014	Piet	Huizinga		Modeling	Modeling Session
30-6-2014	Susan	Taljaard	Water Quality	Modeling	Modeling Session
30-6-2014	Lara	van Niekerk	Ecologist	Modeling	Modeling Session
30-6-2014	Andre	Theron		Validation	Presentation & Discussion
30-6-2014	Bafana	Gweba		Validation	Presentation & Discussion
30-6-2014	Cikizwa	Mbolambi		Validation	Presentation & Discussion
30-6-2014	Hellen	Mpe		Validation	Presentation & Discussion
30-6-2014	Christo	Rautenbach		Validation	Presentation & Discussion
30-6-2014	Roy	van Ballegooyen		Validation	Presentation & Discussion
30-6-2014	Marileen	Carstens		Validation	Presentation & Discussion
30-6-2014	Janine	Cunningham		Validation	Presentation & Discussion
30-6-2014	Susan	Taljaard		Validation	Presentation & Discussion
30-6-2014	Lara	van Niekerk		Validation	Presentation & Discussion
2-7-2014	Edith	Mertz	Ecologist	Gaining insight	Interview
3-7-2014	Altus	Eitner	Government	Gaining insight	Interview
3-7-2014	Dick	Naidoo	Government	Gaining insight	Interview
8-7-2014	Richard	Meissner	International Relations	Validation	Presentation & Discussion
8-7-2014	Nikki Funke	Funke	Public Policy	Validation	Presentation & Discussion
8-7-2014	Elliot	Moyo	Antropologist	Validation	Presentation & Discussion
8-7-2014	Marius	Claassen	Ecologist	Validation	Presentation & Discussion
8-7-2014	Karen	Nortje	Antropologist	Validation	Presentation & Discussion
8-7-2014	Winile	Masangane	Student	Validation	Presentation & Discussion
16-7-2014	Louiza	Duncker	Antropologist	Validation	Presentation & Discussion
16-7-2014	Zama	Nkuna	Researcher-HIE	Validation	Presentation & Discussion
16-7-2014	Ednah	Mamakwa	Candidate Researcher	Validation	Presentation & Discussion
16-7-2014	Maselanga nye	Matji	Manager	Validation	Presentation & Discussion
16-7-2014	Bongi	Maposa	Researcher Wash & Public Health	Validation	Presentation & Discussion
16-7-2014	Esther	Ngorima	Researcher Water Quality	Validation	Presentation & Discussion
16-7-2014	Philip	Page	Researcher Numerical modeller	Validation	Presentation & Discussion

## APPENDIX C INTERVIEW WITH HUBERT THOMPSON

**Date: 02-06-2014; Time: 09:00**

**Hubert Thompson was interviewed for his expertise on South African Water law. He is the author of the book: *Water Law: A Practical Approach to Resource Management and the Provision of Services*.**

The South African water law has Roman-Dutch origins. The legal principle of the laws are a combination of dominus fluminis (the water is owned by everyone) and riparian (you can have rights on water).

- In 1912 There was a National Water Act;
- In 1956 a new National Water Act was published to include industrial users;
- In 1998 the latest National Water Act was put in place. This still recognized many parts of the previous acts.

### **Rights to water**

- There are three different kinds of uses identified in South African law:
  1. Taking water from a body (river, basin, aquifer);
  2. Discharging waste water into a water body and;
  3. Storing water.
- These different uses are identified in section 21 & 22 of the water Act.

There are four types of authorization of water use

1. According to **schedule 1**: small volumes of water for e.g. domestic use by people living in the vicinity of a river).
2. Existing lawful water use: water-use which you were using and were entitled to before 1998 (section 32 & 34)
3. License: these can be individual or for a group. After application an investigation is done into the alternatives such as conservation and water cleaning. Section 41 sets the procedure, section 27 deals with the criteria.

**Resource Directed Measures (RDM)**: three attributes are determined:

1. The class of the rivers (section 12-17)
2. The resource quality objective
3. The reserve (the basic human need for water and aquatic requirements (EWR)).

If the water resource is under stress the minister can make the users reapply for licenses → **compulsory licenses** (section 43-48).

**General authorization** (section 39) can be given to certain users and uses.

When a **drought** occurs → schedule 3, item 6

The CMA can limit or prohibit by general admission or by individual letters to users.

### **Rationing of the domestic use of water**

- The total volume of water to the municipality is rationed
- The municipality can restrict by using their bylaws, which they have to publish and notice

- Examples of actions:
  - Only certain amount of water for a certain user.
  - Even house numbers can water on a certain day and uneven on another
  - Prices can go up (e.g. cheap on the first M<sup>3</sup> and then ascending prices.
  - Traffic police can enforce the bylaws

### **Agricultural rationing**

- No water to cash crops (seasonal crops)
- Minimum water to permanent crops (trees etc.) just so they won't die

### **Industrial rationing**

- Dependent on their importance in jobs, added value and dependence on water.

**Registration process:** it is difficult to see who uses what, therefore registration processes can be enforced to make people register (section 26 1c).

**Verification and validation** (section 35) can be executed to see whether users are within their right when consuming water.

**Water charges** (section 56-60) for using water. Varies from area to area, user to user and use to use.

### **Pricing strategy** (section 56)

- Price is not a condition in the license
- CMA may set prices according to the strategy
- Section 59 says that if you use water you should pay.

### **Institutions**

- DWA/S: Department of Water Affairs / Sanitation (name changed a week ago);
- Minister is the custodian (public trustee) and can:
  - Publish strategies (section 5-7);
  - Resource directed measures (boundaries) (section 12-17);
  - Regulation (general rules e.g. no mining close to rivers);
  - By establishing institutions (CMA's) (Section 26)
- There will be 9 CMA's formed (section 77-90)
  - *"Progress of the CMAs to date: six CMAs had been gazetted administratively, although these were not yet operational. Those six were, Crocodile (West) – Marico, Mvoti, Thukela, Usutu to Mhlataze, Gouritz and Olifants-Doorn. Two of the CMAs were operational, those being Inkomati (ICMA), established in 2004, and Breede-Overberg (BOCMA), established in 2005"*  
<http://www.pmq.org.za/report/20120306-department-agriculture-forestry-and-fisheries-their-strategic-plan-an>
- Mandate isn't at the CMA immediately, but needs to be transferred over time:
  - A CMA can develop a CMS (section 80)
  - Other functions need to be **delegated** (section 63) or **assigned** (section 72-73) by the minister to the CMA
  - **Delegate:** the CMA is **responsible**, however the minister still **accountable**
  - **Assigned:** the CMA is both **responsible and accountable**

Schedule 4 is on how the CMA and the minister interact, the internal operations and how the CMA is structured.

If a CMA is not operational or functional all powers vest with the minister.

**Water User Associations (WUA)** (section 91-98)

First (and still) there are Irrigation Boards which support self-regulation and have members looking after their own interest.

Unlike Irrigation Boards the WUA are for all water users. The Irrigation Boards are supposed to be replaced by WUA's. These can take management actions and can be erected everywhere but needs to be approved.

Now the minister sets and implements rules and policy → in the future the minister sets the rules and the CMA's execute them.

**Directors:** if you don't comply with the rules. The minister can fine you (section 53 & schedule 5 item 5).

**PAJA:** Promotion of Administrative Justice Act. Gives protection to the public from the ministers. This is a generic act that supervises not only the water sector.

APPENDIX D UNCERTAINTY RANGES/SPACE FOR SYSTEM DYNAMICS MODEL

The system dynamics model that is used in the study uses many variables. Some of these variables are quite certain, such as the capacity of the Wolwedans Dam. However other are more uncertain. This appendix lists the variables used and describes the value or uncertainty range that has been chosen.

Model variable	Description	Range	Units
Reduction of runoff by upstream trees etc. ( $Streamfl_{forrest}$ )	The amount of runoff that is reduced by forestry. Methods are available to assess this, currently the value is backwards engineered from a more extensive study (Mallory et al., 2013, pp. 4–3).	7500 - 9500	$\frac{m^3}{month}$
Rain on Wolwedans dam ( $rainWdf(t)$ )	Currently not in model (see Appendix E).	-	$\frac{m^3}{month}$
Evaporation from Wolwedans dam ( $evapWdf(t)$ )	Currently not in model (see Appendix E). In reality this should be a function of the water surface as well, however this has been kept out of the current model.	-	$\frac{m^3}{month}$
Runoff into Wolwedans dam ( $runoffWdf(t)$ )	The runoff into the Wolwedans dam is just downstream from the quaternary catchment area K20A. The time dependent function that is used is based on simulated runoff for the period 1920 to 2010. The unit for this is $m^3$ per unit of time (see Appendix E for more on the table functions).	0,01-27,22	$\frac{m^3}{month}$
Capacity of the Wolwedans dam ( $cap_{WD}$ )	The amount of million cubic meters of water can be contained in the dam at maximum capacity. This is found in (Mallory et al., 2013, pp. 3–2) and is relatively certain.	25,5	$m^3$
The population of the Mossel Bay municipality ( $x_2$ )	Information taken from the Census (Census, 2011)	89430	person
Birth rate of Mossel Bay ( $br_{mb}$ )	<i>Had difficulty finding accurate values, see migration for approach in this model.</i>	-	$\frac{person}{person * month}$
Death rate of Mossel Bay ( $dr_{mb}$ )	<i>Had difficulty finding accurate values, see migration for approach in this model.</i>	-	$\frac{person}{person * month}$
Net migration rate Mossel Bay ( $mr_{mb}$ )	Since little data was found on birth, death and migration rates the growth over ten years has been used to calculate a net growth rate for the three combined (Census, 2001 & 2011).	0,00187	$\frac{person}{person * month}$
The average staying time for tourists ( $astt$ )	An estimate for the average time that tourists stay on their holiday in the area. No data was found on this, so an estimate is used.	0,10 - 1	month
The average amount of tourists in Mossel Bay region ( $at_{mn}$ )	The average amount of tourists that are staying. This value is multiplied by the seasonal impact function to get to how many tourists would normally arrive. No data was found on this, so an estimate is used.	15.000-25.000	person
Average demand for water per person per month ( $dpp$ ).	The average water demand per person in the Mossel Bay region. The basic reserve component is 25 liters per person per day (0,75 cubic meters per person per month) (DWA, 2013). The UN states 50 liter per person per day is required (1,5 cubic meters per person per month) and Germany uses 122 liter per person per day (3,6 cubic meters per person per month) (Institute Water for Africa, 2014).	0,75 – 3,5	$\frac{m^3}{person * month}$
The surface of the forest area upstream of the Wolwedans Dam ( $Surface_{forrest}$ )	It is found that this is 28,8 square kilometer (Mallory et al., 2013, pp. 4–3).	28,8	$km^2$
A streamflow reduction per square kilometer constant ( $sfr_{forrest}$ )	This is deducted from a deeper study into this (Mallory et al., 2013, pp. 4–3). That study used the 2006 streamflow reduction curves generated by ACRU (Smithers & Schulze, 1995).	8622	$\frac{m^3}{km^2 * month}$
The estuarine health ( $x_4$ )	This is an arbitrary indicator for estuarine health. This should be validated with the ecologists so that it captures the main behavior that the estuary would exhibit given the water supplied. There should always be a translation step by experts to make sense of this value.	0-2	Dimensionless

Appendix D Uncertainty Ranges/Space for System Dynamics Model

The maximum health the estuary can have ( $health_{max}$ )	The maximum value for the indicator for estuarine health.	2	Dimensionless
The time over which an increase in health is spread ( $delay_{healthincrease}$ )	The time the estuary needs to recover its health from being without water for a certain period. This value needs to be calibrated using experts and data on the estuary.	48 - 250	month
The time over which a decrease in health is spread ( $delay_{healthdecrease}$ )	The time the estuary will take to decrease in health when being supplied less than is required. This value needs to be calibrated using experts and data on the estuary.	5 - 40	month
Recovery time of tourist opinion on flood ( $delay_{raqb}$ )	The time that the effects of a low water quality or flood diminishes for tourists. This is an estimate that should be validated.	12 - 60	month
Duration of effect flooding ( $duration_{flood}$ )	The duration a flood has a negative effect on a community. This is an estimate that should be validated.	12	month
Variable for flood in estuary ( $flood_{overflow}$ )	A flood occurs if the water level in the estuary rises. The water level is dependent on the amount of water in the estuary. In goes: overflow, water served, rainfall and (some) runoff and out goes water into the sea. In this case the variable is only measured using a certain overflow of the dam. It provides a reasonable estimation for floods.	750.000	$\frac{m^3}{month}$
The demand of the PetroSA GTL plant ( $demand_{petrosa}$ )	PetroSA has an allocation of 5,6 million m <sup>3</sup> /annum from the Wolwedans Dam. This is being used fully in recent years (Mallory et al., 2013, pp. 4–2)	460.000	$\frac{m^3}{month}$
The total amount of land available for agriculture upstream ( $ta_{au}$ )	Estimate – no reliable data available to me at this time. The area, consumption per square kilometer have been reversed engineered from the consumption figures.	100.000	km <sup>2</sup>
Total area of agricultural land upstream ( $x_8$ )	Estimate – no reliable data available to me at this time. The area, consumption per square kilometer have been reversed engineered from the consumption figures.	10000	km <sup>2</sup>
Delay to construct or abolish agricultural land ( $delay_{agri}$ )	Delay for farmers to respond to a change in the situation of water management. This is an estimate that needs validation.	36-60	month
The average consumption of water for crops ( $consumption_{crops}$ )	Estimate – no reliable data available to me at this time. The area, consumption per square kilometer have been reversed engineered from the consumption figures.	5	$\frac{m^3}{km^2 * month}$
$tippingpointattr_{au}$	The point in which farmers really start to get appalled by the water shortages. This is an estimate that needs validation.	0,7 - 0,9	Dimensionless
$maxattr_{au}$	The maximum value for the indicator for attractiveness of agriculture upstream.	2	Dimensionless



## APPENDIX E TABLE FUNCTIONS IN SYSTEM DYNAMICS MODEL

This appendix the table functions that have been used in the System Dynamics model will be briefly introduced.

$runoffWdf(t)$ : Table function to determine the runoff into the Wolwedans dam. This function is based on (simulated) hydrological data over a period from 1920 to 2010 (see appendix A). In Figure 59 the table function is presented as a graph. For  $rainWdf(t)$  &  $evapWdf(t)$  similar graphs will be used as input. However these are presently not yet made available.

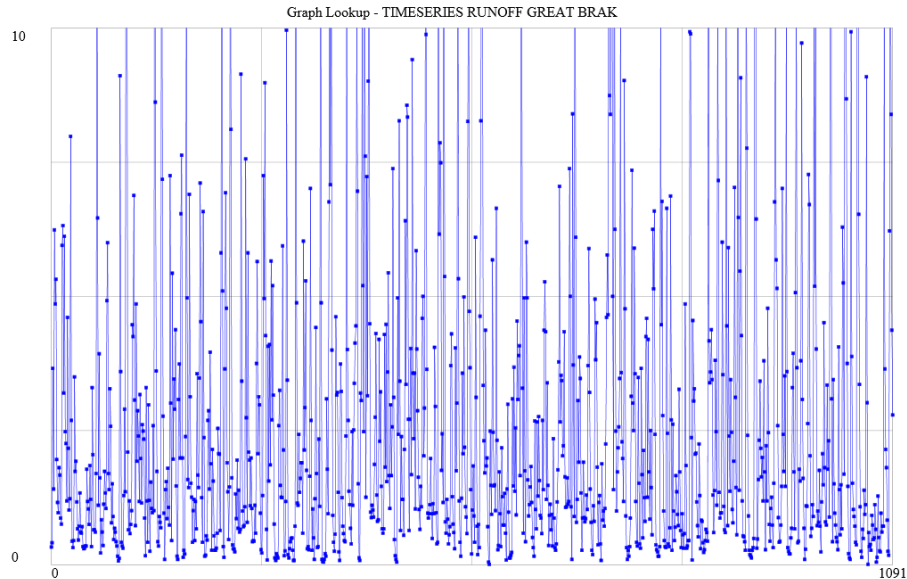


Figure 59: Table function runoff into Wolwedans dam

$touristf(t)$ : Table function to determine the number of tourists over time. This function is added to account for the different seasons of the year regarding the number of tourists that reside in Mossel Bay. Since a large share of the water is used by tourists this is added. The function is based on a study by Soer (2005) on tourism in South Africa. In Figure 60 the table function is presented as a graph. The x-axis (time) has a maximum of 12 in which each number represents a month from January to December.

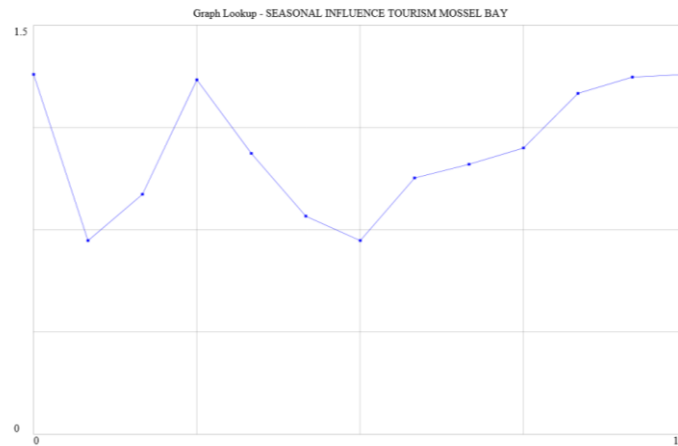


Figure 60: Table function for tourists over time

$waterrequiredf(x_4)$ : Table function for the water required for the estuary based on the current level of health of the estuary. This is based on the expert session that was held at Stellenbosch together with personal correspondence with Jill Slinger. This function might be debatable and could be a good candidate for testing multiple table functions against each other. In Figure 61 the table function is presented in a graph. At normal health (a value of 1 on the x-axis) the requirement will be set at 800.000 cubic meters per annum. At low health this will increase to 1.100.0000 cubic meters per annum and at high health 600.000 cubic meters per annum. The assumption hereby is that a healthy estuary is less ‘thirsty’ than an unhealthy estuary is.

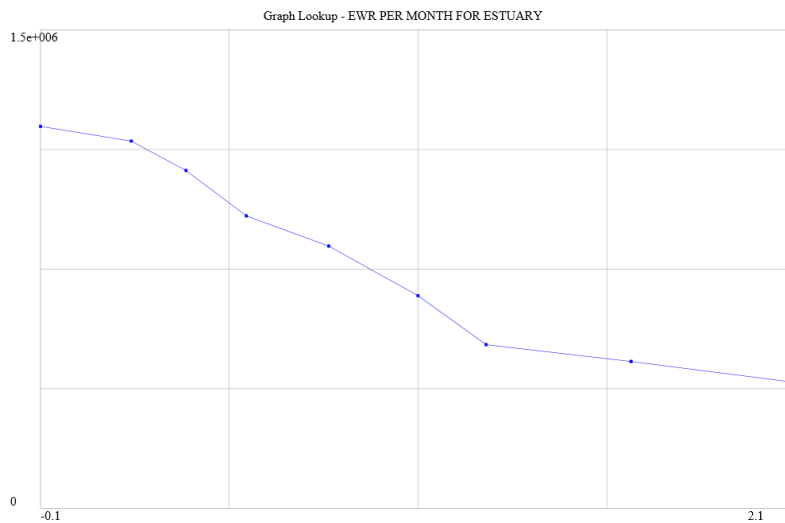


Figure 61: Table function for water required for estuary over estuarine health

$effect_{wqt}f(x_4)$ : Table function for the effect that a low water quality in the estuary has on the attractiveness to tourists. The effect only occurs when the estuarine health gets below 1 and will especially start having an effect if it gets below 0,5. In Figure 62 the table function is presented in a graph.

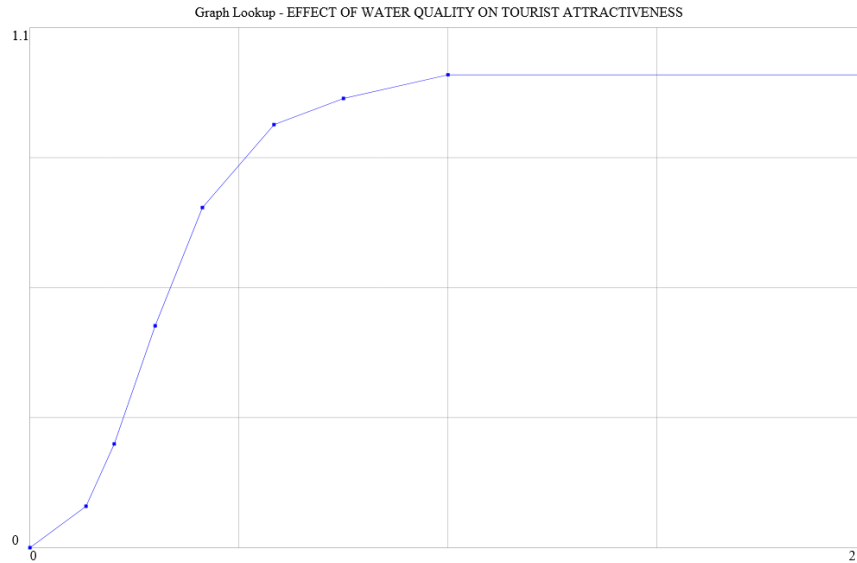


Figure 62: Table function for the effect of water quality on the attractiveness for tourists

$operating_{petrosa}f(x_7)$ : Table function to determine the level of operation at PetroSA depending on the fraction of its demand that is being met. Since PetroSA operates three units that can be switched on or off the operating level will have three levels as well. In Figure 63 the table function is presented in a graph.

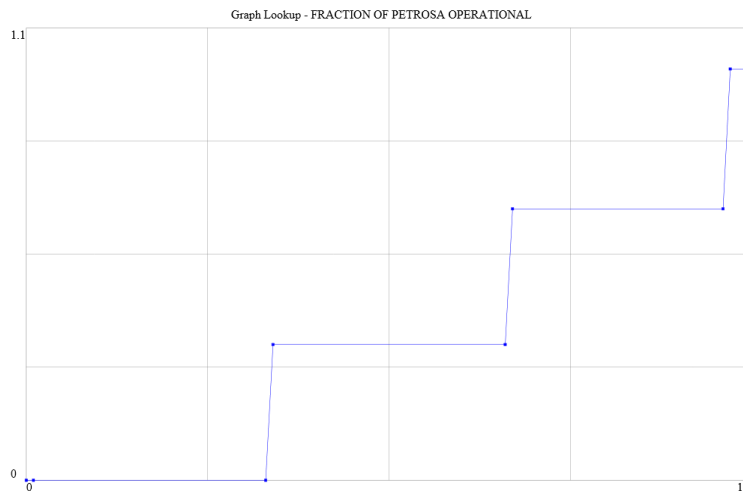


Figure 63: Table function for the level of operating at PetroSA depending on the fraction of demand for water supplied.

*irrigationf(t)*: Table function to account for the seasonal variation in the demand for irrigation for agriculture. At this moment this is just an estimate that should be further evaluated and validated by experts from the region.

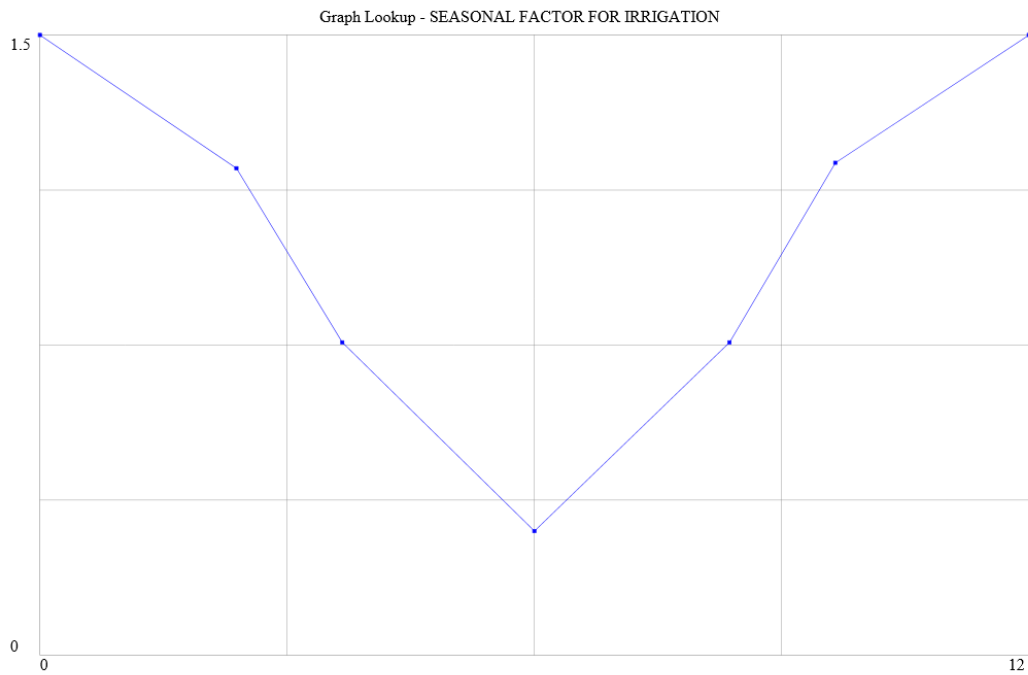


Figure 64: Table function for the seasonal influence on irrigation water requirements

APPENDIX F SUB-MODELS IN VENSIM

The following images show the structure of the model as implemented in Vensim.

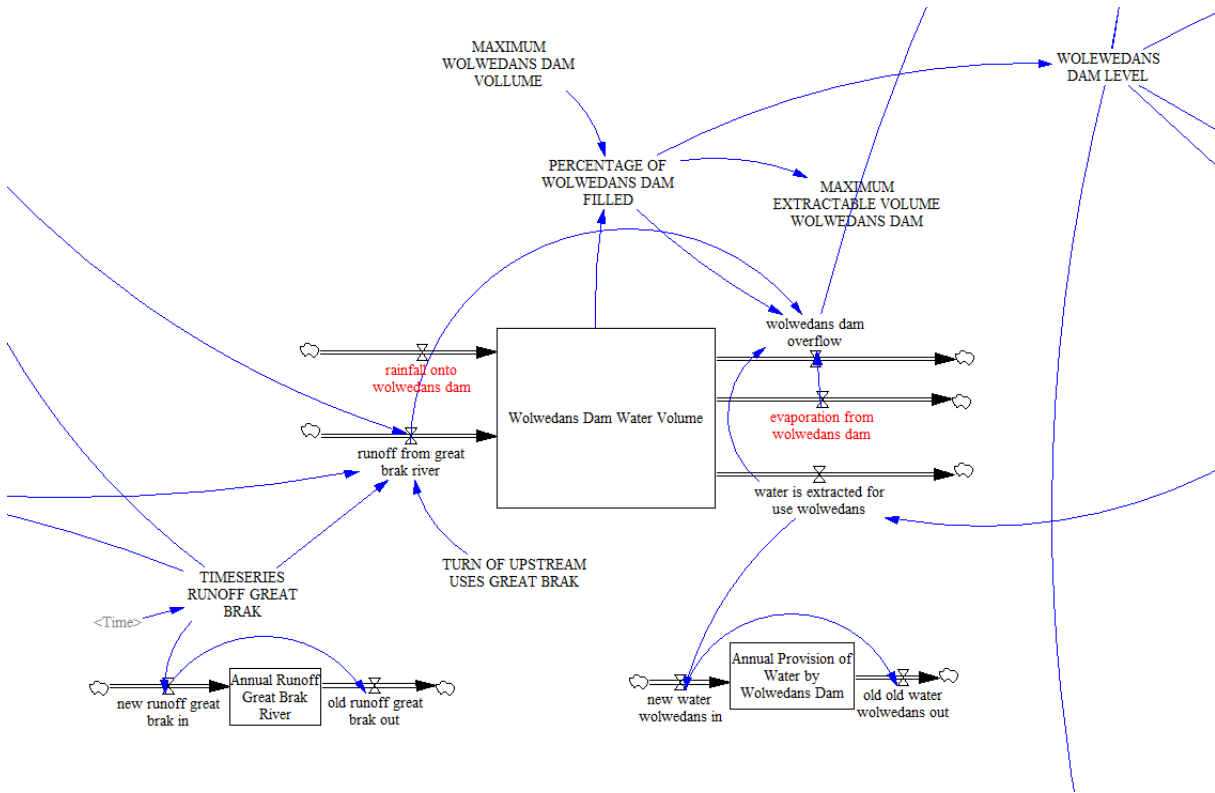


Figure 65: Wolwedans Dam Sub-Model

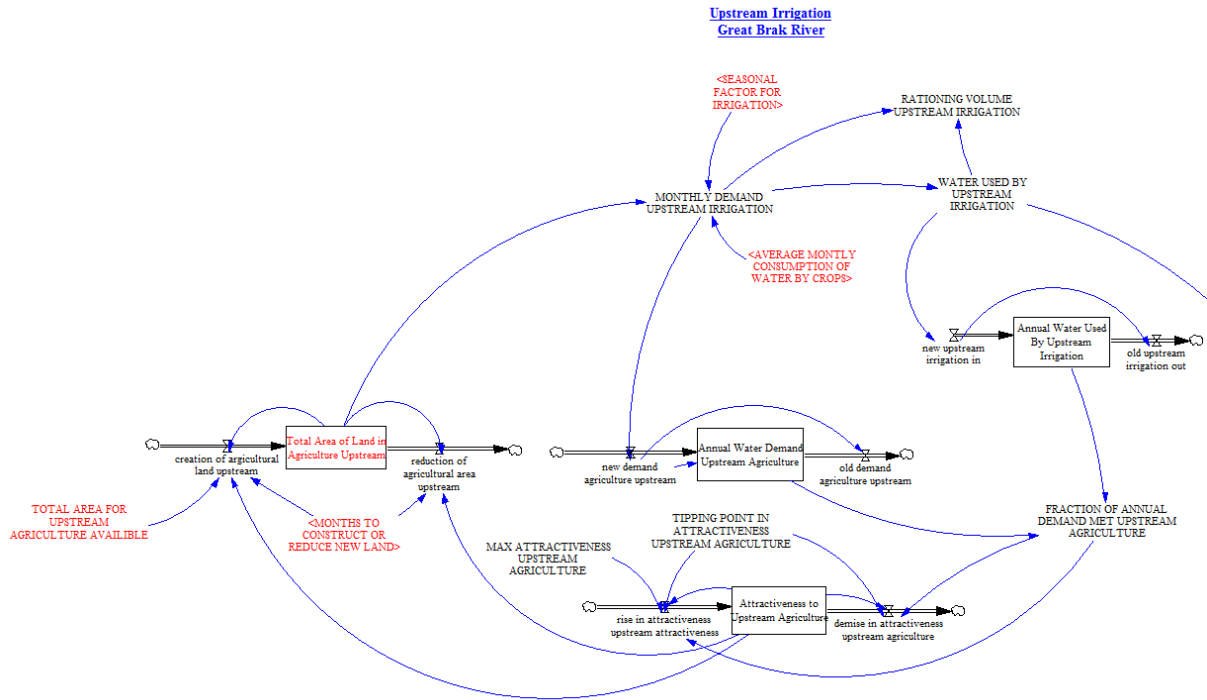


Figure 66: Upstream Agriculture Sub-Model

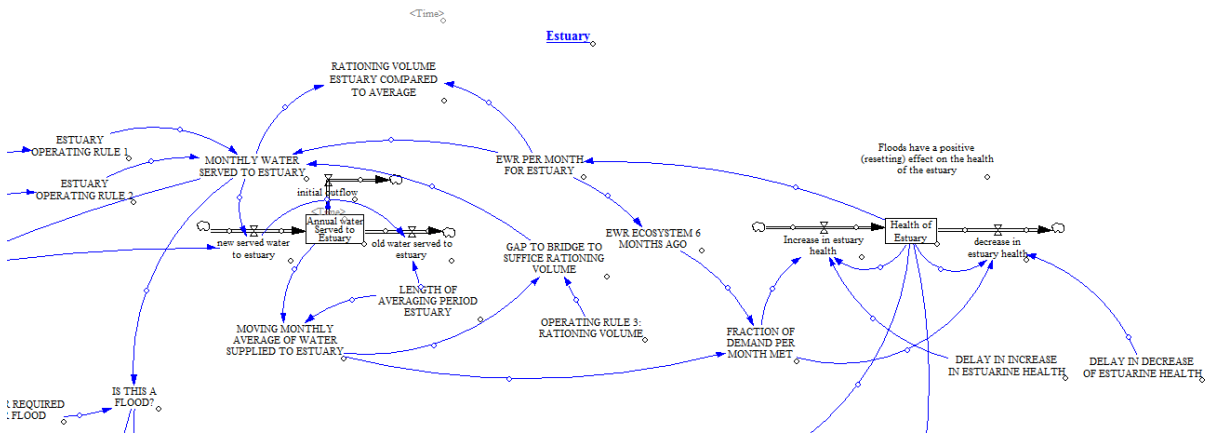


Figure 67: Great Break Estuary Sub-Model

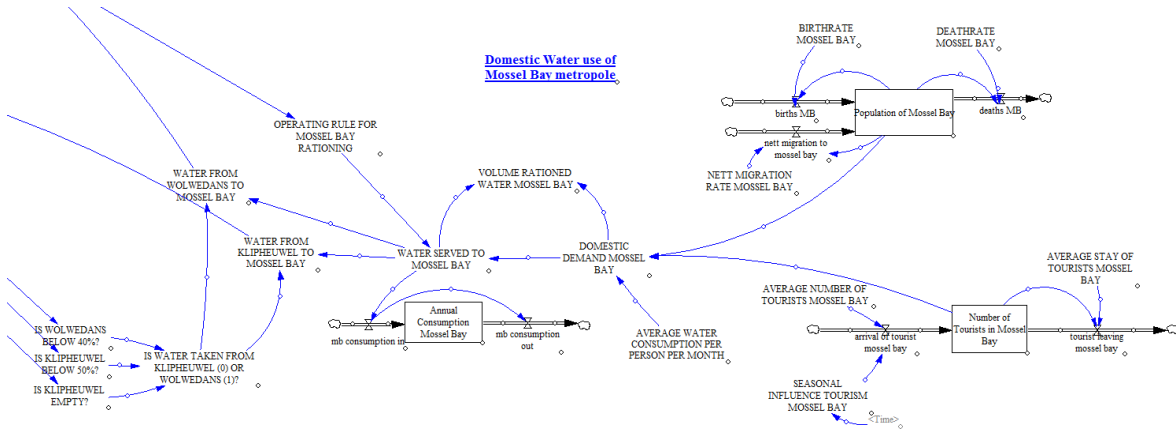


Figure 68: Municipality of Mossel Bay Sub-Model

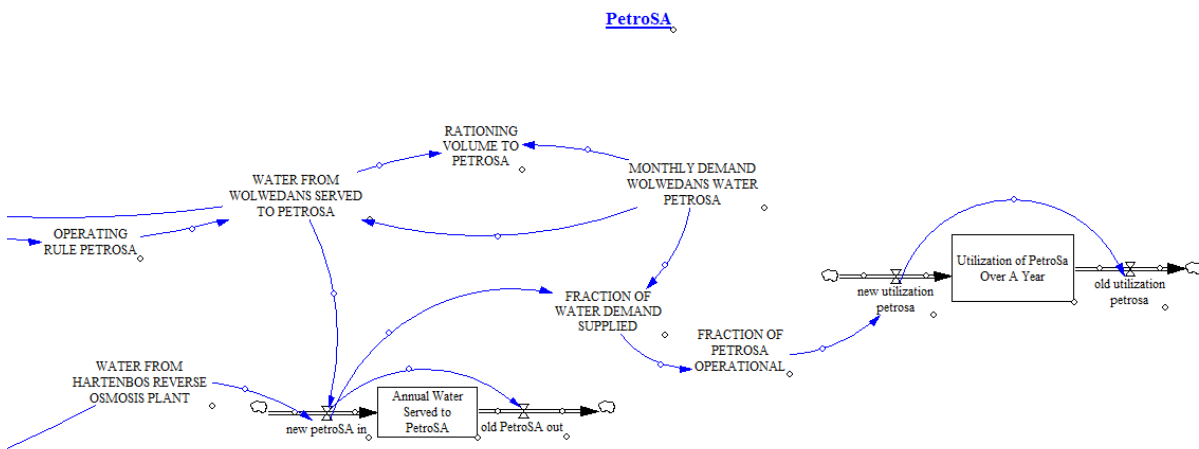


Figure 69: PetroSA Sub-Model

APPENDIX G EXAMPLE MODEL RESULTS

The following graphs show the exemplary model results. Since this article was mostly about the use of the model as a Boundary Object rather than the model results or validity of the model the graphs are left unexplained in this article. For more information contact the researcher.

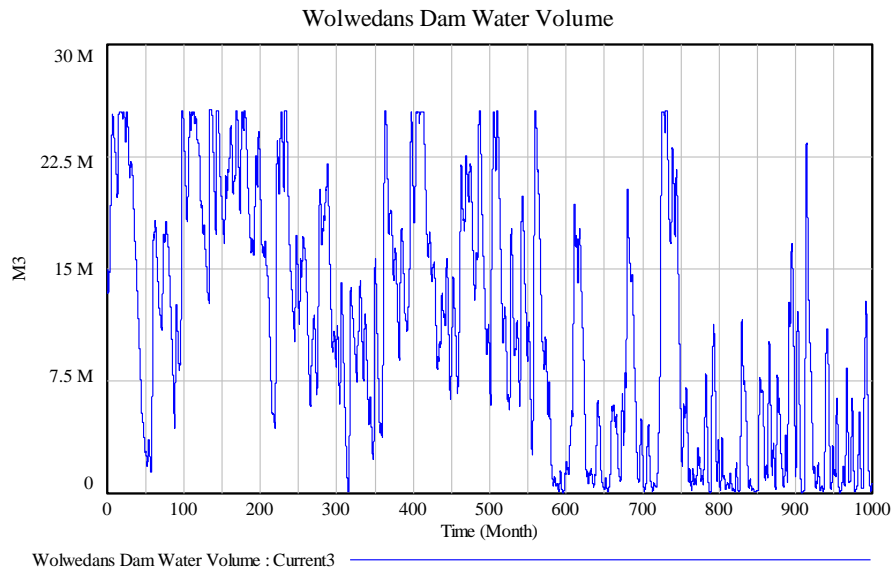


Figure 70: Graph of a Single Run for the Wolwedans Dam Water Volume

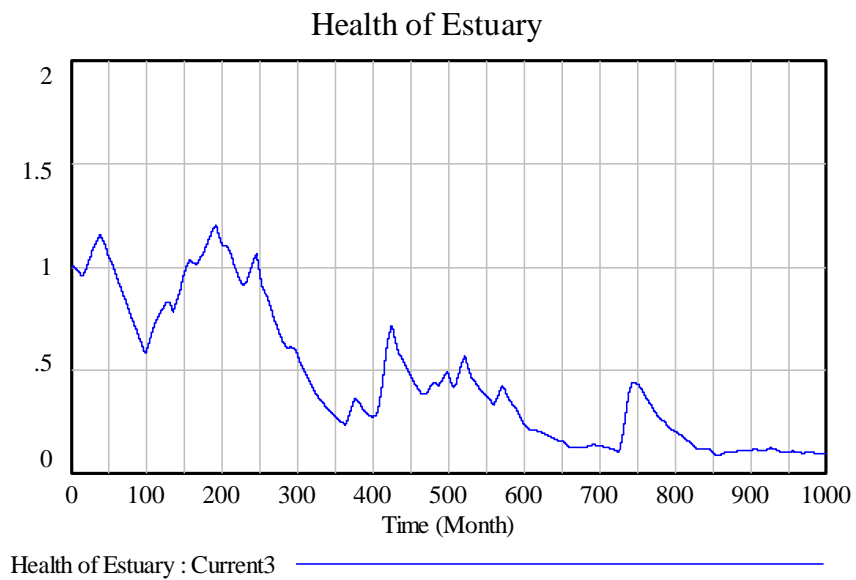


Figure 71: Graph of a Single Run for the Great Brak Estuary Health



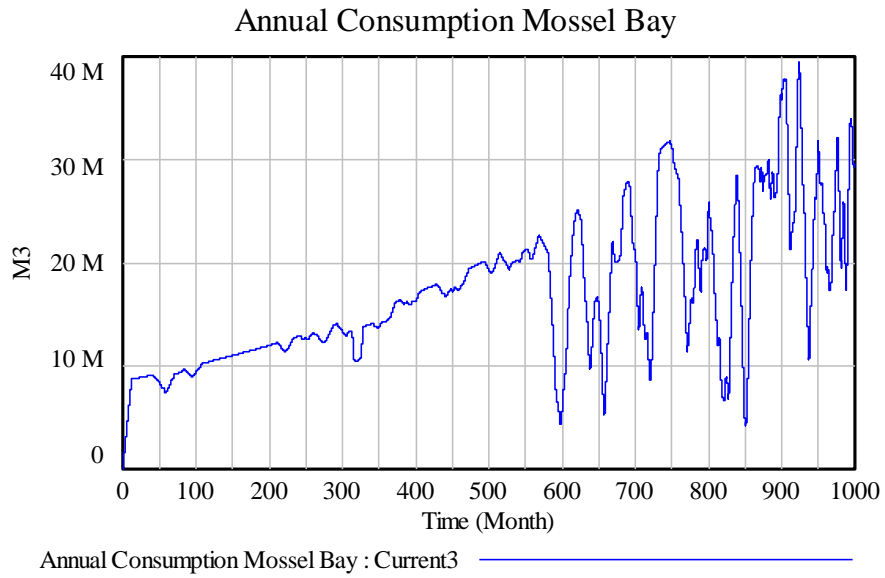


Figure 72: Graph of a Single Run for the Consumption by the Mossel Bay Municipality

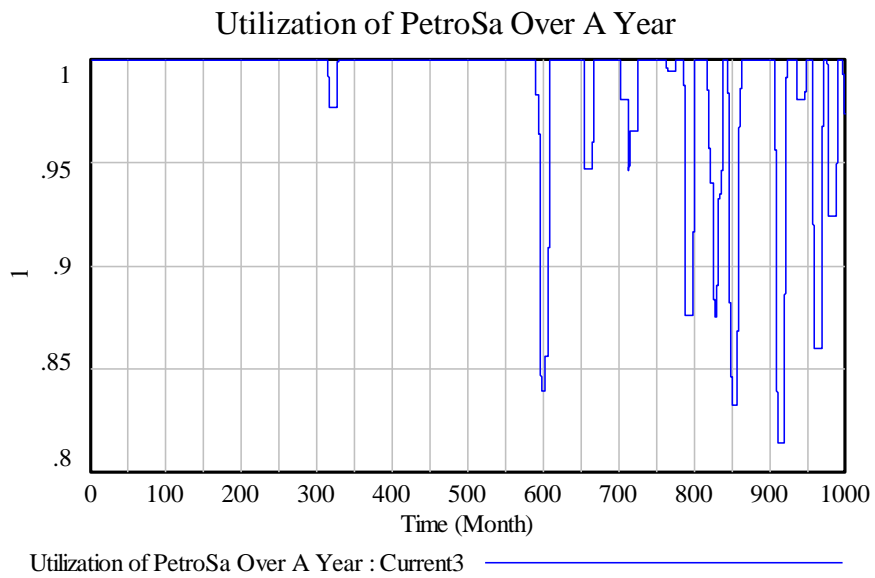


Figure 73: Graph of a Single Run for the Utilization of PetroSA over a year

APPENDIX H VERIFICATION OF EULER METHOD FOR SYSTEM DYNAMICS MODEL

A small test was performed changing the time step of the Euler integrator method for solving the differential equations. If changing the time step would cause different model behavior that would be a problem. In Figure 74 test results on a running average created in the model has been done. It did not show deviation for the time steps under 1. Therefore no clues were found that the Euler integration method is not coping with the discrete input.

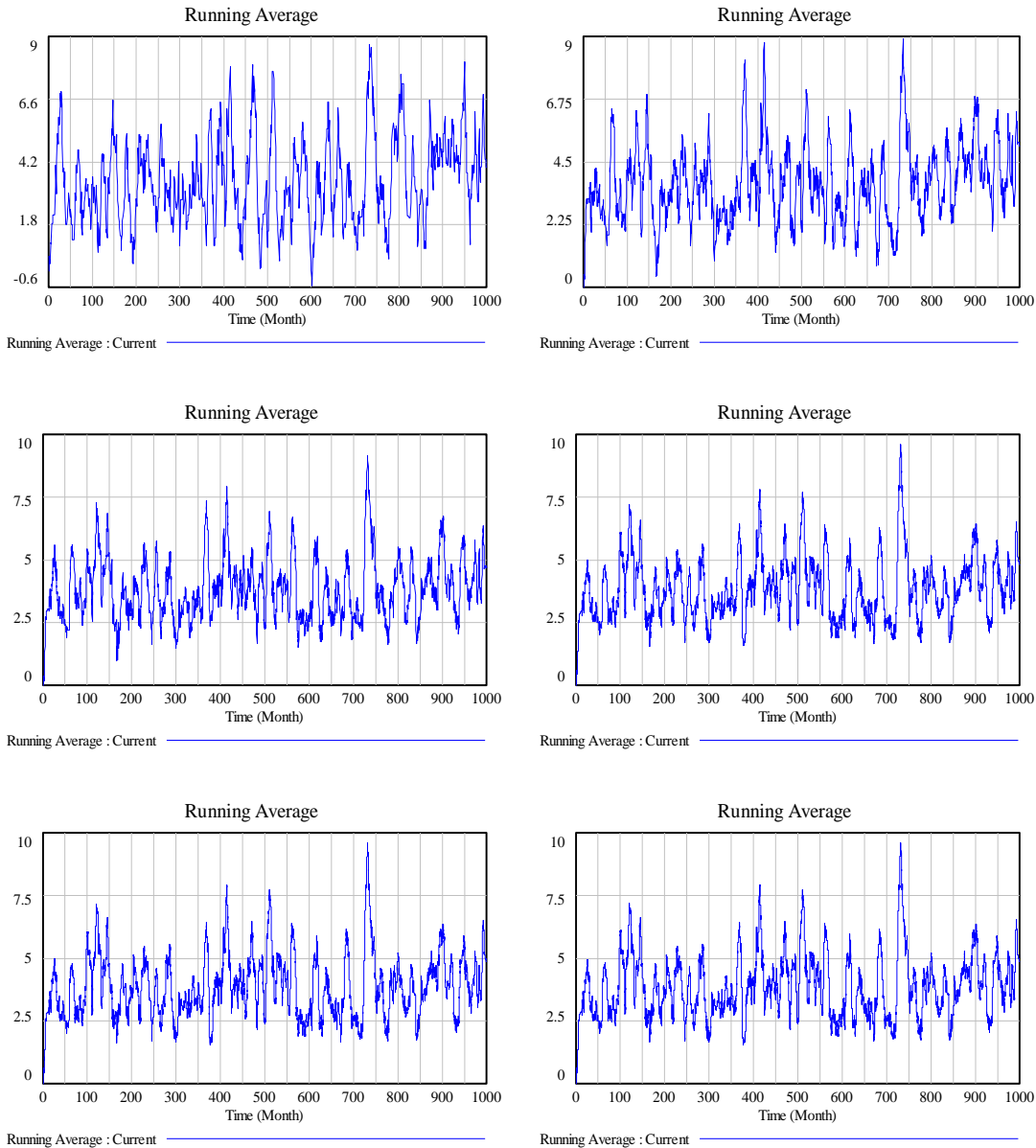


Figure 74: Tests with different time steps

The time steps used from right to left, top to bottom: 1; 0,5; 0,25; 0,125; 0,0625; 0,03125; 0,015625 and 0,0078125.

APPENDIX I DIFFERENT SOURCES OF RESOURCE DIRECTED MEASURES STUDIES

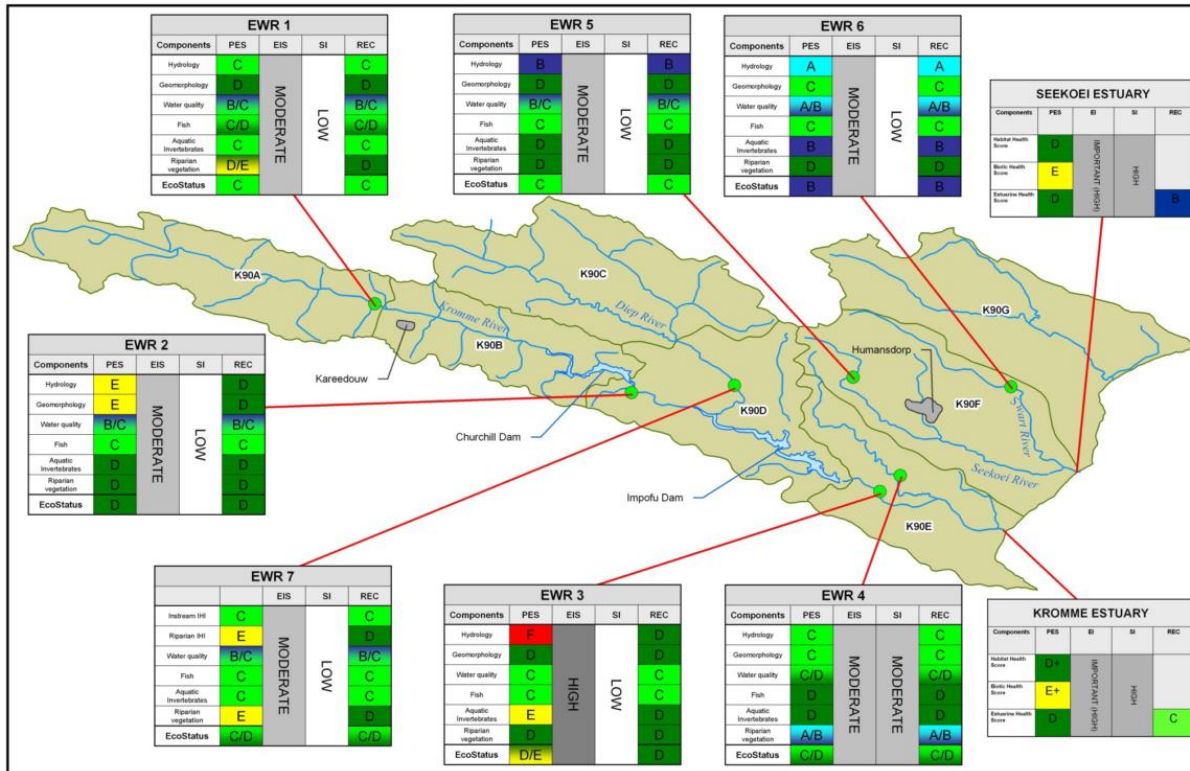


Figure 75: Map of the Kromme/Seekoei study area showing the PES, Ecological Importance and Sensitivity (EIS) and REC per EWR site and estuary (Scherman, 2012, p. 4)

## APPENDIX J MODELING AN TEMPORARILY OPEN/CLOSED ESTUARY

An estuarine system contains many complex aspects. Many of these have been simplified for modeling purposes. It is strived to have relatively valid model that is recognizable for experts, yet keeping it at the highest abstraction level possible. This appendix goes into how the estuarine system works and what is and is not implemented in the model.

The first characteristic of the Great Brak estuary is that it is a temporary open/closed system. This means that a breachable berm separates the estuary from the ocean. The berm is breached when the water level of the water inside the estuary is higher than the sea level and the berm. The berm then overflows and flushes partly into the sea. The estuary water level is dependent on the inflow from the Wolwedans dam which is controlled unless there is a dam overflow. With the controlled releases artificial breaching is possible, using a bulldozer and controlled water inflow from the Wolwedans dam. Artificial breaching is common practice in the Great Brak estuary. To artificially breach the mouth about 500-750 thousand cubic meters of water is required, depending on the timing of the attempt (Piet Huizinga, personal communications). Figure 76 is a sketch for understanding the terms as used in this paragraph.

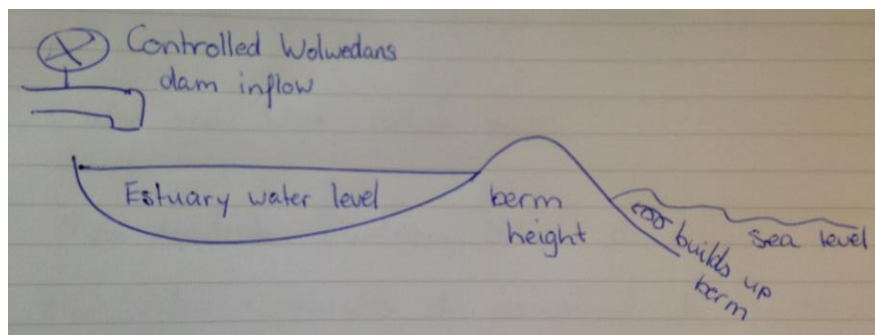


Figure 76: Sketch for understanding the berm

The opening and closing of the mouth has large impacts on the estuary. The exchange with the sea water affect the water quality, it flushes the system. The different species of fish and other animals use need the opening and closing for their breeding. And the estuary water level will go down, which can prevent a flood.

The timing of the opening and closing is also of importance. For example: the Great Brak estuary provides breeding ground for 27 species of fish having different breeding periods across the year (Quinn, Breen, Whitfield, & Hearne, 1999). In sessions with experts on the estuary the graph in Figure 77 was sketched to see the effect of the opening of the mouth at different times in the year.

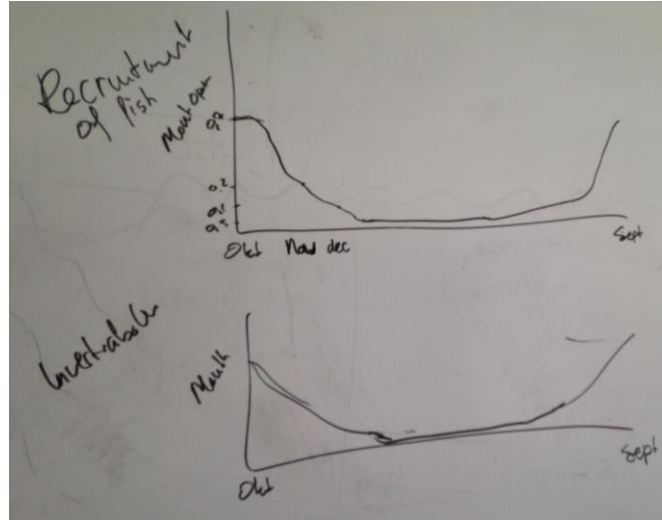


Figure 77: Effects of the state of the mouth on fish in general (upper) and invertebrates (lower)

Since the construction of the Wolwedans dam the water to the estuary has reduced dramatically. The operational management of the estuarine mouth now plays an important role for the health of the estuary. With only a fraction of the water that was supplied before the mouth can be kept open at moments in the year at which it is ideal.

From a high level modeling perspective this proposes challenges in time-base and in level of abstraction. In reality the decision making for supplying water to the estuary and artificial breaching is being done on a day-to-day basis (or in case of an eminent flood hour-to-hour basis). The annual water allocation is normally used in a couple of 500-750 thousand cubic meter breaching related releases at well-timed moments.

The current modeling uses a time base of months and provides the annual water requirement for the estuary evenly across the year. The model cannot support a smart and planning dam operator that chooses to use the water in bursts to breach the berm.

To still remain valid the model uses the assumption of adequate estuary release management. It assumes that if the estuarine manager receives a certain amount of water over a longer period of time. He or she will use that water with will timed bursts to achieve a certain mouth open and closing state over time. If too little water is available the mouth will be open in too few moments in time. This will cause the water quality to go down, since that requires flushing of the estuary, or the ecosystem health to go down, since the breeding season for certain fishes wasn't optimal.

In the model the health of the estuary is a proxy of the fraction of water that is supplied form the amount that is required to sustain its health. The speed at which the health deteriorates can be different form the speed at which it recovers. More details are found in the model specification.