Schriftenreihe IWAR

224

TECHNISCHE UNIVERSITÄT DARMSTADT

IWAR

Martin Zimmermann

Sustainable Transformations of Water Supply Regimes. The Cuvelai-Etosha Basin in Central Northern Namibia.

Herausgeber:
Verein zur Förderung des Instituts IWAR der TU Darmstadt e.V.

Zimmermann, Martin

Sustainable Transformations of Water Supply Regimes. The Cuvelai-Etosha Basin in Central Northern Namibia. / Hrsg.: Verein zur Förderung des Instituts IWAR der TU Darmstadt e.V.
Darmstadt: Eigenverlag, 2013
(Schriftenreihe IWAR 224)

ISSN 0721-5282
ISBN 978-3-940897-22-0

Referent: Prof. Dipl.-Ing. Dr. nat. techn. Wilhelm Urban
Korreferent: Prof. Dr.-Ing. Manfred Ostrowski

Tag der schriftlichen Einreichung: 23.08.2013
Tag der mündlichen Prüfung: 08.11.2013

Herstellung: Lasertype GmbH, Holzhofallee 19
64295 Darmstadt

Vertrieb: Institut IWAR
TU Darmstadt
Franziska-Braun-Straße 7
64287 Darmstadt.
Telefon: 06151 / 16 3648
Telefax: 06151 / 16 3739

Sustainable Transformations of Water Supply Regimes

The Cuvelai-Etosha Basin in Central Northern Namibia

Dem Fachbereich Bauingenieurwesen und Geodäsie
der Technischen Universität Darmstadt
vorgelegte

Dissertation

zur Erlangung des akademischen Grades des
Doktors der Ingenieurwissenschaften (Dr.-Ing.)

von
Martin Song-il Zimmermann
Diplom-Wirtschaftsingenieur
geboren in Duisburg

München im August 2013
D17

Preface

The research of this thesis has mainly been carried out over a period of six years. I spent three of these six years as a scholarship holder in the postgraduate school (Graduiertenkolleg) "Topology of Technology" of the German Research Foundation (DFG). The other three years, I have worked as a researcher at the Chair of Water Supply and Groundwater Protection, Institute IWAR, at Technische Universität Darmstadt. Particular thanks are due to my doctoral supervisor Prof. Dipl.-Ing. Dr. nat. techn. Wilhelm Urban for the confidence placed in me as well as his advice. Furthermore, I would like to thank Prof. Dr.-Ing. Manfred Ostrowski for his willingness to act as the second supervisor.

The topic of the study is closely linked to the research project "CuveWaters – Integrated Water Resources Management in the Cuvelai-Etosha Basin (Central-Northern Namibia)" which is funded by the German Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF). The project is led by PD Dr. Thomas Kluge from the Institute for Social-Ecological Research (ISOE) in Frankfurt am Main. Project partners are the Chair of Water Supply and Groundwater Protection as well as the Chair of Wastewater Technology of the Institute IWAR at Technische Universität Darmstadt. Namibian cooperation partners are the Desert Research Foundation of Namibia (DRFN), the Namibian Ministry of Agriculture, Water, and Forestry (MAWF), and branch offices of the GIZ (German Society for International Cooperation) and the BGR (German Federal Institute for Geosciences and Natural Resources) in Namibia.

The main objectives of the research project CuveWaters are to reduce the dependency on the water of the Angolan-Namibian border river Kunene, to develop endogenous water resources, to introduce innovative and adapted techniques, and to examine their social as well as technological feasibility. The central idea is to test and establish a multi-resources-mix of diverse water supply and sanitation techniques. Special thanks are due to Dr. Stefan Liehr from the ISOE with whom I conducted a part of the thesis' interviews and Dr. Steffen Niemann who has provided the fundamental idea of the CuveWaters project.

Furthermore, I would like to thank a number of colleagues, friends, and family members for their reviews and advice: Dr. Thomas Schiedek, Dr.-Ing. Alexander Sonnenburg, Dr. Komeine Nantanga, Walter Holch, Alexander Jokisch, Summer Lo, Micha Zimmermann, Samuel Chang, Philipp Benz, Marian Brenda, Elmar Schulte-Tigges, and Jana Kaiser. In addition, a number of student assis-

tants helped to evaluate the data: William Schreiber-Madrid, Nils Messinger, Simon Widera, and Tobias Kröger.

Last but not least, thanks are due to the villagers of Epyeshona, to all interviewees for their time and contributions, to the German Academic Exchange Service (DAAD) for co-financing my research stay in Namibia, as well as to my family and my friends for their support throughout the past years.

Abstract

In this thesis, an interdisciplinary modelling approach for water resources management and its application is presented that is able to deal with socio-technical systems that are characterised by a multiplicity of variables, interdependencies, and actors. The case study area is the Cuvelai-Etosha Basin, which is located in central northern Namibia. Approximately 850,000 people or 40 % of the Namibian population live in this area, which comprises only about 14 % of the country's area. The region is characterised by high precipitation variability (50-990 mm per year), a very high evaporation rate, the lack of perennial rivers, and the salinity of the groundwater in large parts of the area. These issues are a challenge for the regional water supply. The water supply regime in central northern Namibia is a hybrid between a centralised large technical system and several decentralised or traditional water supply techniques (e. g. Oshanas, earth dams (Omatale), dug wells (Omuthima and Oshikweyo), rainwater harvesting). The large technical system is fed by the Namibian-Angolan border river Kunene and consists of an open canal and a pipeline scheme with a length of about 2,000 km. A growing water demand due to population growth, migration and urbanisation, as well as technical and organisational problems, illegal extractions, and vandalism will probably jeopardise the situation since the local water demand exceeds the natural resources.

The main research question is how the observed socio-technical system can be transformed in a sustainable manner and which key factors enable or impede such systemic transformations. The study is based on theories and concepts of systems theory, cybernetics, technological transitions, as well as socio-technical systems. Several modelling techniques were used in order to answer the research question. The foundation of the model was formed by the Grounded Theory, which is a qualitative method of social empirical research. Interviews with relevant stakeholders provided a deeper insight into their problem perceptions and world views. After the identification of relevant system variables, their interrelations and roles within the system were analysed by using the Sensitivity Model. In doing so, it was possible to identify outstanding variables as well as processes and to reveal potential regulators, systemic hazards, and viability indicators. Furthermore, cause-effect chains and feedback loops were analysed, based on cybernetic approaches. These findings helped to identify regulation mechanisms for open and closed loop control. Finally, various water supply scenarios were simulated and then assessed and compared in terms of systemic risks and viability indicators.

The analysis showed that the water supply technique of rainwater harvesting might be the most promising niche technology that is able to initiate sustainable transformation processes with desirable outcomes. Furthermore, the technique of floodwater harvesting might be used in order to stabilise the system in a post-transition phase and to strengthen its resilience. Finally, capacity development measures are suggested, due to their positive impacts on a large number of other system variables. In addition, major hazards and risks to the system mainly stem from precarious feedback loops that have undesirable consequences such as an uncontrollable build-up or collapse of processes and an undesirable resilience which impedes any kind of development or transformation. In terms of indicators for the viability of the system, technical problems with the large-scale water supply system are said to reduce the water supply security. Furthermore, traditional water supply techniques are said to foster livestock farming and to deteriorate the users' health considerably. All in all, the interviewees' most important contribution was highlighting the relevance of traditional and decentralised water supply techniques as well as the significant role they play as a complement to the pipeline scheme. The implications of all of these findings might serve to develop policies for sustainable transformations of socio-technical systems.

Zusammenfassung

In der vorliegenden Untersuchung wird ein interdisziplinärer Modellierungsansatz für die Bewirtschaftung von Wasserressourcen und dessen Anwendung vorgestellt, der imstande ist, sozio-technische Systeme zu erfassen, die sich durch eine Vielzahl von Variablen, Abhängigkeiten und Akteuren auszeichnen. Untersuchungsraum ist das im zentralen Norden Namibias gelegene Cuvelai-Etosha-Becken. Hier leben etwa 850.000 Menschen bzw. 40 % der namibischen Bevölkerung auf einem Gebiet, das nur ca. 14 % der Fläche des Landes umfasst. Prägend für diese Region sind eine hohe Variabilität des Niederschlags (50 bis 990 mm pro Jahr), sehr hohe Verdunstungsraten, das Fehlen ganzjähriger Oberflächengewässer sowie oftmals hohe Salzgehalte des Grundwassers, was eine Herausforderung für die regionale Wasserversorgung darstellt. Das Wasserversorgungsregime in zentralen Norden Namibias ist ein Hybrid aus einem zentralen großtechnischen System sowie mehreren dezentralen oder traditionellen Wasserversorgungstechniken (z. B. Oshanas, künstliche Seen (Omatale), handgegrabene Brunnen (Omuthima und Oshikweyo), Regenwassernutzung). Das großtechnische System wird durch den namibisch-angolanischen Grenzfluss Kunene gespeist und besteht aus einem offenen Kanal und einem Rohrnetz mit einer Länge von insgesamt rund 2.000 km. Ein steigender Wasserbedarf aufgrund von Bevölkerungswachstum, Migration und Urbanisierung, technische und organisatorische Unzulänglichkeiten, illegale Wasserentnahmen und Vandalismus stellen Gefährdungen für die Infrastruktur dar, da der lokale Wasserbedarf die natürlichen Ressourcen übersteigt.

Die zentrale Forschungsfrage lautet, wie das betrachtete sozio-technische System auf nachhaltige Weise transformiert werden kann und was die wesentlichen Faktoren sind, die eine solche systemische Transformation ermöglichen oder behindern. Die Studie basiert dabei auf Theorien und Konzepten der Systemtheorie, Kybernetik, technologischer Transformationen sowie sozio-technischer Systeme. Mehrere Modellierungsansätze wurden zur Beantwortung der Forschungsfrage verwendet, wobei das Fundament aus der Grounded Theory besteht, bei der es sich um ein Verfahren der qualitativen empirischen Sozialforschung handelt. Interviews mit relevanten Stakeholdern gewährten einen tieferen Einblick in deren Problemwahrnehmungen und Weltanschauungen. Nachdem die relevanten Systemvariablen ermittelt wurden, konnten ihre Wechselwirkungen und Rollen innerhalb des Systems mithilfe des Sensitivitätsmodells analysiert werden. Dadurch war es möglich, hervorstechende Variablen und Prozesse, insbesondere potenzielle Stellschrauben, systemische Ge-

fährdungen und Indikatoren der Funktions- bzw. Lebensfähigkeit des Systems, zu identifizieren. Darüber hinaus konnten basierend auf kybernetischen Ansätzen Ursache-Wirkungs-Ketten und Rückkopplungen untersucht werden. Diese Erkenntnisse haben dazu beigetragen, Steuerungs- und Regelungsmechanismen, wie z. B. Regelkreise, zu analysieren. Abschließend sind unterschiedliche Wasserversorgungsszenarien simuliert worden, die im Hinblick auf systemische Risiken sowie auf Indikatoren der Funktions- und Lebensfähigkeit des Systems bewertet und verglichen wurden.

Die Auswertung der Ergebnisse ergab, dass die Regenwassernutzung die vielversprechendste Nischentechnologie dafür ist, erwünschte und nachhaltige Transformationsprozesse zu initiieren. Außerdem kann die Technik des Floodwater Harvesting dazu eingesetzt werden, das System in der Phase nach einer Transformation zu stabilisieren und dessen Resilienz zu gewährleisten. Abschließend können Maßnahmen des Capacity Development aufgrund ihrer positiven Auswirkungen auf eine große Zahl anderer Systemvariablen empfohlen werden. Abgesehen davon sind wesentliche systemische Gefährdungen und Risiken auf prekäre Rückkopplungen, die zu einem unkontrollierten Aufschaukeln oder Zusammenbruch von Prozessen führen können, sowie auf unerwünschte, jegliche Transformation oder Entwicklung verhindernde Resilienz zurückzuführen. In Bezug auf Indikatoren der Funktions- und Lebensfähigkeit des Systems kann konstatiert werden, dass technische Probleme der großtechnischen Wasserversorgung die Wasserversorgungssicherheit verschlechtern. Ferner werden traditionelle Wasserversorgungstechniken dafür verantwortlich gemacht, die traditionelle Viehhaltung zu stärken und die Gesundheit der Nutzer erheblich einzuschränken. Insgesamt gesehen war der wesentlichste Beitrag der Gesprächspartner, die Bedeutung traditioneller und dezentraler Wasserversorgungstechniken sowie deren entscheidende Rolle in Ergänzung zum Rohrnetzsystem hervorzuheben. Die Implikationen all dieser Ergebnisse können letztendlich zur Entwicklung von Strategien für nachhaltige Transformationen sozio-technischer Systeme dienen.

Table of contents

List of figures

List of tables

List of abbreviations and symbols

α	Activity
a	Year
AIDS	Acquired immunodeficiency syndrome
AP	Stakeholder group „administration and politics“
β	Passivity
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BMBF	Bundesministerium für Bildung und Forschung
BMC	Basin management committee
cf.	confer
CIM	Cross-Impact Matrix
d	Day
DAAD	Deutscher Akademischer Austauschdienst
DANIDA	Danish International Development Agency
DFG	Deutsche Forschungsgemeinschaft
DRFN	Desert Research Foundation of Namibia
DRWS	Directorate of Rural Water Supply
DWSSC	Directorate of Water Supply and Sanitation Coordination
e. g.	exempli gratia
EI	Stakeholder group "national and international governmental as well as parastatal organisations"
EL	Ecological dimension
EN	Economical dimension
et al.	et alii
FINNIDA	Finnish International Development Agency
FL	Water-related feedback loop
FN	Non-water-related feedback loop
GDP	Gross domestic product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GT	Grounded Theory

GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (since 2011 Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ)
GWP	Global Water Partnership
h	Hours
ha	Hectare
HD	Hetergeneity difference
HDI	Human development index
HIV	Human immunodeficiency virus
HQ	Heterogeneity quotient
i. e.	id est
IBMC	Iishana Basin Management Committee
ICWE	International Conference on Water and Environment
IMF	International Monetary Fund
ISE	Fraunhofer Institute for Solar Energy Systems, Freiburg
ISOE	Institut für sozial-ökologische Forschung, Frankfurt am Main
ISSA	Informationsstelle südliches Afrika
IWAR	Institut für Wasserversorgung, Abwassertechnik, Abfalltechnik, Industrielle Stoffkreisläufe sowie Raum- und Infrastrukturplanung der Technischen Universität Darmstadt
IWRM	Integrated Water Resources Management
km	Kilometre
kWh	Kilowatt hours
l	Litre
LWC	Local Water Committee
m	Metre
MAWF	Ministry of Agriculture, Water and Forestry
mm	Millimetre
N$	Namibian dollar
NamWater	Namibia Water Corporation Ltd.
NGO	Non-governmental organization

No.	Number
NWR	Non-water-related
OHSIP	Oshakati Human Settlement Improvement Project
PI	Political, institutional, and organisational dimension
PPP	Purchasing power parity
RWH	Rainwater harvesting
SADC	Southern African Development Community
SADF	South African Defence Force
SC	Social and cultural dimension or stakeholder group "science and consulting engineers"
SD	System Dynamics
STS	Science, technology and society studies
SWAPO	South West Africa People's Organization
TE	Technological dimension
TUD	Technische Universität Darmstadt
UFZ	Helmholtz-Zentrum für Umweltforschung
UNDP	United Nations Development Programme
WM	Stakeholder group "water ministry"
WPC	Water Point Committee
WR	Water-related
WSU	Stakeholder group "water supply utility"
WU	Stakeholder group "water users"
WUS	World University Service

Für Joung-ok Zimmermann
und in Erinnerung an
Reinhold Karl Zimmermann
(1935-2005)

"Central northern Namibia can be understood as a complex system of different interacting factors: urbanisation processes, livestock farming, crop production, water supply with its origin in Angola, subsistence economy, management at a customary level etc. Regarding this system, it is important not to look only at water but instead to look at the whole system." (Comment of a Namibian ministry official, 07a-AP-05)

1 Introduction

The concept of Integrated Water Resources Management (IWRM) became more popular among engineers, planners, and scientists in the water sector as a result of the debate on sustainable development triggered by the United Nations at the beginning of the 1990s (Snellen, Schrevel 2004). There is a broad consensus that the Global Water Partnership (GWP) provided the best definition of the approach so far:

"IWRM may be defined as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (GWP 2000)

Apart from the aspects of administrative and spatial integration, sustainability, participation, and interdisciplinarity can be identified as some of the concept's theoretical core issues (ICWE 1992). It can be assumed that the observed broad consensus among experts is only due to the wide scope of interpretation of these notions (Biswas 2004). When looking at recent research projects in the field of water resources management (UFZ 2009), it often seems that these topics are not adequately dealt with. However, in the context of water projects in developing countries, the issues mentioned are crucial for the success and viability of proposed institutional or technological transitions.

In the majority of cases, tools and methods are used that allow for a deductive model building of the problems to be tackled, which means that model structures are already defined in advance and, in some cases, the assumptions made are not even verified. It is questionable whether it is possible to fully understand an observed system by using preconceived hypotheses. Such technocratic approaches may be sufficient for administrative purposes such as feeding databases but not for planning purposes, where the aim is to secure water resources as well as water supply and, thus, to improve livelihoods in a development context.

Another major problem of technology-driven concepts is that they often neglect the influence or even existence of path dependencies. However, the awareness of historically developed interdependencies is essential for the understanding of the specific behaviour and the properties of a system which is to be managed. Furthermore, when assessing the sustainability of a large technical system, such as a supply infrastructure, and seeking solutions for possible problems, experts are often inclined to focus on merely deterministic aspects and to exclude cultural and social implications. Apart from the common understanding of the notions of sustainability (Hartig 1795, Hauff 1987, von Carlowitz 2000), integrative or systemic approaches (Jörissen et al. 1999, Bossel 1999) often seem to be neglected.

What is also often forgotten is that even the problems identified in an observed context are not necessarily evident or can be objectively verified. It has to be questioned whose problems have to be solved and which targets have to be met. External experts and also every internal stakeholder might perceive problems differently. The responsible planner, manager, or decision-maker should not only be aware of this but should also be enabled to analyse the heterogeneity of perceptions and world views. This is crucial in order to avoid one-sided decisions or measures, e. g. solely technocratic or engineering-driven ones. Apart from that, resource and technology-driven perspectives often disregard traditional water supply techniques which may play an important role within a system, as will be demonstrated below. All addressed issues require not only a broad understanding of inter- and transdisciplinarity (Burger 2005; Jahn 2005; Mittelstraß 2005; Schmidt 2005; Pohl, Hirsch-Hadorn 2006) but also appropriate theoretical and methodological approaches.

In this thesis, a modelling approach and its application is presented which addresses and overcomes the deficiencies described. The methodology mainly aims at the analysis and assessment of socio-technical systems. Complex real-world problems and especially the problems of water supply management in developing countries are characterised by a multiplicity of variables, interdependencies, and actors. The proposed approach is able to comprehend such technological regimes, whereas conventional methods only deal with separated or isolated issues and are, thus, not appropriate for a development context. With this approach, conclusions for the management of adapted institutional and technological transformations can be drawn. Before the approach is explained in more detail in Section 1.2, the case study in central northern Namibia and its characteristics are introduced.

1.1 The Cuvelai-Etosha Basin in central northern Namibia

The case study area is the Namibian part of the so-called Cuvelai-Etosha Basin in the central north of the country. Namibia is located in the south west of Africa and borders on Angola in the north, Zambia in the north east, Botswana in the east, South Africa in the south east and south, as well as on the Atlantic Ocean in the west. The country's capital is Windhoek. According to the census of 2011, Namibia has a population of about 2.1 million of which 42 % live in urban and 58 % in rural areas (National Planning Commission 2012). Namibia's economy is heavily dependent on mining of diamonds, uranium, zinc, and other minerals (CIA 2013). The GDP (PPP) per capita in 2012 is 7,771 US$ (International Monetary Fund 2013), which is relatively high compared to other African countries and is several times higher than the average of other members of the Southern African Development Community (SADC) (Heyns 2005). However, with a Gini coefficient of 59.7 in 2010 (CIA 2013), Namibia has one of the world's most unequal income distributions. Additionally, the state has a Human Development Index (HDI) of 0.608 in 2012 (UNDP 2013) and is, thus, categorised as a country with medium human development (rank 128 among 186 countries).

Namibia was a colony of the German Empire between 1884 and 1915 and was known as German South-West Africa (GIZ 2012, ISSA 2013). From 1904 until 1908, German imperial forces committed genocide on the Herero and Nama, due to their uprising (Kössler, Melber 2004). Some historians claim that these incidents anticipated the Apartheid system and the Holocaust (Madley 2005). After the defeat of the German forces during World War I, Namibia was occupied and administered by South Africa as a mandate and, then, annexed after World War II (CIA 2013). Between 1966 and 1989, the South West Africa People's Organization (SWAPO) fought a war of independence against the South African Defence Forces (SADF) until a truce and free elections were negotiated (GIZ 2012, ISSA 2013). Since 1990, Namibia is an independent representative democratic republic governed by the SWAPO party.

The Cuvelai-Etosha Basin is named after the Cuvelai system of ephemeral and intermittent streams, called Oshanas, extending from southern Angola to northern Namibia, which drain, occasionally, even into the Etosha pan. The whole Cuvelai-Etosha catchment comprises 166,650 km² whereby 113,580 km² (68 % of the total area) are on Namibian territory and 53,370 km² on Angolan (32 %) (Transboundary Freshwater Dispute Database 2012). The Namibian part of the catchment contains four of the 13 national administrative regions, namely Oshana, Oshikoto, Ohangwena, and Omusati, which is why the region is also known as the “Four O Region” (Figure 1.1). Almost 850,000 people live in this area (Table 1.1), which is approximately 40 % of the Namibian population (Araki 2005, Kluge et al. 2008) but the four administrative regions comprise only about 10.3 % of the country’s area (around 824,000 km²) whereas the Namibian part of the catchment comprises 13.8 %. The population density amounts to about 10 inhabitants per km² regarding the administrative boundaries or 7.4 regarding the catchment area, whereas the population density of Namibia is about 2.5 per km², making it one of the most sparsely populated countries in the earth.

Table 1.1 Population and surface area of the four regions in central northern Namibia (National Planning Commission 2012)

	Population	Area [km²]
Ohangwena	245,100	10,706
Omusati	242,900	26,551
Oshana	174,900	8,647
Oshikoto	181,600	38,685
Total	844,500	84,589

Although Namibia is a multi-ethnic state, the northern region is almost entirely inhabited by the Owambo (also known as Ambo or Aawambo), who make up half of the Namibian population and are, thus, by far the largest ethnic group of the country. Their language, Oshiwambo, belongs to the group of Bantu languages whose various dialects can be found across southern, central, and eastern Africa (cf. Bleek 1862). The Owambo consist of twelve different tribes of which eight inhabit northern Namibia and four southern Angola (Pack, Pack 2012). Central northern Namibia was called “Owamboland” during colonial times.

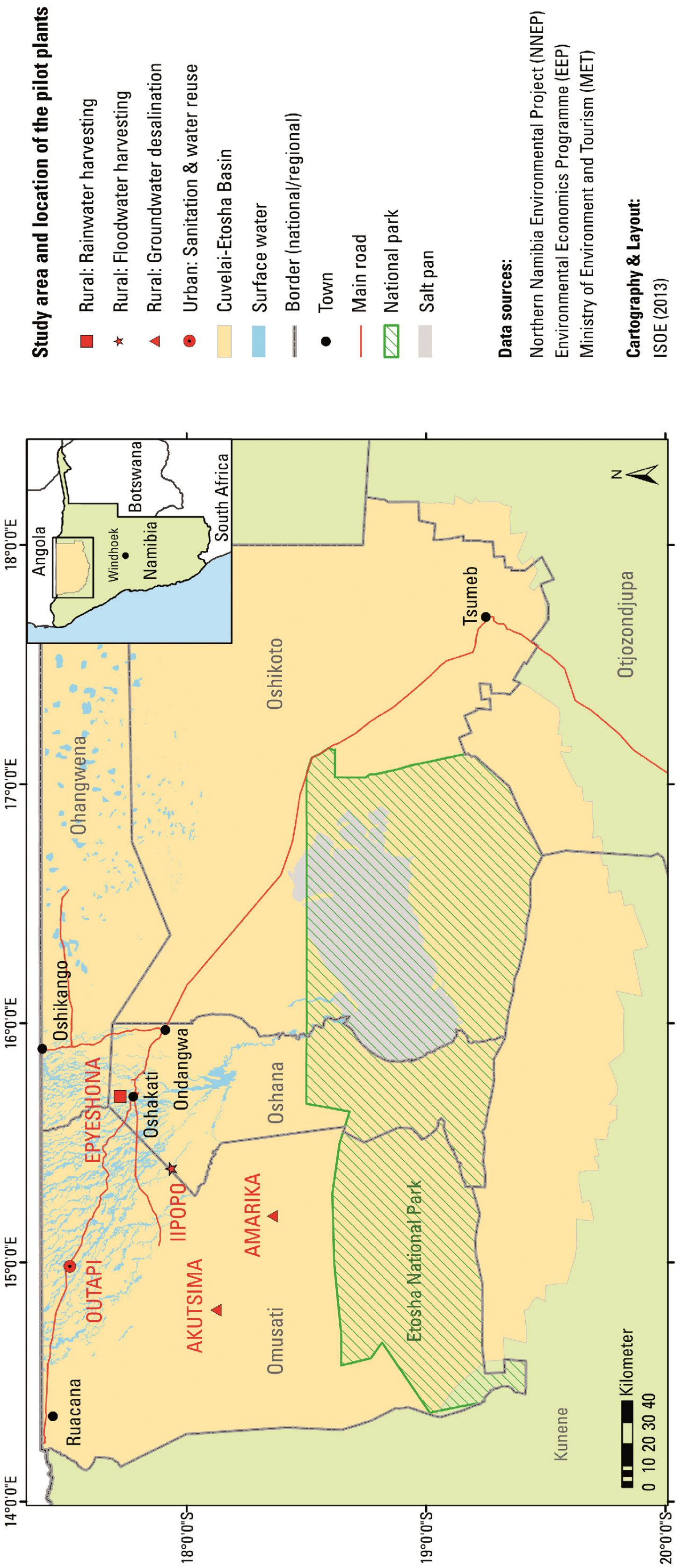

Figure 1.1 The Cuvelai-Iishana sub-basin in central northern Namibia (including pilot plant locations of the CuveWaters project, map created by ISOE 2013)

Oshakati is the regional capital of the Oshana region and was only founded in 1966 (Hangula 1993, cited in Niemann 2000). During the Namibian war of independence, the city served as an operational base for the SADF in their fight against the SWAPO which mainly consists of Owambo people (Kube 1985, Gleichmann 1994, cited in Niemann 2000). One of the outstanding processes that characterise the north is a rapid migration into the major cities: Oshakati, Ongwediva, and Ondangwa, but also into Oshikango and Outapi, for instance. According to the census of 2011, Oshakati has an official population of 35,600, Ondangwa of 21,100, and Ongwediva of 19,300 (National Planning Commission 2012). However, Oshakati's mayor estimates that the population of her city is around 45,000 (Interview 07a-AP-01). The agglomeration of the three cities forms the second largest concentration of population, after Windhoek, and is an important commercial centre for the entire north. At Christmas time and on other public holidays, the population is thought to triple due to family gatherings, thus posing an enormous challenge for urban supply and disposal systems. Nevertheless, the majority of the regional population lives in rural areas and in typical rural conditions. Here, people are often unemployed and practice subsistence economy, for instance, rain-fed crop farming (Marsh, Seely 1992) and livestock farming (Deffner et al. 2008).

Namibia is said to be the most arid country in sub-Saharan Africa, due to its high potential evaporation rate which is, for example, up to 3,000 mm per annum in the north (ACACIA Project E1 2004). The semi-arid region is characterised by high precipitation variability that ranges from 50 to 990 mm per year (Figure 1.2), including consecutive droughts. However, the average annual rainfall is about 470 mm per year (Sturm et al. 2009). Furthermore, there are seasonal alternations of a dry period during winter from May until September and heavy rainfalls during summer from October until April (Figure 1.3) in which up to 96 % of the annual precipitation occurs. Due to the area's shallow topography and depending on the amount of rainfall, severe floods can occur at the end of the rainy season (called Efundja), as happened in March 2011, for instance.

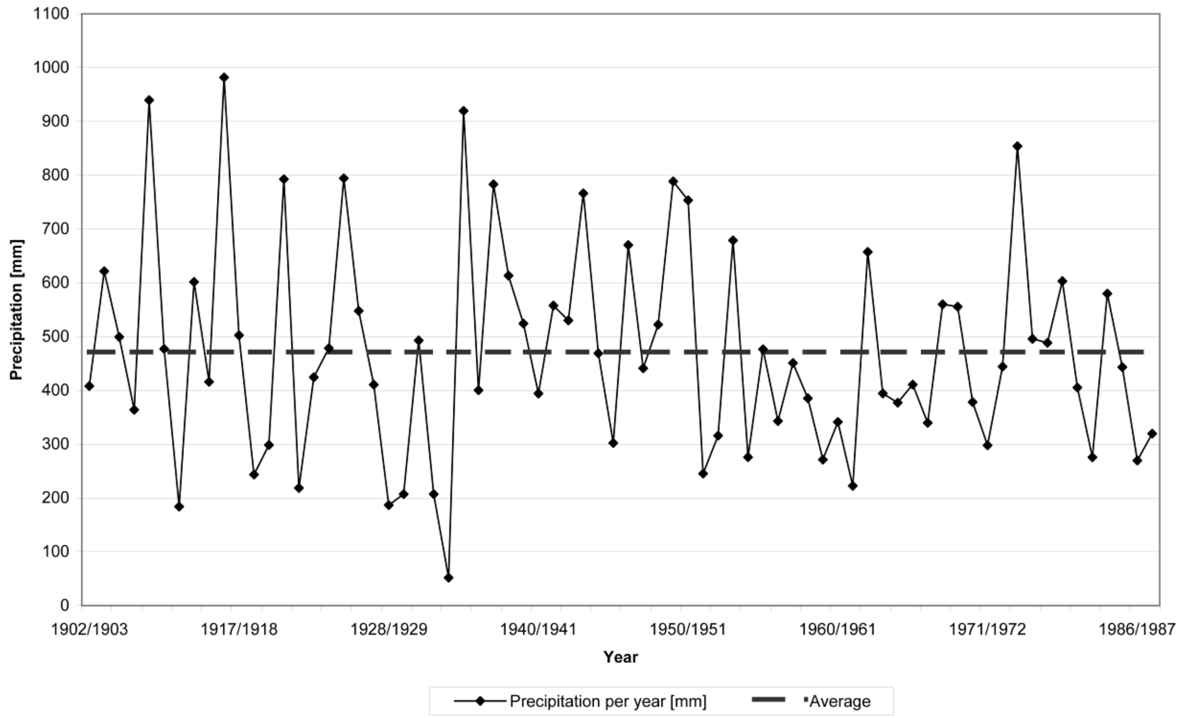

Figure 1.2 Annual precipitation in Ondangwa 1902-1988 based on data of the Namibia Meteorological Service (Zimmermann 2010b)

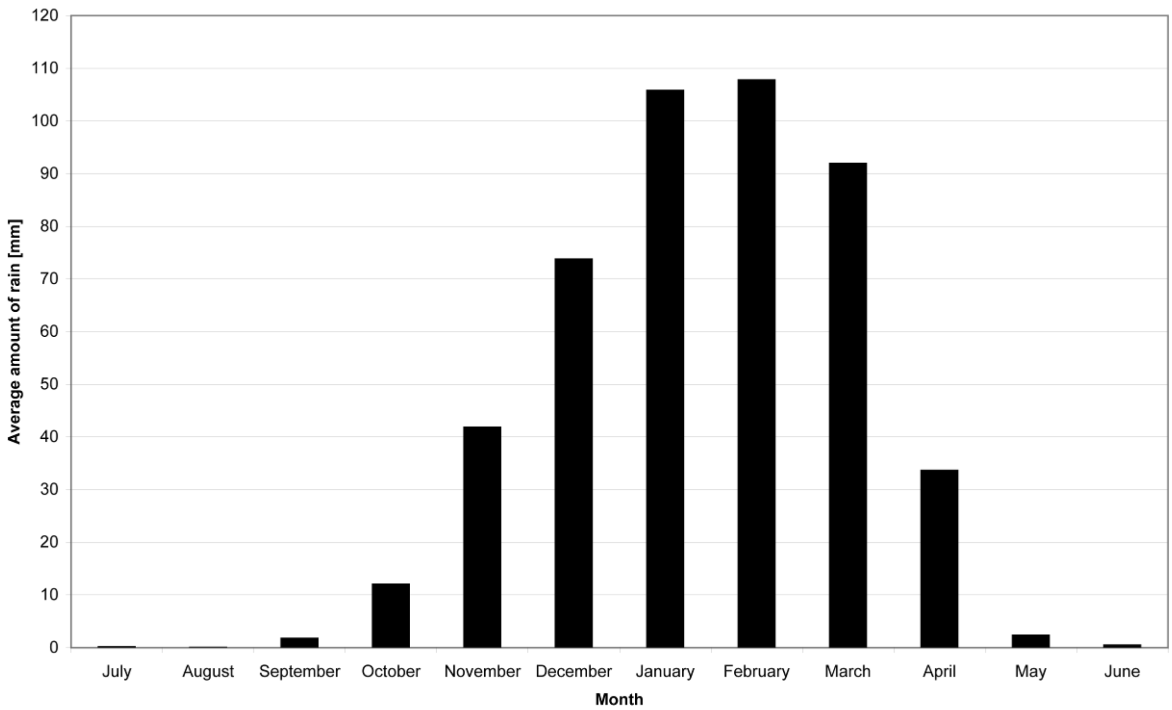

Figure 1.3 Seasonal distribution of precipitation in Ondangwa 1902-1988 based on data of the Namibia Meteorological Service (Zimmermann 2010b)

The absence of perennial rivers and the salinity of groundwater aquifers in large parts of the region are further serious problems (Ministry of Agriculture, Water and Rural Development 2000). The national water act's guideline values on the conductivity of water are often exceeded, which poses increased health risks (Government of the Republic of Namibia 1956). Thus, supplying water is extremely challenging because demand greatly exceeds the supply from local water resources. The water supply regime in the region is a hybrid of a large-technical system and several decentralised water supply techniques, some of which are traditional, for instance, earth dams within Oshanas (Omatale), dug wells (Omuthima and Oshikweyo), and rainwater harvesting. In the early 1970s, the large-scale water supply system was established that initially served to supply SADF military camps (Schümer 1977; Goldberg 1989; Reichelt 1990; Stern, Lau 1990; cited in Niemann 2000). It is fed by raw water from the Namibian-Angolan border river Kunene that is abstracted at Calueque dam on Angolan territory (Figure 1.1). The system consists of a 150 km long open canal, four water treatment plants, and a pipeline scheme with an overall length of about 2,000 km (Kluge et al. 2008; Zimmermann, Urban 2009; Figure 1.4). The concrete lined open Calueque-Oshakati canal transfers raw water from Calueque dam up to the Oshakati treatment plant for several purposes, such as potable water, livestock watering, and irrigation. The raw water is withdrawn at Calueque dam and discharged into the canal 2.4 km downstream of the dam (NamWater 2006). The capacity of the canal varies from 10 m^3/s at the beginning to 0.8 m^3/s at the Oshakati treatment plant (NamWater 2006). The Olushandja dam, approximately 120 km northwest of Oshakati, serves to balance and store the raw water from the Kunene River. It has a capacity of around 42.3 million m^3 and a surface area of about 29 km^2 (NamWater 2006). The four water treatment plants are located along the canal. The first one in the North West is in Olushandja, followed by Outapi, Ogongo, and finally Oshakati. The Olushandja treatment plant consists of two purification processes with capacities of 740 m^3/day and 1,600 m^3/day (NamWater 2006). The Outapi treatment plant produces 66 m^3/h of potable water and supplies Outapi Town, Onakayale Centre and three rural schemes (NamWater 2006). The Ogongo treatment plant has a capacity of 1,500 m^3/h and supplies five distribution lines (NamWater 2006). Finally, the Oshakati treatment plant produces up to 2,000 m^3/h and serves large areas of the Oshana, Ohangwena, and Oshikoto regions (NamWater 2006).

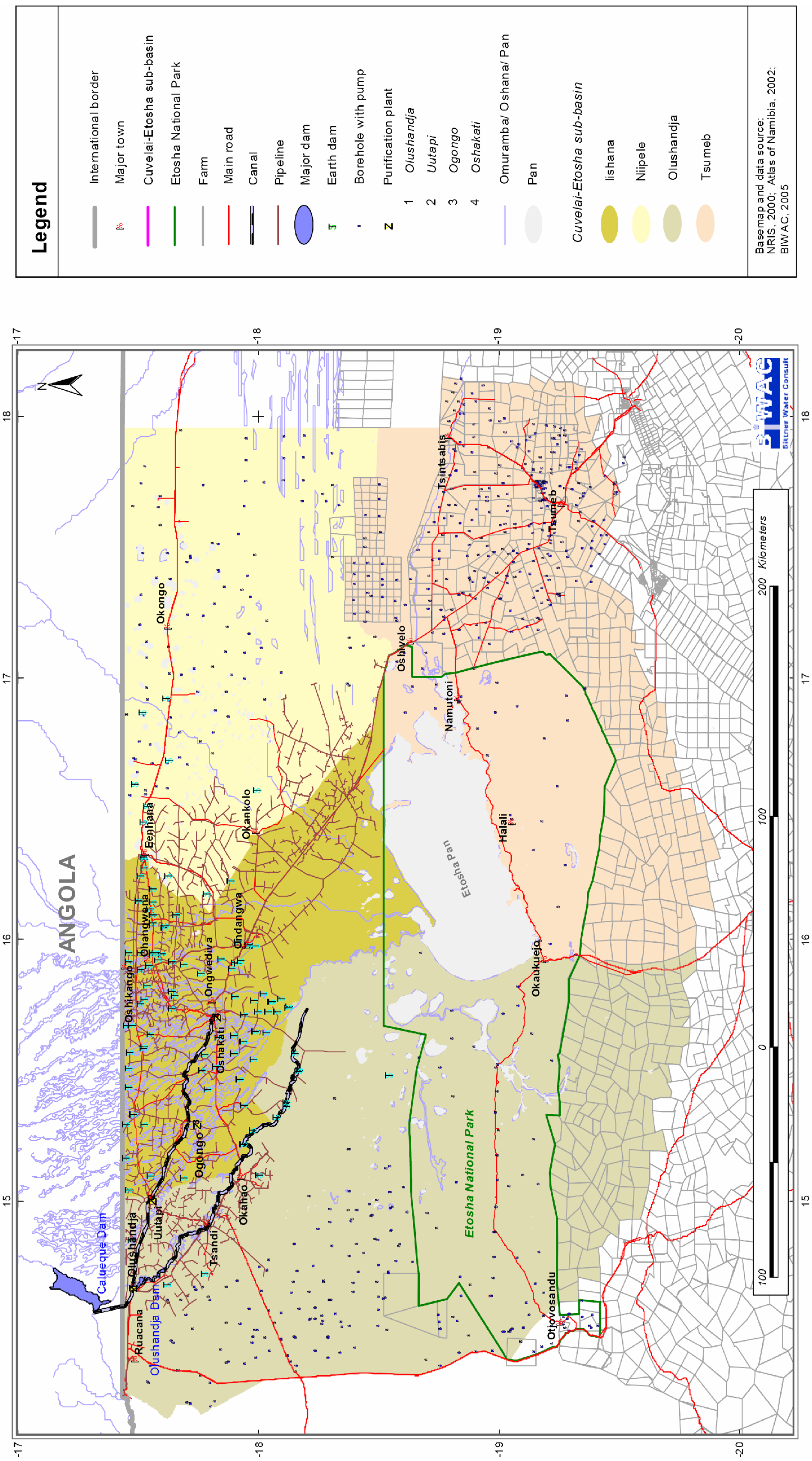

Figure 1.4 GIS map of the water supply pipeline scheme in central northern Namibia (map created by Bittner Water Consult)

The water is purified and distributed all over the region by the Namibia Water Corporation Ltd., also known as NamWater. The utility was set up in 1997 as a commercialised water corporation by the Namibia Water Corporation Act of 1997 (Government of the Republic of Namibia 1997) under the supervision of the Ministry of Agriculture, Water and Forestry (MAWF). The water-related legislative framework comprises, amongst others, the Water Act of 1956 (Government of the Republic of Namibia 1956), the National Water Policy White Paper of 2000 (Government of the Republic of Namibia 2000), and the Water Supply and Sanitation Sector Policy of 2008 (Government of the Republic of Namibia 2008). The Water Resources Management Act of 2004 (Government of the Republic of Namibia 2004), which replaces the Water Act of 1956, and the Water Resources Management Bill, which was approved by the Cabinet in 2010 (The Namibian 2010), make provision for the establishment of basin management committees (BMCs) to make sure that an integrated management and development according to the principles of IWRM takes place at the basin level (IWRM Joint Venture Consultants Namibia; IBMC 2008). As a result, the Cuvelai Basin Management Committee was establish in 2003 and the Iishana Sub-Basin Committee in 2005 (IWRM Joint Venture Consultants Namibia). Despite these necessary measures, however, population growth of up to 2.8 % (Kluge et al. 2008), migration (Niemann 2000), urbanisation, and the increasing withdrawal of Kunene water on the Angolan side might increase the demand for water and jeopardise supplies.

1.2 Research design

The methodology of this study comprises several methods and modelling tools in order to address the issues mentioned above. In this section, only the general framework is described and the main research questions are formulated. Theoretical and methodological details of the approaches will be given when they are actually applied in the respective chapters and when their explanation is necessary. Figure 1.5 presents the modelling approach in a nutshell. The approach is roughly based on the fundamental phases of modelling, namely the model building, a structural analysis of the model, a simulation of scenarios, and finally the assessment as well as interpretation of results. Thus, the methodology is also rudimentarily inspired by the structure of planning processes (Fürst, Scholles 2001).

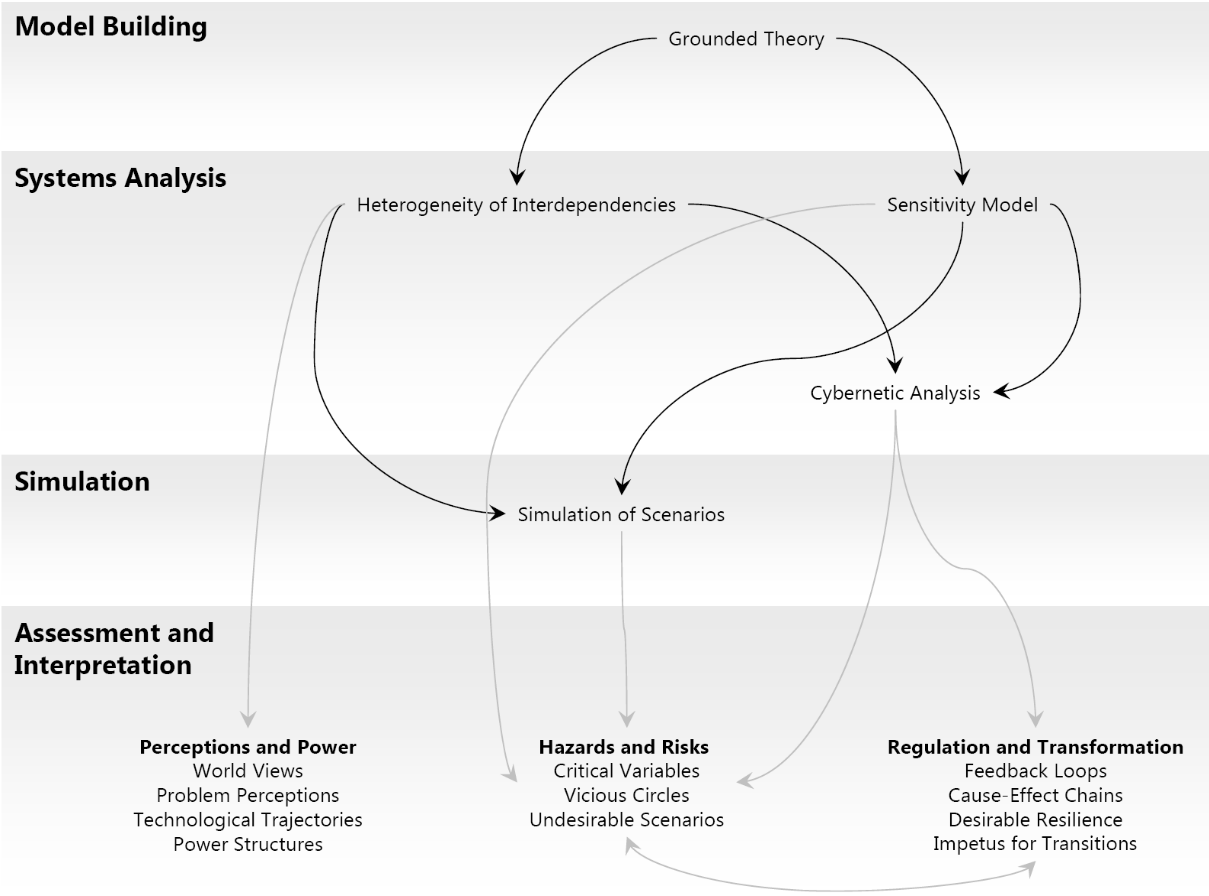

Figure 1.5 Research design

Five methods are combined for this study. The foundation of the model is formed by a qualitative method of social empirical research that is called Grounded Theory (Chapter 3). In particular, by analysing interviews with relevant stakeholders, core topics and problems mentioned by them can be identified. These are the components or system variables of the model. However, Grounded Theory only allows for the description and explanation of processes in the system. In order to simulate scenarios, a modelling technique is necessary that is, amongst others, able to operationalise simulations. This is why a semi-quantitative modelling approach is introduced: the Sensitivity Model (Chapter 4.1). This tool is able to reveal the inherent structure of the model by analysing and assessing the interrelations between the system variables. In doing so, it is possible to identify outstanding variables that are essential for understanding the system. In another procedure, the heterogeneity of the interviewees' statements is assessed by making use of a corresponding indicator (Chapter 4.2). Thus, the direction and heterogeneity of the system's interdependencies are determined. Based on these findings, two cybernetic analyses can be carried out. On the one hand, relevant feedback loops within the system can be identified (Chapter 4.3). On the other, cause-effect chains of selected variables are determined (Chapter 4.4). Finally, a number of water supply scenarios and scenarios for key factors can be simulated (Chapter 4.5).

Apart from fundamental questions regarding the structure of the model, research questions on three areas of focus can be answered by applying the proposed methodology (Chapter 5), namely questions about differing perceptions of stakeholders and the role of power structures in enabling or impeding systemic transformations, questions related to hazards and risks to the system, as well as questions about the regulation and transformation of the system:

- What are the system's relevant variables and how do they influence each other?
    - What are the specific properties and roles of variables within the system?
    - Which system variables with a passive role can be used as indicators for the viability of the system?
- How do different stakeholders perceive problems and the interplay of variables within the system?
    - Which systemic interdependencies are perceived homogeneously or heterogeneously among the stakeholders?
    - Is there a correlation between certain world views of stakeholder groups (e. g. opinions on technological solutions) and their power to impede or enable technological transitions?
- What are the main hazards and risks to the system?
    - Which variables are critical for the system?
    - Which feedback loops within the system are precarious?
    - Which (water supply) scenarios have undesirable consequences?
- What are the key factors that enable or impede systemic transformations?
    - Which self-reinforcing feedback loops can be used to initiate transformation processes?

- Which balancing feedback loops can be used for closed loop control and contribute to the resilience of the system?
- Which cause-effect chains can be used for open loop control?

2 Theoretical framework

2.1 Systems, cybernetics, and beyond

The concept of systems (from Late Latin *systema* "arrangement", from Greek *systema* "organised whole") can be traced back to the philosophers of ancient Greece. Aristotle explained the *holon* ("the whole") as being characterised by its parts, on the one hand, and the interrelations among the parts, on the other (Ropohl 1999b). Even though he did not use the term "system", he already described two core properties of systems, namely elements and structure. Lambert (1782, 1787) is said to be the first to define a system as "a whole composed by parts in a purposeful way" (Ropohl 1999b). Thus, he stresses that function is essential to systems. In addition, system integrity can be seen as another core property (Bossel 1992a, 1992b, 2004). This means that an inside and an outside of systems can often be defined, although the boundaries of a system might not always be clear. Systems also demonstrate other properties: they often have a hierarchy (i. e. consist of subsystems), are often complex, and, thus, emergent (i. e. they feature new properties or structures which cannot only be explained by their components).

The biologist Ludwig von Bertalanffy can be considered as the founder of modern systems theory (Ropohl 1999b). His contributions to science are the General System Theory (Bertalanffy 1949, 1969) and the theory of open systems. Bertalanffy wanted to overcome thinking in mono-causal ways and linear relationships. He advocated interdisciplinarity and coined concepts such as self-regulation and steady state. Another key contributor to systems theory is Norbert Wiener. He proved, with his work on "Cybernetics or control and communication in the animal and the machine" (Wiener 1948), that similar processes can be observed in very different domains, such as technology, nature, organisms, psychology, and society. Wiener coined the concepts of feedback loops and closed loop control.

During the 1950s, 60s, and 70s, general systems theory and cybernetics were applied to a wide range of different research fields. A well-known example is the book "The limits to growth" (Meadows et al. 1972) in which the earth's human-environment system, including industrial development, is simulated by using Forrester's System Dynamics (1961, 1972). The model predicted the collapse of the earth system in several scenarios, amongst others, due to overpopulation, environmental pollution, as well as the depletion of resources and thus contributed to creating environmental awareness in its audience.

Heinz von Foerster followed a constructivist approach by considering the observer or investigator of a system. He coined the notion of second-order cybernetics or the cybernetics of cybernetics, in which the modeller, or cybernetician, influences the observed system and is influenced by it (von Foerster 1974, 1995). The concept of self-referentiality can be rediscovered in sociological systems theories. Niklas Luhmann's social systems are autopoietic or self-referential in that they reproduce themselves by communication or meaning (1984). Luhmann's theory is partially based on Talcott Parson's theory of the social system (1951) which, in turn, derives from Parson's action theory (1937) and is inspired, amongst others, by Wiener's cybernetics.

Cybernetics (from Greek *kybernetes* "steersman, governor" and *kybernisis* "government, regime") is the science of the rules for the regulation and control of systems. A central idea of cybernetics is that systems can reach a dynamic equilibrium through information processing using feedback loops. This form of stabilisation is called closed loop control and can be seen as a form of systemic self-regulation. A feedback loop is a cause-effect chain (of flows of matter, energy, or information) that has a circular shape so that cause and effect cannot be distinguished anymore. Such objects are, for instance, analysed in mathematical graph theory.

Unlike the traditional understanding of causal relations, a systemic or cybernetic view focuses on the notion of interdependencies, which are characterised by circular causal relations. A system element is not necessarily the single cause of an effect. The element itself again may be influenced by the entity it is affecting, not to mention other variables. Although the causal abstraction of cause and effect is still a component of observed interrelations, systemic descriptions and explanations are never reduced to the mere causality. The aim of systems sciences is more of a holistic analysis of an interplay of entities than its reduction to atomistic explanations.

Positive and negative feedback loops can be differentiated. The latter are used for closed loop control and are also called balancing feedback loops due to their potentially stabilising properties. In a negative feedback loop, an output parameter of a process, e. g. a signal, is fed back to the input or the origin of the process with opposite sign, whereby it counteracts or reduces the input parameter (Figure 2.1). In doing so, the regulation mechanism is able to limit growth as well as oscillations and stabilises the process under certain conditions. It is, therefore, also contributing to the resilience of the process (cf. Holling 1973). Closed loop control is used in mechanical and electrical engineering but negative feedback loops can also be found, for instance, in the hormonal regulation of living organisms, predator-prey interaction, counter-cyclical fiscal policy, social behaviour, or learning processes. Balancing feedbacks are said to be reliable even with model uncertainties or when the model structure does not exactly represent the observed processes (Wiener 1948).

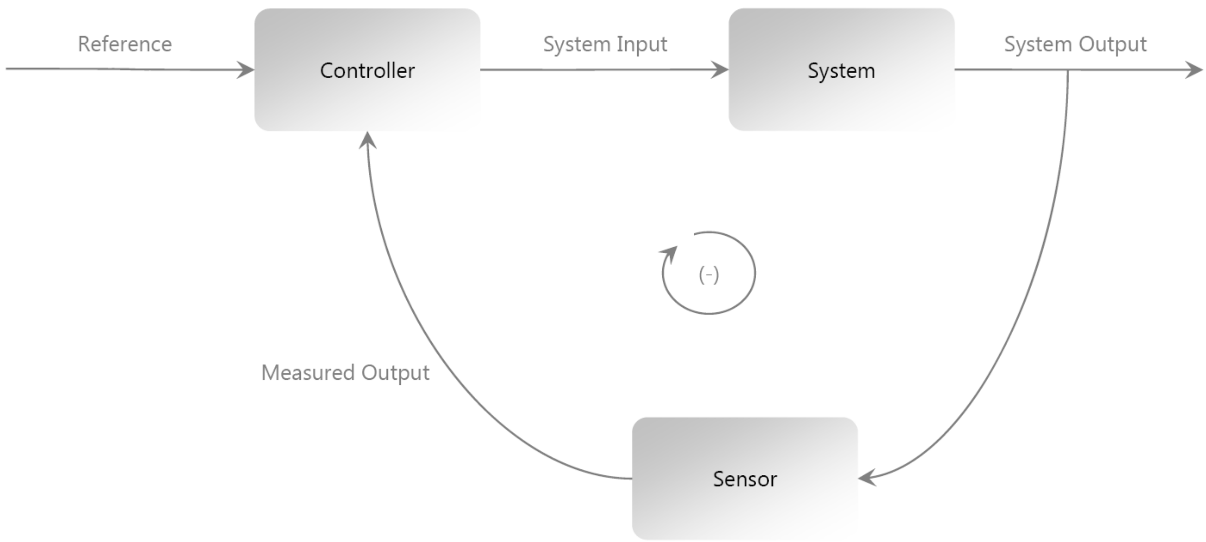

Figure 2.1 The basic principle of closed loop control

In a positive feedback loop, however, the output parameter is fed back with the same sign, whereby it amplifies the input parameter. Such a self-reinforcing feedback loop might lead to a build-up or collapse of the process under certain conditions. It has to be emphasised that the terms "positive" and "negative" might be somewhat misleading in this context, since they do not necessarily implicate an increase or a decrease of systemic processes.

From the graph theory perspective, a feedback loop can comprise any number of nodes (system elements or variables) and edges (interrelations or interdependencies) between each pair of them, as long as the whole chain forms a loop. The interdependencies can be positively or negatively related. In this case, negative feedback loops consist of any number of positively related interdependencies and/or of an uneven number of negatively related interdependencies. Positive feedback loops, however, consist of any number of positively related interdependencies and/or of an even number of negatively related interdependencies.

The actual behaviour of a feedback loop depends on whether the impulse(s) or signal(s) between system variables is (are) either amplified or damped. Negative feedbacks only have a balancing nature if an impulse sent out by a variable returns with the opposite sign and if the impulse is damped (i. e. it is multiplied by a factor w between -1 and 0; Figure 2.2). This is independent of the initial impulse's sign, e. g. an increase or a decrease of the initial variable. In other cases, negative feedbacks lead to constant oscillation (if the factor w equals -1; Figure 2.2) or even an increasing oscillation (if the factor w is less than -1; Figure 2.2).

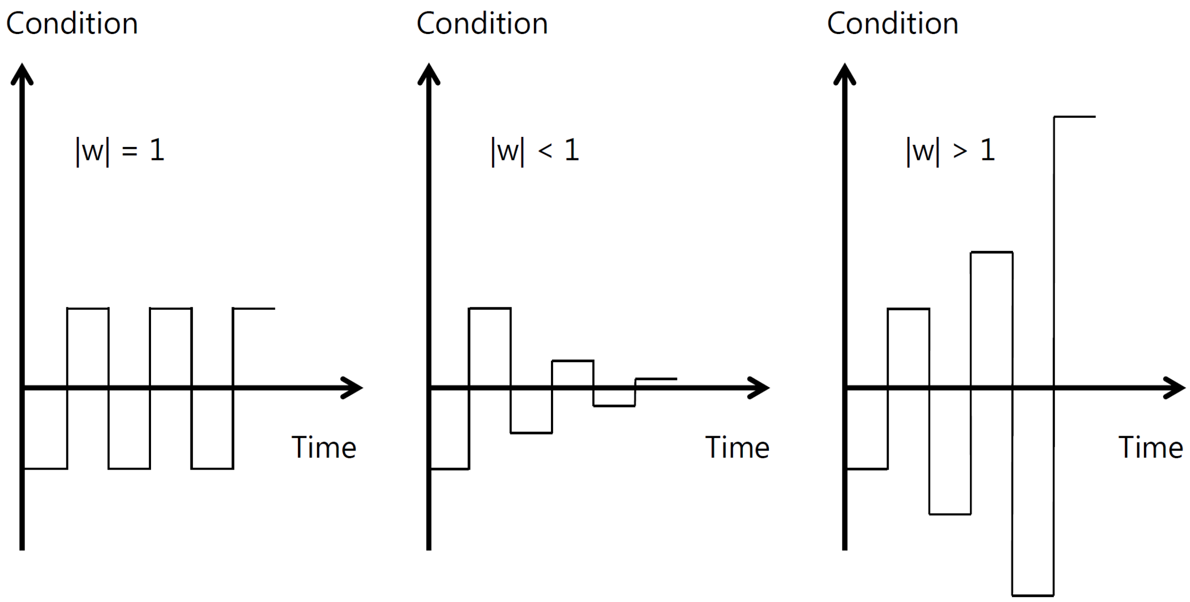

Figure 2.2 Negative feedback loops (adapted from Matthies 2003)

Positive feedback loops might have a self-reinforcing nature, since an impulse sent out by a variable returns with the same sign. This is again independent of the initial impulse's sign, e. g. an increase or a decrease of the initial variable. Positive feedbacks can lead to linear growth (if the factor w equals +1; Figure 2.3) or exponential growth (if the factor w is greater than +1; Figure 2.3). As long as the impulse is damped (i. e. the factor w is between 0 and +1), however, positive feedbacks will reach a state of equilibrium after a period of decreasing growth (Figure 2.3).

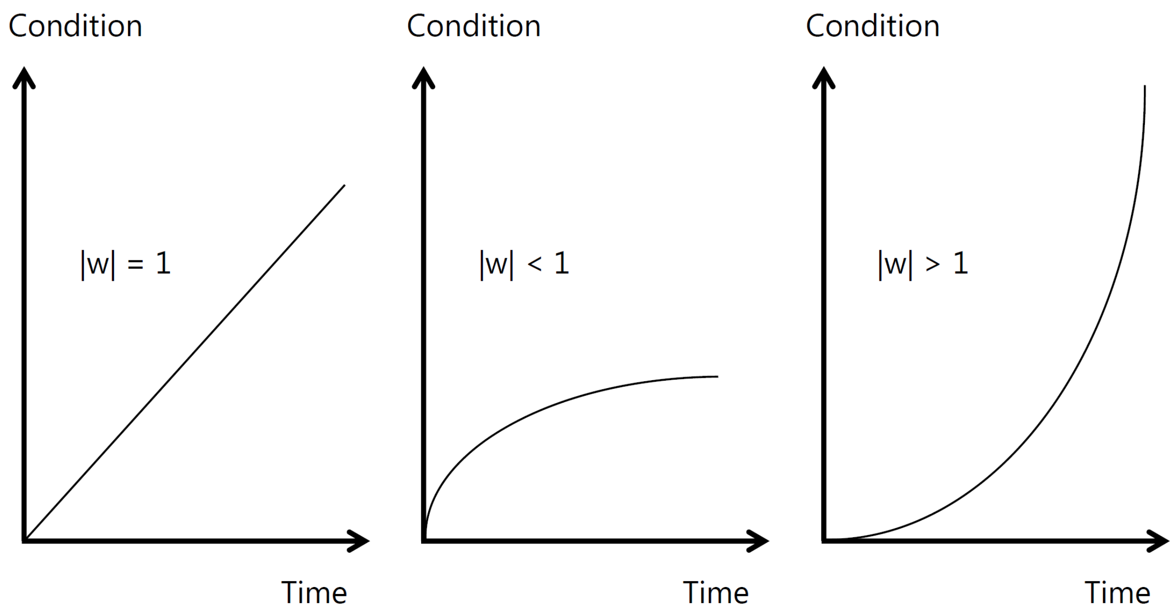

Figure 2.3 Positive feedback loops (adapted from Matthies 2003)

In this respect, negative feedback loops might be used for closed loop control, in order to control or stabilise a (sub-) system, on the one hand. On the other, they might also lead to a stabilisation or resiliency of undesirable circumstances or processes, e. g. poverty, and can be interpreted as vicious circles. In his systemic or cybernetic theory of development, the sociologist Raymond Boudon (1979) speaks about vicious circles of reproductive processes. This kind of stagnation is seen as a key factor that prevents any form of social change or transformation.

Furthermore, positive feedback loops are not only destabilising self-reinforcing mechanisms that lead to a build up or a collapse of processes but also mechanisms that are able to create a momentum to initiate transformations or desirable developments. Boudon (1979) states that the way out of vicious circles of reproductive processes are so-called cumulative processes, in which stocks are built up through cumulation, just as in self-reinforcing feedback loops. As described, these feedbacks will eventually reach a new dynamic equilibrium and lead to a stabilisation of the growth as long as they can be controlled.

2.2 Socio-technical regimes and regime transformations

Water supply systems can be seen as socio-technical systems (Joerges 1988, Mayntz 1988, cited in Monstadt, Naumann 2004). The concept of socio-technical systems refers, on the one hand, to the interdependencies between society and technology. Social and technological aspects of an observed system are inseparable and, thus, cannot be considered or analysed separately. On the other hand, it refers to general systems theory.

The concept of socio-technical systems arose in the field of organisation and labour studies (Emery, Trist 1960; cited in Ropohl 1999b). Ropohl (1979, 1999a) suggested it as a general concept to describe and explain technology. A number of social scientists have applied a broader concept of technology. Instead of the engineer's view of the (material) artefact or technique, they extended their focus and included the political, administrational, institutional, economical, social, and cultural context of an observed technology. Well-known examples are Thomas Hughes' studies on the evolution of large technical systems (1983, 1999), Bruno Latour's Actor-Network Theory (2007), and, in general, the research field of Science, Technology and Society studies (STS). In summary, it can be said that technologies are seen as "socially shaped and society shaping" (Hughes 1987, cited in Berkhout et al. 2003).

In order to explain technological stability, change, innovation, and transition, researchers have employed the concept of technological regimes (van de Poel, Franssen 2002). Nelson and Winter (1977, 1982) are supposed to be the first ones to use the notion of technological regimes in the context of an evolutionary theory of economic change (van de Poel 2003). Rip and Kemp (1998) define technological regimes as (cited in van de Poel, Franssen 2002):

> *"The rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures."*

This rule set is said to guide the search activities of engineers as well as the actions and interactions of other actors involved in technological development (van de Poel 2003). The concept of technological regimes is able to describe and explain the predominance of a (dominant) technique as well as the rules that enable or constrain directions of development (van de Poel, Franssen 2002). Hence, it is supposed to be promising for the understanding of technological development and developing options for steering or managing technology in society.

One definition of transitions is that they are interdependent transformation processes that take place in several different areas such as society, technology, economy, institutions, behaviour, culture, ecology, and belief systems (Rotmans, Kemp, Asselt 2001). Another definition says that a technological regime is transformed if one or more of its core or constitutive rules change (van de Poel 2003). These rules refer to design criteria, design tools, promises, expectations, or guiding principles (van de Poel 2003). In both definitions, a transition is a change from one to another dynamic equilibrium of a socio-technical system.

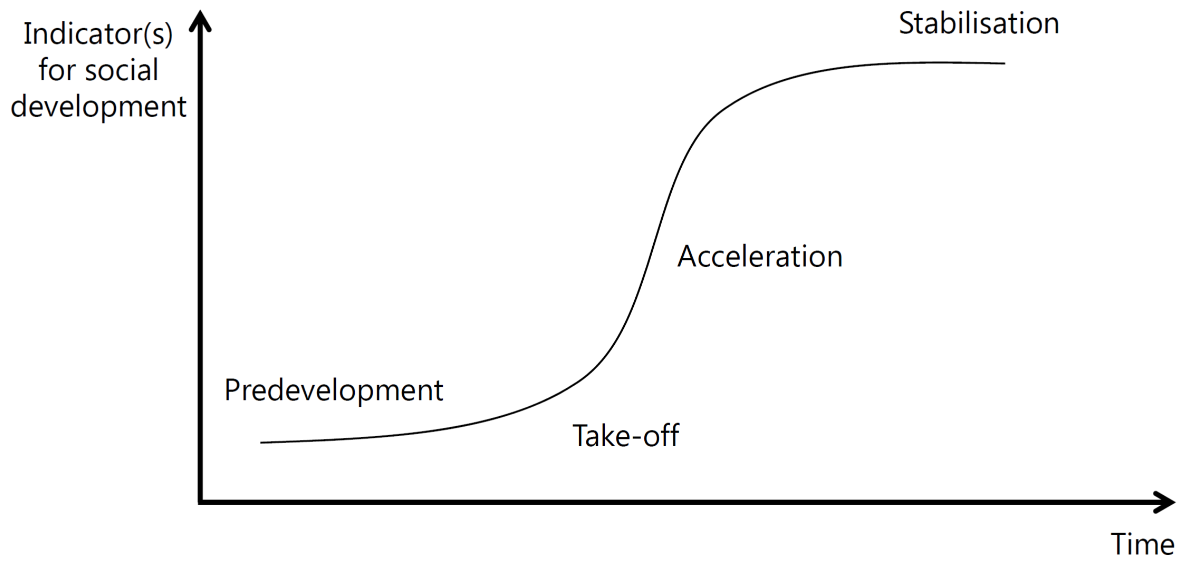

Figure 2.4 Transition phases (adapted from Rotmans, Kemp, Asselt 2001)

Four different phases can be distinguished during transition processes (Rotmans, Kemp, Asselt 2001; Figure 2.4). The transition starts with a predevelopment phase in which no visible changes to the status quo occur. In the take-off phase, the state of the systems begins to shift. Structural changes accelerate in the breakthrough phase, due to an accumulation of socio-cultural, economic, institutional, and ecological changes. These processes are self-reinforcing because of positive feedback loops (Rotmans, Kemp, Asselt 2001). In the stabilization phase, finally, the speed of change decreases and a new dynamic equilibrium is reached.

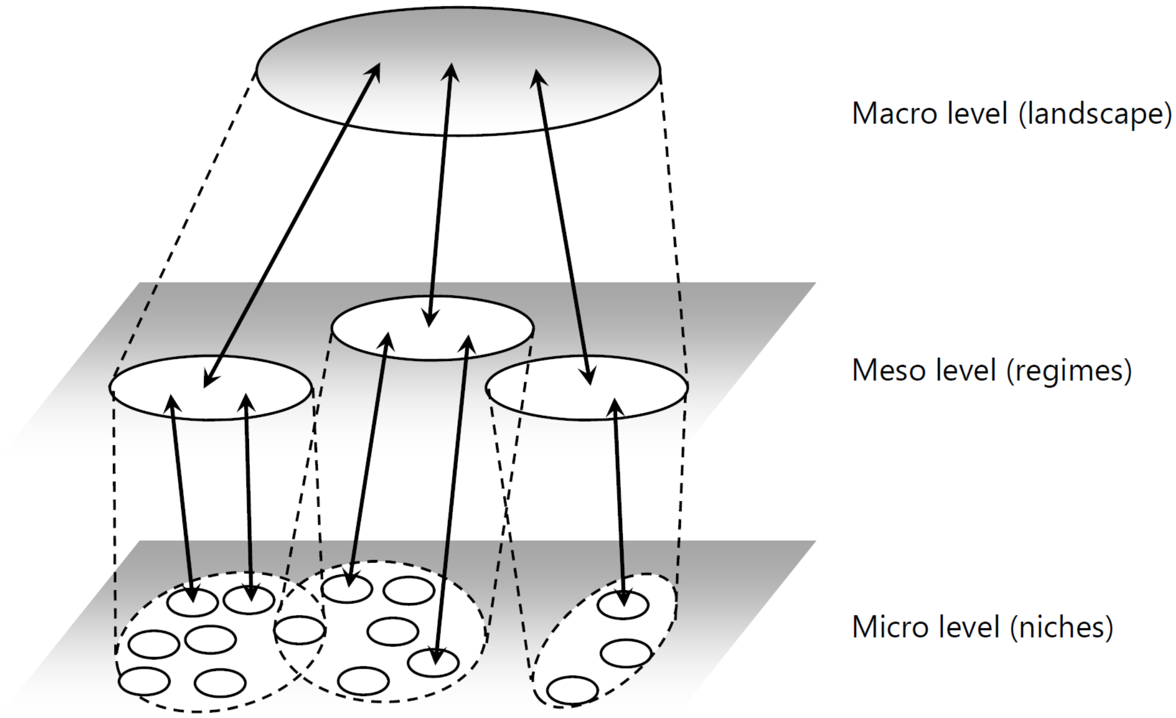

Figure 2.5 Multi-level approach in transition research (adapted from Rotmans, Kemp, Asselt 2001)

A multi-level approach has been developed by transition management researchers in order to describe changes in socio-technical systems (Rip, Kemp 1998; Geels, Kemp 2000; Rotmans, Kemp, van Asselt 2001). In this model, technological regimes are located at the meso level (Figure 2.5). At the macro level, they are embedded in a socio-technical landscape that comprises material infrastructure, political culture and coalitions, social values, world views and paradigms, the macro economy, demography, and the natural environment (Rotmans, Kemp, van Asselt 2001). The micro or niche level, in turn, refers to individual actors and technologies as well as to local practices (Rotmans, Kemp, van Asselt 2001). Niches are supposed to be protected spaces for the development of new and/or alternative techniques by means of experimentation, since they are free from market pressures (Kemp et al. 1998). Furthermore, niches are said to be important for the development of radical innovations that may help to transform existing technological regimes (Kemp et al. 1998, 2001; cited in van de Poel 2003). The development of new artefacts is supposed to be crucial for the successful transformation of a technological regime (van de Poel 2003). However, innovations are not very radical, due to the inherent properties of the artefacts developed. It is rather the ability of radical innovations to transform some of the core rules of the existing regime (van de Poel 2003). Furthermore, there is no guarantee that the artefact actually designed and produced will have the desirable properties even if actors agree on the technical features and specifications an artefact has to meet (van de Poel 2003).

Changes at the niche level are said to occur comparably fast and may be non-linear, while transitions at the regime level take longer. Studies show that transitions at the landscape level may even take between 50 and 100 years (Rotmans, Kemp, Asselt 2001). However, so-called windows of opportunity might be opened up by radical external and internal changes, such as incidents, accidents, catastrophes, revolutions, paradigm shifts, or simply changing user needs, which can accelerate transition processes. A specific niche technique might accumulate and, eventually, reach a critical mass. Thereby, the hegemony at the regime level might shift from the dominant technology to a niche technology.

The directions of development a technological regime can take (technological trajectories) is crucially influenced by so-called technological paradigms (Dosi 1982). In this sense, engineers and decision makers of a technological regime decide in which direction it develops as well as how and which problems are solved based on their values, experiences, and motives. This might be one of the reasons why such systems tend to sustain themselves. Actors in charge therefore might rather perceive transformation as a threat than as an opportunity. Systems remain in a state of self-preservation and self-referentiality (cf. Luhmann 1984). A technological regime's inertia or persistence, thus, might lead to path dependencies and a lock-in in an unsustainable state.

Nevertheless, beside self-reinforcing feedback loops and niche technologies, inherent innovation patterns of existing technological regimes play a considerable role within regime transformation and the development of radical innovations (van de Poel 2003). Furthermore, outsiders are supposed to play an important role (Tushman, Anderson 1986; Utterback 1994; Bijker 1995; van de Poel 2000, 2003). However, some researchers state that transitions are not only niche-based and, thus, suggest a transition typology, i. e. regime changes through endogenous renewal, re-orientation of trajectories, emergent transformation, and purposive transitions (Berkhout, Smith, Stirling 2003).

From a niche-based perspective, a regime transition is said to be completed when a niche technology has been established alongside a dominant technology or when it has fully replaced the latter. Although transition processes are never deterministic and, thus, cannot be controlled entirely, they can at least be influenced by management or government policy (Koziol, Veit, Walther 2006). Transitions can involve a number of possible development paths whose direction, scale, and speed can be modified to a certain degree (Rotmans, Kemp, Asselt 2001) by using the model of technological regimes and transitions as a method for change.

A wide range of stakeholders on different levels is usually involved in transition processes (Geels et al. 2008), e. g. engineers and researchers, market-based actors, such as companies, government and policy-makers, as well as actors from the civil society, such as interest groups, NGOs, and other organisations and individuals. The process of creating shared visions and goals can be accompanied and conducted by transition management. In this context, it has to be considered that every stakeholder might have a different preference and a different power to influence the decision making process. These power relations bias the interactions among the actors and might, therefore, enable or impede transformation (cf. Foucault 1982). The governance of socio-technical transitions is, hence, less top-down oriented and rather seeks to embrace a multiplicity of world views and problem perceptions through a broad participation of stakeholders, in order to create a common transition objective, transition visions, and, thus, public support (Rotmans et al. 2001).

3 Model building

When dealing with interdependent problems as in the described case study, conventional deductive methodologies used by water engineers and planners are not appropriate. A fundamental question is which requirements an adequate methodology should meet. First of all, it should be grounded in social-empirical terms in order to take relevant social processes and cultural aspects as well as the stakeholders' perceptions into account. At the same time, the method should be capable of modelling systemic interdependencies. Only in very few cases will both aspects be completely combined, which is why corresponding interfaces have to exist that allow for a seamless integration of social-empirical data and modelling.

3.1 Grounded Theory

In this study, individual interviews were conducted, since group-oriented approaches often bring many problems and disadvantages for the integration of stakeholders. These problems mainly centre around group-dynamic processes which bias or, at worst, annul the validity of the collected data. For instance, groups tend to discuss in an unstructured or inaccurate manner (Rogers, Roethlisberger 1988; cited in Vennix 1999) or they try to avoid any conflicts, which leads to a lack of critical reflexion on the topics discussed (Janis, Mann 1977; cited in Vennix 1999), and finally, the participants often adopt a defensive position to prevent a loss of face, which also leads to a negative interview quality (Klimoski, Karol 1976; Argyris 1994; cited in Vennix 1999). Furthermore, the opinion leadership of individuals or factions within the group, and power constellations based on gender, age, ethnicity, religion, or traditional hierarchies play a major role. This is why the application of group interviews in the context of developing countries is limited and, in the particular Namibian case, rejected, since local traditional authorities can influence and bias the discussion.

Individual interviews can be distinguished methodologically as well as in terms of their scientific-theoretical approach. Centralised top-down approaches are deductive and thus do not meet the requirements of participatory research, which are of crucial importance in a development context. The preconceived hypotheses used in such approaches impose theories on the data. Hence, inductive methods have to be considered that allow for a direct and systematic derivation of hypotheses or models out of the underlying data. One of the most prominent representatives of inductive social-empirical methods is the so-called

Grounded Theory (Glaser, Holton 2004). This approach was developed by the sociologists Barney Glaser and Anselm Strauss in the 1960s (Glaser, Strauss 1967). Although, in principle, quantitative data can also be used, only qualitative data was recorded in the present example. Several qualitative social-empirical methods are available, such as structured, focused, or semi-structured interviews. By systematic evaluation or so-called theoretical coding, codes or concepts can be identified in the interview transcripts that are empirically grounded and not biased by preconceived assumptions (Glaser, Holton 2004). These codes are topics or problems that have been mentioned by the interviewees repeatedly and can be analysed, for instance, in terms of ambiguities or heterogeneities. To analyse the interrelations among codes, a so-called coding paradigm and axial coding (Strauss, Corbin 1990) have been used. These comprise general theoretical concepts, such as phenomena, causal relations, actions of actors etc. (Kelle 2005), and will be described below. The data was constantly compared with previously identified codes or concepts in order to assign it to existing concepts or to generate new concepts. This procedure is called the constant comparative method. Through this iterative and recursive analysis, it is ensured that all relevant aspects are considered. In doing so, it is possible to create a verbal model of the system which allows for the description and explanation of the systemic interdependencies while also comprehending the world views or perceptions of all stakeholders. The name “Grounded Theory” might be misleading, since its application results in hypotheses or an empirically grounded model rather than in a theory in a narrower sense. Apart from this, the method aims at social phenomena and processes. Nevertheless, the individual and collective reconstruction of a system’s functionality and its problems must be seen as such a process.

The sample of the empirical survey consists of more than 60 interviews with 53 interviewees. During a field trip in 2007, 36 interviews with 28 interviewees were conducted. In a second field trip in 2009, 25 interviewees were questioned. In the last case, the interviewees were accompanied by the interviewer for a period of roughly two months. Hence, a rudimentary participant observation could also be carried out to identify and analyse the routines and perceptions of the water users. Relevant stakeholders from the international, national, regional, and local level were interviewed (Figure 3.1). The interviewees can be assigned to different areas but the focus is on water users and representatives of the water sector. In addition, officials from ministries, administration and politics, from national and international governmental and parastatal organisations, as well as from NGOs and scientific institutions were surveyed. Consulting engineers, traditional authorities, and other individuals such as water users were also questioned. Without the latter, insights, especially into rural conditions, would not have been possible. The broad spectrum of interviewees ensures that the points of view of those who make policies and influence the system, as well as of those who are affected, are included. The decision which stakeholder to interview next or which data to collect next was not only guided by the idea of covering a broad range of stakeholder groups but also by recommendations of the interviewees. This procedure is called theoretical sampling. New data was collected until no more new codes or concepts emerged and a so-called theoretical saturation occurred.

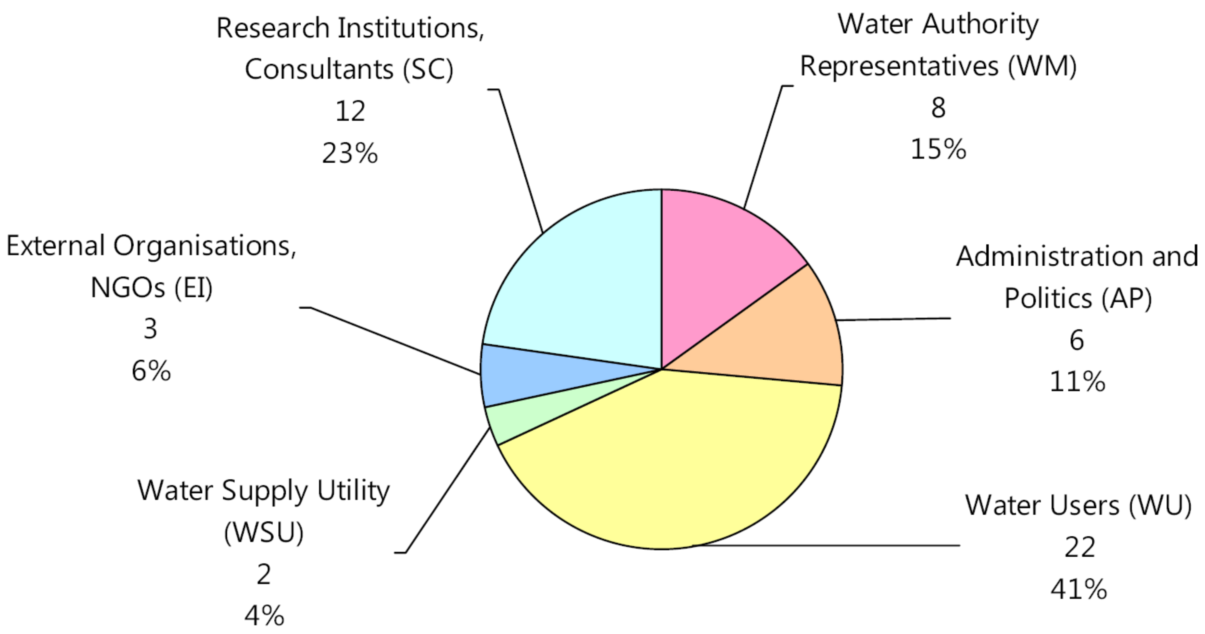

Figure 3.1 Number and affiliation of the interviewees

The discussions were conceived as semi-structured or focused interviews to meet the requirements of the inductive approach. Contrary to structured interviews, no preconceived questionnaires were used; thus, the conversation was kept thematically open as long as possible, which allowed for an unaffected integration of the interviewees' world views. The only guideline for the conduct of the interviews and for the evaluation of the interview transcripts (axial coding) was the focus on the provision, acquisition, and utilisation of water, including all impacts, effects, requirements, and constraints on the system that were observed and identified. These interdependencies comprise technological, ecological, social, economic, as well as political and institutional aspects. Furthermore, the observed interrelations were explored in terms of time and space, for instance, with regard to past and assumed future developments. In this context, path dependencies are of particular interest. For the spatial dimension, the differentiation between urban and rural structural classes is crucial. An analysis of the involved actors and stakeholders was also conducted. Not only was specific information about these groups recorded, but also details of their relationships to each other, as well as constellations within the network of actors. Thus, their perceptions of problems, goals, interests, influence, power, expectations, and options for action could be identified, as well as how they were affected by systemic impacts and/or actions. This implies a clear distinction between a deterministic system of entities, which is described with the system variables mentioned above, and a contingent system of actions (Ropohl 2005). Since the focus is on the perceptions of the interviewees, the identified interdependencies are, of course, ambiguous. Although there are some approaches, e. g. the Dynamic Actor Network Analysis (Bots, van Twist, van Duin 1999), the system of actions will not be modelled in terms of causal relations. Beyond that, no other approaches for stakeholder analysis, such as the Actor-centred Institutionalism (Mayntz, Scharpf 1995), have been considered, because this would have diverted the study's focus into a different direction.

Apart from that, Grounded Theory as it is applied in this study provides two major results: On the one hand, a set of codes (or system variables as they will be called below) including their properties and, on the other hand, interdependencies between each two of them. Although Grounded Theory could be used beyond the process of model building, it only serves to create the basic qualitative model in this study. Further analytical and interpretive steps will be taken over by modelling techniques presented in Chapter 4.

In addition, it has to be mentioned that certain water supply techniques tested by the research project CuveWaters were known to most of the interviewees. This is due to the fact that the techniques were presented to them during preliminary project workshops, for instance. Hence, the interviewees' statements also contain their views and opinions on these technologies. The decentralised water supply techniques for rural areas comprise rainwater harvesting (RWH), groundwater desalination, and floodwater harvesting. The technical solutions will be briefly explained below in the context of each corresponding system variable.

The interview transcripts were rendered anonymous and reference numbers are used for each interview (Table A.1). The first section of the number refers to the phase of data collection. The interviews of the 07a phase were conducted by two interviewers[1], whereas the interviews of the 07b and the 09 phase were carried out by the author alone. The second section of the number relates to the stakeholder group of each interviewee. WM comprises representatives of the Ministry of Agriculture, Water, and Forestry as well as its Directorate of Rural Water Supply. Officials of NamWater are assigned to the group WSU. Representatives of other ministries as well as of administration and politics in general are subsumed under AP. The group WU comprises individuals, especially (rural) water users but also traditional authorities. Officials of national and international governmental as well as parastatal and non-governmental organisations (NGOs) are assigned to EI. Interviewees from scientific institutions and also consulting engineers are subsumed under SC. The third section of the reference number is the consecutive number of the interviewee. However, in some cases, more than one code refers to the same interviewee as in the case of 09-SC-01 and 07b-SC-03; 07a-WM-02, 07a-WM-03, and 07b-WM-01; 07a-WM-01, 07a-WM-10, and 07b-WM-04; 07a-WSU-01 and 07a-WSU-02. This is due to the fact that either the interview was conducted in a different context or the contents of an interview necessitated a separate entry.

3.2 Identification of system variables

The set of system variables consists of 37 elements, which are shown in Table 3.1. The variables are arranged in five groups according to their analytical dimension, i. e. technology; politics, institutions, and organisation; ecology; society and culture; as well as economy. What the system elements represent will be explained briefly below.

[1] These interviews were conducted together with Dr. Stefan Liehr from the Institute for Social-Ecological Research (ISOE, Frankfurt/Main, Germany) within the research project CuveWaters.

Table 3.1 Full set of system variables

Dimension	No.	Name of system variable
Technological dimension (TE)	1	Large-scale water supply
	2	Technical problems with the large-scale water supply system
	3	Oshanas and excavation dams (Omatale)
	4	Shallow dug wells (Omuthima)
	5	Groundwater and dug wells (Oshikweyo)
	6	Rainwater harvesting
	7	Sanitation problems
	8	Other water supply techniques
Political, institutional, and organisational dimension (PI)	9	Governance and management problems
	10	Water supply and sanitation policies
	11	Land policies
	12	Integration and decentralisation
	13	Inter-regional conflicts
Ecological dimension (EL)	14	Scarcity of water resources
	15	Salinity of groundwater
	16	Floods, droughts, and climate change
	17	Poor quality and availability of grazing land
	18	Soil degradation
	19	Deforestation
	20	Environmental pollution and risks for biodiversity
Social and cultural dimension (SC)	21	Population growth and migration
	22	Urbanisation
	23	Rural concentration and immobility
	24	Health
	25	Disparities and exclusion
	26	Low level of education and understanding of water issues
	27	Perception of water prices
	28	Self-organisation and participation of users
	29	Misuse and vandalism
	30	Security of water supply
	31	Security of food supply
Economical dimension (EN)	32	Subsistence and poverty
	33	Traditional crop farming
	34	Traditional livestock farming
	35	Lack of irrigation and horticulture
	36	Weak regional economy
	37	Angolan water demand

(1) Large-scale water supply. The first system variable comprises not only the technical infrastructure described, i. e., the canal from the Kunene River, four water treatment plants, and the pipeline scheme which covers almost the whole region, but also its institutional and administrative framework. Apart from this, the system variable is characterised by its current tendency to grow continually and its actual capacity limits.

(2) Technical problems with the large-scale water supply system. The second system element deals with problems within the large-scale water supply system, e. g. water losses, vandalism, misuse, and problems with maintenance.

(3) Oshanas and excavation dams (Omatale). Oshanas are the ephemeral and intermittent rivers of which the Cuvelai system consists. They bring the surface runoff from southern Angola's precipitation into the region. Oshana water can be used during the rainy season and it is also possible to retain it with excavation dams (Omatale).

(4) Shallow dug wells (Omuthima). Omuthima are shallow dug wells that are mainly used for the storage of Oshana runoff. This traditional technique has been used for generations.

(5) Groundwater and dug wells (Oshikweyo). Hand dug wells are a common method for making use of groundwater resources and can mainly be found in undeveloped rural areas, less often in peri-urban areas.

(6) Rainwater harvesting (RWH). Corrugated iron roofs are common in peri-urban and developed rural areas and ideal for the purpose of RWH. In the majority of cases, however, this potential is not used by the population.

(7) Sanitation problems. In the urban areas, approximately half of the households are connected to the central sewage system that consists of sewers and oxidation ponds. In peri-urban and rural areas, only a few inhabitants can afford a pit latrine.

(8) Other water supply techniques. This variable includes potential alternatives and options that are no longer in use, such as historical dams, deep groundwater, distant water resources, and small to medium-scale water treatment techniques.

(9) Governance and management problems. The first system element of the political, institutional, and organisational dimension comprises organisational deficiencies in politics, administration, and water supply management, including financial problems and poor governance.

(10) Water supply and sanitation policies. An agreement between Namibia and Angola to share the Kunene runoff is of particular importance for the region. This is considered as a key system element by some interviewees.

(11) Land policies. This element comprises the traditional management of communal land and the administrative regulation of commercial land. Problems and effects on a sustainable use of land and water resources are subsumed here.

(12) Integration and decentralisation. These topics refer to the problems of a joint management of land and water resources as well as the problems of political and administrative decentralisation processes that also affect the organisation of water supply services.

(13) Inter-regional conflicts. Conflicts between Angola and Namibia are theoretically possible, due to the limited amount of Kunene water. Furthermore, competition for grazing land within northern Namibia can be observed.

(14) Scarcity of water resources. The first system variable of the ecological dimension addresses the hydrological availability of several water resources, i. e., surface water, groundwater, and precipitation. Their depletion, due to overexploitation and declining groundwater tables, is discussed here.

(15) Salinity of groundwater. Apart from the mere availability of groundwater, aquifers prove to be saline in large parts of the region. The salinity even seems to be increasing, according to observations, which is a severe problem for people and livestock in the region.

(16) Floods, droughts, and climate change. This variable comprises exogenous shocks to the system in terms of natural hazards. In particular, climate change is controversially discussed by the interviewees. Nevertheless, these issues implicate effects on currently used and possible future water supply techniques.

(17) Poor quality and availability of grazing land. A deterioration of grazing land in terms of quality and quantity is observed by the interviewees. This is mainly due to the high livestock density. Another reason mentioned is the increasing immobility of farmers, which possibly stems from land management and water infrastructure.

(18) Soil Degradation. Especially bad agricultural practices, due to a lack of knowledge and skills, contribute to soil deterioration. Natural hazards might intensify the situation and jeopardise the regional food supply.

(19) Deforestation. The population's high demand for wood causes deforestation which, in turn, contributes to desertification. This is seen as a serious problem in the region, due to the lack of awareness regarding sustainable use of natural resources.

(20) Environmental pollution and risks for biodiversity. The growing population produces an increasing amount of waste, which is a danger for ecosystems and society. Furthermore, water supply techniques, such as the open canal from

Angola but also earth dams in Oshanas, influence and change regional fish populations.

(21) Population growth and migration. Birth rates and gross immigration into the region are high. The first system variable of the social and cultural dimension addresses socio-economic reasons for these processes, implications for the functionality of the water supply system, as well as the emigration of well-educated people and the role of HIV/AIDS.

(22) Urbanisation. This variable is closely related to population growth and migration. Mostly young people leave the rural areas and move into the peri-urban informal settlements of major cities for supposedly better job opportunities. This leads to changing water usage patterns.

(23) Rural concentration and immobility. It is controversially discussed whether water supply infrastructures impede or contribute to concentration processes. Beside other social and technical infrastructures, water pipelines might induce people to stay in rural areas and reduce the necessity to move.

(24) Health. Health hazards stem from using unsafe water sources. However, poverty, the lack of education, hygiene, and sanitary facilities, alcohol consumption, HIV/AIDS, as well as water-related diseases, such as malaria, bilharzia, and cholera, also play a considerable role.

(25) Disparities and exclusion. Although it is said that the water supply scheme covers 80 to 90 % of the population in central northern Namibia, people in peripheral areas still have no access to tap water. This also applies to other technical infrastructures such as electricity and streets. Furthermore, the gap between rich and poor has an influence on the usage as well as the management of water resources.

(26) Low level of education and understanding of water issues. Educational deficiencies in the population, especially the rural poor, as well as in public services and politics are addressed by the interviewees. This affects the water supply management and the users' understanding of water-related issues.

(27) Perception of water prices. Due to the low level of education and understanding of water issues, water prices are often perceived as being too high. This influences the users' willingness to pay and causes a payment problem. The costs of tap water are often compared to the costs of alternative techniques and, finally, also to the times before Namibia's independence, when water supply services were free of charge.

(28) Self-organisation and participation of users. Public water points are administrated by Committees, which consist of water users. They collect fees and carry out minor repairs. In doing so, an organisation at the grassroots level is ensured. However, since their work is completely voluntary, informal structures, misuse, and a lack of motivation can be observed.

(29) Misuse and vandalism. Illegal withdrawals of water for several purposes can be observed at the open canal, such as irrigation, livestock watering, washing laundry, and construction works. Sometimes even parts of the canal's concrete walls are removed or pumps and hoses are used to extract water.

(30) Security of water supply. The dependence on external water resources and on a large technical system is considered as a problem. Many variables presented here pose a risk to the regional water supply. Furthermore, besides major and minor complications with pipelines, cut-offs can occur if branch lines run into debt.

(31) Security of food supply. It is said that, in the early 1970s, central northern Namibia was self-sufficient in terms of food. This is not the case anymore. Over-population, lack of agricultural know-how, and the degradation of soils might be a danger for food security.

(32) Subsistence and poverty. This variable is the first one of the economical dimension. The livelihoods of the rural poor are characterised by subsistence farming, unemployment, poverty, and vulnerability. The situation of the peri-urban dwellers is comparable. This has consequences for the financing of water supply services.

(33) Traditional crop farming. Rain-fed cultivation of pearl millet (Mahangu) is one of the pillars of the rural population. This is mainly carried out using simple means and traditional know-how. It is said that the efficiency of farming methods does not provide a sufficient food supply for the population anymore.

(34) Traditional livestock farming. The livestock is the second pillar of the rural population's subsistence and mainly comprises cattle but also goats, donkeys, pigs, and chicken. Water from dug wells, *Omuthima*, *Oshana* or earth dams is used to water the animals. The large number of livestock carries risks for land and water resources.

(35) Lack of irrigation and horticulture. Irrigated agriculture is almost exclusively practiced within governmentally supported projects (e. g. Etunda). Examples of using efficient drip irrigation systems or carrying out gardening are

the exception. The greatest hindrance for a wider implementation of irrigation and horticulture is a lack of know-how.

(36) Weak regional economy. The situation in central northern Namibia is characterised by unemployment, a weak industry sector, and the availability of only basic services. The main problem is that markets are not established, due to a lack of entrepreneurial skills.

(37) Angolan water demand. Although it is not the case at the moment, economic growth, and increased activities are predicted for southern Angola in the long term. It is said that water is being withdrawn illegally for irrigation purposes on the Angolan side of the canal.

3.3 System variables of the technological dimension

In the technical dimension, the terms “technique” or “technology” refer to all observed kinds of acquisition, treatment, and delivery of drinking water. Hence, this implies a broad understanding of the notion of technology. According to theories of the sociology and philosophy of technology (Rammert, Schulz-Schaeffer 2002), technologies range from material artefacts to the mere (immaterial and maybe even implicit) knowledge of, for instance, water sources and qualities. Furthermore, the term “drinking water” is not specified more precisely since waters of differing qualities are used for drinking purposes.

In the following, the interview statements are presented, unless stated otherwise. Scientific expertise was only made use of if necessary, i. e. if statements were obviously wrong. Ambiguous or contradictory statements by the interviewees are also indicated but will be dealt with in detail in Chapter 4.2. The contents are arranged in topics according to the above mentioned codes or system variables. When referring to the “supply side”, officials and experts of the supply utility as well as authority representatives of the corresponding administrative bodies, including politicians, are being referred to (WM, WSU, and AP). The “demand side” consists of stakeholders of the civil society, e. g. water users as well as experts of NGOs, external consultancies, development organisations, and research institutions (WU, EI, and SC).

According to observations made by the author, five spatial categories can be roughly distinguished in the region. They refer to differing settlement structures found in the urban centres and remote peripheral areas. This is particularly important in terms of the allocation or mapping of certain phenomena to these spatial classes. Basically, the categories are subdivided into developed and undeveloped areas, where developed means that an area is supplied with tap water and/or electricity and streets. Developed urban areas are central districts close to a main road in cities like Oshakati or Ondangwa, which are usually connected to a sewage system. Examples for informal urban areas are the nine informal settlements of Oshakati in which 65 to 75 % of the city's population lives. So-called "locations" in rural areas are predominantly characterised by retail outlets, services, crafts, and Cuca shops (Shebeens or public bars) and usually but not necessarily developed. In general, locations can be found along tarred roads but also in rural village centres. Finally, developed rural areas as well as undeveloped rural areas are both mainly characterised by (subsistence) agriculture.

3.3.1 Large-scale water supply

The first system variable is the large technical water supply scheme, which is, of course, a central, if not the most important, system element. The water supply infrastructure is seen as the one with the highest priority compared to traffic or other infrastructures, especially by authority representatives. Thus, the supplier says that the system's benefits outweigh the negative impacts by far. The water supply in the region depends mainly on surface water. Most of the domestic demand is met by pipeline water. The large technical supply scheme is fed by the water of the Kunene River. Around 80 to 90 million m^3 of water are officially withdrawn per year from the Kunene runoff at an extraction point close to Calueque dam on Angolan territory. However, this is just a fractional amount in comparison to the total runoff. As is usual for a surface water source, treatment is necessary to achieve drinking water quality standards. This is accomplished by four treatment plants, of which the Oshakati water treatment facility has the largest output of tap water, with about 1,400 to 1,600 m^3/h. In total, around 3,300 m^3/h of raw water are treated by the four regional plants according to NamWater. The pipeline water is of comparatively high quality.

The water pipeline scheme covers nearly the whole region and provides a tight network of pipes as well as public and private water points. According to NamWater, the infrastructure takes the tap water as far north as Oshikango, as far south as Omapale, and as far east as Omutsegwonime. Depending on the radius around a water point, the percentage coverage of the large technical water supply ranges from 75-80 %, according to the Ministry of Agriculture, Water, and Forestry (MAWF), or up to even 90 %, according to the Department of Rural Water Supply[2] (DRWS). Thus, it is said that only a small percentage of the population remains without access to tap water. But this is not seen as a serious problem, since the expansion of the pipeline branches is continuing. The completion of the Ruacana south and the Amanzi schemes will increase the coverage, so that the entire region is served with potable water. The situation of the population is considered good by the representatives on the supply side, due to the available access to the improved water source.

In rural areas, several public water points as well as private taps are connected to each pipeline branch. Water points are located at every 3 to 5 km, at the least. In the village of Epyeshona, which lies in the Okatana constituency around 5 km north of Oshakati and which has been one of the major locations of the author's field trips, there are three public water points which are located less than 1 km away from the village. These water points belong to the Ekuku-Amatanga branch line, which has a total of seven public taps. Foreign experts are astonished by the high density of water points and consider this unusual for Africa. The Epyeshona water point No. 3, for instance, is used by about 15 households, whereby each so-called homestead consists of between five and 15 inhabitants. Water point No. 2 is used by approximately seven households or around 40 people. The usage of communal taps is not very popular since the water has to be carried in buckets to the users' homesteads. Currently, it is said that the majority of households, around 80 %, are using private taps as far as this is affordable and the number is increasing on this branch of the pipeline.

Limits to the water supply system are not dictated merely by hydrological water availability, as we will see later, but in the capacity of the purification plants, the canal, and the pipeline scheme itself. The main limit, however, is not the treatment capacity of the plants, since these could be upgraded but could still only treat the water reaching them. Thus, the canal capacity is the main limiting factor. According to NamWater, this stands at approximately 2,880 m^3/h at the Oshakati treatment plant, which is where the canal ends. Although a concrete projection has not been made yet, government representatives state that the limitations of the water supply system and its capacity can already be seen.

2 The Directorate has been restructured and renamed as "Directorate of Water Supply and Sanitation Coordination" (DWSSC).

"The [water] supply system is constructed for too few people taken population growth into account." (MAWF official, 07a-WM-08)

Other officials say that the water supply is not the critical factor in the region. An increase in water abstraction from the Kunene River is not expected in the future and the capacity of the canal is sufficient. Challenges such as a growing demand can be dealt with by using technical solutions, e. g. an upgrade of the treatment plants or the expansion of the pipeline system.

The expansion of the pipeline network is an ongoing process, especially in rural areas but also in informal settlements around the major cities of the region. The construction of new pipelines is seen as a necessary measure by the supply side, due to increasing demand caused by population growth. Generally, new pipelines and an increase in the number of water points seem to have only positive connotations and their benefits are emphasised. New water points, through extensions of the pipeline scheme, are expected to reduce the pressure on the existing water points. In the first years of the water supply system, in the mid 1970s, the pipeline was only built along and to existing agglomerations and infrastructure, such as roads, schools etc., which caused an acceleration in the concentration processes. After this phase, the pipelines also spread into less populated areas which slowed down those processes. This also complies with governmental policies to control urbanisation and migration. The only limits to an extension of the network are seen in conservancies or nature reserves. However, the priorities of the supply side are to reach total coverage, so that

"[…] soon everybody will be served with tap water." (Official of the Ministry of Regional Local Government, Housing & Rural Development, 07b-AP-01)

"[The goal] is reached when everybody has access to water." (MAWF official, 07a-WM-08)

3.3.2 Technical problems with the large-scale water supply system

The second technical system variable deals with problems within the large-scale water supply system. These comprise system-inherent water losses and problems with maintenance and repair. The total systemic water losses (including distribution losses), based on estimates of the author, are at least 70 %, realistically 75 % or even more, of which losses due to evaporation and leakages in the open canal account for roughly 65 %.

"Problems of the supply system are leakages and evaporation at the canal part of the system." (Official of the Iishana Basin Management Committee, 07a-WM-05)

According to officials, there are 25 % losses between Calueque and Olushandja and then another 30 % by Oshakati (cf. Figure 1.4). Consultants state, in studies on water losses in the system that were conducted at the beginning of the 2000s, that one day the point will be reached when this cannot be continued anymore. These losses are not only due to evaporation and leakages but also to illegal abstraction for irrigation purposes on the Namibian as well as on the Angolan side of the border, vandalism, and other forms of misuse.

> *"There are a number of damages of the canal walls; […] parts of the concrete wall of the canal are sometimes used as walls for Cuca shops." (Official of the Directorate of Rural Water Supply (DRWS), 07a-WM-07)*

Despite the problems, it was observed that, even at the end of the dry season, the canal was still well filled (Figure 3.2). At some sections, the water level was even above the canal wall. The same applies to Olushandja dam and Calueque dam.

The first installations of the pipeline scheme date back about 35 years, which makes maintenance and repairs necessary. These comprise the modification of structural elements or the replacement of parts of pipeline with new material. It is said that there are many ongoing rehabilitation projects but they face several problems and this is seen as a serious danger for the complete supply system.

> *"The main threat for the water supply system is […] the lack of maintenance of the technical infrastructure." (MAWF official, 07b-WM-04)*

In technical terms, maintenance is problematic due to the length of the pipeline. Furthermore, it is stated that the value and lifespan of the infrastructure is declining. Representatives of the supply utility complain that new pipelines, which are supposed to have a lifespan of 30 years, in reality last only 15. Another problem is the availability of spare parts. The construction materials used often have to be delivered from Windhoek and technicians complain that they have to wait for two weeks for deliveries. The maintenance required due to the aging of the pipeline is very cost intensive. Officials state that the utility lacks money for these purposes, which can sometimes make maintenance impossible.

Figure 3.2 Open canal between Olushandja dam and Oshakati

Finally, problems are also seen in the water treatment processes. The purification of surface water makes flocculation and the use of disinfection chemicals necessary. Their transport, deposit, and handling is said to be difficult, if not dangerous. For instance, the chlorination process is complicated because the production of undesirable carcinogenic disinfection byproducts must be avoided. As a result of these problems, calls for alternatives have become louder.

> *"The water supply is in danger and it is the basis for everything." (DRWS official, 07a-WM-07)*

> *"Alternative sources of water […] are needed to reduce the stress for the pipeline." (DRWS official, 07a-WM-07)*

3.3.3 Oshanas and excavation dams (Omatale)

The region actually has another water supply system, the so-called Oshanas. Usually, once every year, this ephemeral and intermittent river system, the Cuvelai system, brings the surface runoff from southern Angola's precipitation into the region. The water from the Oshanas can be used directly during the rainy season but it is also possible to retain it with excavation dams, so-called "earth dams" or Omatale (singular: Etale; Figure 3.3). They usually, though not necessarily, lie within the Oshanas or are nearby and, in this case, are fed by a hand-dug canal. Omatale have been an important part of the water supply system since the 1960s and can be found everywhere, especially in rural areas, so that the region is almost littered with them. Earth dams are mostly built by using construction machinery, for instance, as a side effect of road works, where sand is needed as an aggregate. Rural communities have been known to try to build Omatale manually but generally, funding, knowledge, and appropriate machines are necessary. This is also the reason why earth dams are less frequent in remote peripheral areas of the region. Omatale vary considerably in size, depending on the design, but the surface areas can be up to 1-2 ha. Their depth can reach 4.5 m at the end of the rainy season and is around 2 to 3 m during the dry period. It is common to call Omatale "earth dams" but, in fact, they are excavation dams, because no dam or weir is built; instead, the bottom of the reservoir is excavated and deepened.

Figure 3.3 Excavation dam (also known as "earth dam" or Etale) in the village of Epyeshona, Okatana constituency, approximately 5 km north of Oshakati

"There have been lots of earth dams in the past but they have been pushed away by the pipeline." (NamWater official, 07a-WSU-01)

Omatale served for decades as water sources but they are not supposed to play an important role anymore because of the availability of tap water. Some authority representatives even state that earth dams therefore need to be protected. In the last few years, the usage patterns of the Omatale water have changed. Whereas, in the past, people could use the water from January until October, it is said that this is not the case anymore. However, it was observed that even at the end of the dry period, the Omatale were still well filled.[3] Locals also say that there is no real scarcity of water. However, it is also said that most of the Omatale dry out during severe droughts. The water is mainly used for watering livestock. In the rainy season, this is done directly at the Oshanas, whereas, during the dry season, the livestock are driven to the Omatale. Nevertheless, the water is also used for human consumption, even as drinking water, especially in peripheral areas and/or by the poor. Although experts know that dams and lakes are polluted and might harbour severe health risks, the general population is not aware of this. Other usages include brick making, the brewing of traditional drinks, or laundry. Oshanas and Omatale also contain fish, which are caught at the beginning of the rainy season.

The main problem of Omatale, besides their water quality, is the high evaporation rate, which can be up to 2,500 mm per year in central northern Namibia (Kluge et al. 2008). However, the sheer size of the earth dams makes up for this. Another negative aspect is the drain on resources caused by the planning and financing of such projects. In ecological terms, Omatale water is always said to be saline. Representatives of the supply utility claim that the Omatale are only suitable for cattle but land has to be cleared for cattle-raising and this leads to deforestation and land degradation. It is also said that there are cases where the authorities have had to compensate for the loss of available land. Furthermore, earth dams can cause problems for downstream ecosystems. In general, experts state that this source is very unreliable and unpredictable, due to rainfall variability. Building activities upstream, such as roads or shopping centres built across or in the middle of Oshanas, can also prevent runoff from the north reaching the earth dams.

One of the major advantages of Omatale is that they are of benefit to an entire community and not just individual households. The idea that, for instance, the Iishana Basin Management Committee (IBMC) should build earth dams around

3 Observed by the author during a field trip in 2009.

villages in the dry period even meets with approval among some politicians. In particular, the rural population desperately wishes to receive support for the construction of Omatale and expressed this at every opportunity. More Omatale would considerably reduce the walking distance to this water source. Foreign experts were astonished that there is still so much water in the dams at the end of the dry season, despite the extreme evaporation rate. One of the main reasons for this is the presence of loamy and silty layers of soil that can be found throughout the region just below surface. These layers mean that hardly any water seeps into the ground. Rural inhabitants report that Omatale only become completely dry during severe droughts, which occur roughly every ten years. Some government representatives even argue that high evaporation rates are advantageous as they lead to more precipitation; this is, however, unrealistic, according to experts. Another important reason why the population asks for more Omatale is that tap water is perceived as too expensive, especially for purposes other than drinking. Even though earth dams are not promoted by officials on the supply side, politicians concede that Omatale would be beneficial for livestock farming. Furthermore, the population does not consider that growing livestock numbers represent a major risk. Earth dams are also essential for the survival of livestock during the dry season. In addition, more Omatale would contribute to improving the nutrition of the population by adding fish to the diet. One of the greatest potential benefits of Omatale is seen in using their water for irrigation purposes. Some consultants state that the installation of a low cost drip irrigation system for a small household garden would require around 600 litres of water per week which could, in theory, be transported by donkey carts.

Omatale are organised by traditional authorities. Usually the headman of a village manages the usage of the earth dam's water. For community members, access to Omatale and withdrawal of water are not restricted. The headman represents the interests of the village vis-à-vis the regional councillor and is responsible for expressing the community's wishes, for example, for a new earth dam. The government also promotes and organises the construction of earth dams to create jobs, as well as to assist rural communities, mainly in watering their livestock but also for household purposes and even irrigation. Hence, research has been carried out in the past to determine optimal sizes and structures of excavation and storage dams with regard to evaporation, depth, volume, and fluctuation of rainfall, as crucial parameters. Nevertheless, one major problem is that government and communities' definitions of earth dams differ. The former generally thinks of large-scale solutions, whereas rural communities think of smaller installations at specific locations, due to their knowledge of local geological and hydrological conditions. Even among government representatives it is not clear which strategy should be pursued. While some say that it would be very helpful for the people if the earth dams were upgraded by removing sediment and deepening them, others state that this is not a solution, due to the salinity of the groundwater. However, there is considerable support for Omatale across different stakeholder groups on the grounds that earth dams provide a good solution and an alternative source of water.

The situation in peri-urban informal settlements is somewhat different. Since the settlements are much more densely populated, there is a lack of space for earth dams but some lakes can still be found, e.g. in Oshakati's suburb of Pohamba. These lakes are also often a result of mechanical excavations during construction activities and are fed directly by precipitation and/or surface waters of Oshanas. Informal settlements are already populated by the poor and the poorest of them have to consume water from this source, although it is of lowest quality, according to municipal officials.

> *"The people cannot afford paying for the tap water and many unemployed people fetch water from the lake. In the future this will be even worse." (Traditional authority, 07a-WU-01)*

> *„This is also a severe health threat because the people drink lake water." (Local politician, 07a-AP-01)*

Within the CuveWaters project, the technique of floodwater harvesting was intended to store the natural runoff from the Oshanas. While, in the rainy season (from November until April), the region is experiencing floods, the whole area may suffer from droughts in the dry season. Especially in the 1960s and 1970s, attempts were made to store Oshana water in pump storage dams and excavation dams, for utilisation in the dry winter season (Stengel 1963). The major problems of these techniques are the high evaporation rate and the declining quality of the stored water. Instead of using open reservoirs, covered subsurface storages were proposed by the CuveWaters project to avoid these disadvantages.[4] However, it was assumed that the provided water would be of me-

4 The capacity of the floodwater harvesting facility actually constructed by the project CuveWaters after the interviews were conducted is 400 m^3. The pilot plant might be able to supply roughly five households over a period of two years or ten households over one year.

dium quality and thus, was mainly intended to be used for small-scale irrigation. Furthermore, the components of floodwater harvesting were supposed to be constructed from local or at least easily available materials.

3.3.4 Shallow dug wells (Omuthima)

A traditional water supply technique that has been used for generations and is still in use are Omuthima (Figure 3.4). These are shallow dug wells that are mainly used for the storage of Oshana runoff, which is why they are also mostly located within the riverbed. Similar to the Omatale, there are also examples where they lie outside and are fed by hand dug canals. Omuthima are 4-5 m in diameter and have a depth of 8-9 m. Local people say that this technique has not been in use for at least 15 years. However, villagers also report that some Omuthima are still in use in other rural places such as Iipopo. It is also said that their disappearance is mainly due to the expansion of the pipeline system. Steps are usually built into the soil of the walls, in the form of a spiral staircase, so that users can reach the water table. Depending on the time of the year, the water level can be at the very bottom, where, sometimes, an additional wooden ladder leads further even downwards. In almost all observed cases, the Omuthima were not maintained and were completely filled with sediment, so that they were inoperable.

The water from Omuthima has been used for human consumption as well as livestock watering in the past. Nowadays they serve, at best, for brick making or washing, if they contain water at all. The rural population even drinks the water, even though it has the poor quality of surface water, but it is said that it has never harmed anybody. Usually, the sediments that are spilled into the well with every flood have to be removed each year. Every Omuthima typically has an owner but every community member who helps to shovel out the deposits is then allowed to extract water.

Omuthima can be found in developed rural areas and close to cities as well as in remote peripheral parts of the region. One of their major advantages is their depth. Compared to Omatale, Omuthima have a much smaller surface to depth ratio, which reduces evaporation. However, they still fall dry much earlier, due to the smaller volume of water stored. Omuthima never contain water throughout the entire dry season. Furthermore, the water can be saline, depending on their location.

Figure 3.4 Abandoned shallow dug well (Omuthima) in the village of Ondiri Nawa, Uuvudhiya constituency, approximately 40 km south-west of Oshakati

For instance, in the village of Epyeshona, at least five Omuthima can be found directly within the local Oshana, but all of them have been abandoned and are no longer maintained. The same applies to further observations in the region. This can be seen as a clear indication that the Omuthima, as a traditional water supply technique, are dying and that water scarcity is not perceived as a problem by the rural population. Among government representatives and officials on the supply side, Omuthima also play no role.

3.3.5 Groundwater and dug wells (Oshikweyo)

Another traditional water supply technique are the so-called Oshikweyo, which are usually hand dug wells with a depth from 2-3 m up to 5-9 m (Figure 3.5). This is the most common method of making use of groundwater resources and can mainly be found in undeveloped rural areas, less often in peri-urban areas. For instance, in the Okatana constituency, it is said that there is only one such well. In the majority of cases, the wells are not protected, which means that they have neither roofing nor brick walls nor an apron. Oshikweyo are often equipped with a winch and a simple bucket-and-rope system for lifting the water. Sometimes ladder rungs are attached to protected walls, to allow for maintenance.

Figure 3.5 Dug well (Oshikweyo) in the village of Ondiri Nawa, Uuvudhiya constituency, approximately 40 km south-west of Oshakati

In the past, water from dug wells has been mainly used for human consumption but also for watering livestock. Nowadays this is only the case in peripheral areas of the region, where there is poor access to pipeline water. Especially in the southern parts of the region, it is said that there is a large number of wells, e. g. at Oponono, because the land is used for grazing cattle herds. In other areas, wells are also used as an additional water source. The main problem with the groundwater quality is the high level of salinity throughout almost the entire region.

> *"In the 1970s and 80s the water wasn't that saline as today." (Local Water Committee member, 07a-WU-02)*

Authority representatives say that this is one of the main reasons why Oshikweyo are hardly used. Since fresh water aquifers are mostly shallow, they dry out quickly, according to government officials, and deeper aquifers have the problem of salinity. Another challenge is that groundwater tables are sinking. Local communities report that it is no longer possible to reach the groundwater with hand dug wells anymore. By October, which is the end of the dry season, up to 70 % of the wells had been abandoned, according to experts. However, the Oshikweyo that the author saw still contained water at the end of the dry period. This was confirmed by the owners, as was the fact that the water was not saline. This may, however, have been an exception. Another water quality issue arises because Oshikweyo for watering livestock have a well-mouth that is large enough for cattle to enter. For this reason, people say the water is usually cleaner in the morning. Furthermore, there are also typical problems connected with unprotected wells, for instance, animals falling into the well and drowning. Several experts stated that dug wells were more sustainable than the pipeline water or Omatale, because Oshikweyo limited the problem of overgrazing in the past. This has again to do with access to water sources and the pressure on farmers to move on to other locations.

In the past, people used to have their own boreholes. Usually, Oshikweyo are exclusively used by their owners, who comprise the homestead's inhabitants. Nowadays, dug wells are not very sought after by the population of developed rural areas. Basically, there are two reasons why Oshikweyo are rejected. Firstly, this is due to the financial resources of the inhabitants. It is said that to dig a well and to arrange for its protection is too expensive. This does not sound very plausible, considering the costs of alternatives. Secondly, there is a cultural issue, which means that in areas where a tap water supply is provided, the reputation of traditional techniques is lower. This might even be the major reason.

> *"If one has a tap, nobody wants wells anymore." (MAWF official, 07a-WM-09)*

Within the CuveWaters project, decentralised and robust techniques for solar groundwater desalination in remote rural areas were proposed as a possible option to cope with the salinity of the groundwater.[5] The facilities were sup-

---

5 Pilot plants were installed in two selected villages of the Omusati Region after the interviews had been conducted (Zimmermann et al. 2010). Two pilot plants were constructed in the village of Amarika (Otamanzi Constituency): a membrane distillation plant of the Fraunhofer Institute for Solar Energy Systems (ISE, Freiburg, Germany) and a Reverse Osmosis (RO) plant of the proaqua company (Mainz, Germany). The latter system produces about 3,3 m^3/d of drinking water, on average. The brine is mainly reinjected into deeper groundwater layers but partly also evaporated in a pond. Furthermore, an ISETT evaporation plant of the Terrawater company (Kiel) with an average fresh water production of 1.4 m^3/d was installed in the village of Akutsima (Okahao Constituency). Additionally, a multi stage desalination plant of the Solarinstitute Jülich (IBEU) with an aver-

posed to be completely solar-driven, due to the lack of conventional sources of energy such as electricity, oil, or gas. The region features a solar radiation of more than 6 kWh/(m²*d) as well as a mean sunshine duration of 8-9 h/d (Mendelsohn et al. 2003) and would, therefore, meet the energy demand of such plants. The basic concept of evaporation systems is that salt water evaporates through solar-thermal heat, for instance, and then condenses by cooling. Alternatively, membrane technology, such as reverse osmosis, can be used to purify the brackish water. In addition, combined options are available, such as membrane distillation. In the CuveWaters project, desalination techniques were proposed for villages of up to 50 households, in order to supply them with drinking water.

The application of desalination techniques was also discussed by the interviewees. It was agreed that treatment is necessary to achieve drinking water quality. Some government officials say that desalination could be a solution to this problem and that it also would not have significant negative effects. However, most representatives say that it would be very optimistic to believe that such technologies could be sustainable. Only if the technique is simple, can it also be viable, but desalination is complicated and expensive. This applies especially to processes of reverse osmosis and, to some extent, also to solar-thermal ones, according to interviewees from the water utility. Examples of experiences with existing cases were given that highlighted several maintenance problems such as missing spare parts and the lack of technical know-how or the inadequate yield of such facilities that could only meet the water requirements of single households but not of communities, let alone livestock. Furthermore, it is said that such technologies would stimulate the people's demand for more services of this kind, which is not wanted by officials on the supply side, due to the related costs. Some of these representatives said desalination is completely inadequate for the level of technology in the region and, thus, not viable. This solution lacks technical robustness as well as trained technicians or caretakers and is too expensive, they state. Another criticism is that an ecologically important issue like the disposal of the brine has not yet been addressed.

age production 500 l/d was built. The brine of both systems is completely evaporated in ponds.

3.3.6 Rainwater harvesting

Rainwater harvesting (RWH) is a technique that is known to most of the interviewees. Usually, three components are needed in order to collect the precipitation: a relatively impermeable catchment area, a delivery system, and a reservoir. Theoretically, roofs as well as ground areas can be used as catchments. Corrugated iron roofs, which are very common in peri-urban and developed rural areas, are ideal for the purpose of RWH, due to their high runoff coefficients of 0.8-0.85 (Gould, Nissen-Petersen 2003). Traditional thatched roofs can be found in rural areas but they are less suitable, because of problems related to runoff, water quality, and shape. For the construction of ground catchments, materials such as compacted soil, plastic sheeting, or concrete can be used. Concrete lined surfaces, for instance, feature relatively high runoff coefficients of 0.73-0.76 (Prinz 1996, Gould & Nissen-Petersen 2003). It can be assumed that rainwater collection has only become widespread since corrugated iron roofs were introduced. Nevertheless, many interviewees also remember that precipitation was harvested during their childhood.

Rainwater can be channelled via more or less sophisticated installations using gutters and downpipes, although this is not very common. Experts state that there is far too little RWH being carried out in the region. In most cases, cooking pots, buckets, and sometimes oil drums are used to collect the runoff directly from the roof, without guttering. According to the local population, this is due to lack of technical know-how and financial resources, because the reservoir is said to be the most cost-intensive part of a RWH system. Apart from the inadequate containers mentioned, there are no traditional methods for storing rainwater. Only a few people can afford plastic tanks for this purpose. The semi-arid region has a precipitation rate of roughly 472 mm per year (Sturm et al. 2009). However, during the rainy season, and up until March, in particular, it is possible to harvest a considerable amount of rainwater. As local people report, rainwater is mainly used for domestic purposes such as washing laundry, cooking, personal hygiene, but also for drinking. The harvested water is not usually treated with filters or the like.

Some representatives on the supply side state that RWH could be useful since nobody knows what consequences a pipeline breakdown would have, whereas others say that there are no advantages at all. The majority of the interviewees are critical of the technique. One major drawback is the relatively small mean annual rainfall, according to officials on the supply side and other experts. This, combined with the high evaporation rate, is said to limit yields to such an extent that RWH does not make sense, anymore. Another problem is seen in the lack of suitable roofs, according to other government representatives and experts. Although the author has seen evidence to the contrary, corrugated iron roofs are supposed to be almost completely absent in the region. Furthermore, it is stated that they are mostly owned by middle-income households, whereas the poor may not be able to afford them, which is an aspect that has to be considered in any plans to promote RWH. The share of the population that does not have the means to pay for such roofing is estimated at about 1 %, compared to 99 % who do, according to government officials. Furthermore, some experts say that dust and sand being blown onto the roofs by the wind can adversely affect water quality. Generally, quality aspects are considered to be very important, since insufficient care and maintenance of catchments and reservoirs can quickly lead to contamination of the collected water. Interviewees on the supply side compare the quality of the rainwater unfavourably to that of potable water.

> *"Collected rainwater is of bad quality. The Kunene has the purest water, so there is no advantage of having rainwater harvesting." (MAWF official, 07b-WM-04)*

Another point of criticism is the cost of such RWH systems. They are said to be economically inefficient, particularly due to the construction materials needed for the storage tank. Depending on the type of reservoir (e. g. made of ferrocement or bricks), materials such as sand, cement, and reinforcing steel are necessary. These may be locally available but they vary in quality and price. There is a wide range of opinions among the experts regarding the availability and quality of local construction materials. Some say that it is completely impossible to use the local sand, for instance, whereas others claim that there are no problems with it at all. Theoretically, self-made gutters and downpipes could be used instead of ready-made ones, to reduce costs, but investigations showed that the potential savings are relatively small. In socio-cultural terms, there is a problem in remote peripheral areas, where RWH could be a valuable additional source. Here, the mobility of the population is said to be higher due to the transhumance, i. e. the seasonal movement of the people with their livestock. This is not reconcilable with the settled lifestyle that is required for a RWH facility, according to representatives on the supply side.

Interviewees gave examples of how projects run by development organisations have failed. It was reported that RWH facilities that were built by a European development agency at schools in the region did not work properly at first and broke down later. In the end, frustration led to vandalism of the tanks. In another example, it was reported that tanks originally intended for storing rainwater were used for the storage of all kinds of food and goods, because the RWH system became inoperable after some time.

When examining the possibility of using ground areas as catchments for the collection of precipitation, opinions also vary. The so-called ground catchments are difficult to construct and require considerable maintenance, according to officials on the supply side. The materials, tools, and machinery required are said to be cost-intensive and, thus, not viable.

> *"These technologies [RWH using ground catchments] only mean more investments. Still the people are not able to survive droughts or to feed their cattle." (MAWF official, 07a-WM-10)*

Interestingly, another traditional technique does exist that is quite similar to the use of ground catchments. Clay layers, which can be found in the soil of the region, are traditionally used to thresh the Mahangu, which is a widely cultivated pearl millet and the key component of the population's nutrition. For this purpose, the upper sandy layers of soil are removed to uncover a plain and firm pan-like area of several square metres. In these 'Odobes', the accumulation of rainwater during the rainy season is a side effect and the accumulated water remains there until May at least, according to locals. Experts say that the water from these ponds is used for household needs and also for livestock watering. The clay catchments retain the water because of reduced infiltration and percolation.

> *"Alternative technologies like rainwater harvesting are needed." (Municipal technician, 07a-AP-02)*

Nevertheless, the interviewees did see some potential for RWH. Government officials, as well as experts, state that, on the household level, the stored rainwater could be used for irrigation. Rural dwellers also expressed their wish to use rainwater for gardening. They say that small-scale agriculture or horticulture could improve their situation and would be appreciated by the people. This approach could be very promising, especially in schools and kindergartens, according to experts and villagers, although the idea has already been investigated and attempted. Schools usually have teaching gardens for their students to learn about gardening but, in the majority of cases, they lack rainwater harvesting facilities. Rural people support the idea that schools should address these basic techniques and sustainable water usage in general. They say that these skills could be implemented at the grassroots level and in a practical way. On the other hand, officials of the supply utility object that RWH might be sufficient for domestic purposes but not even for small-scale irrigation purposes, in terms of quantity. Other representatives of the suppliers state that urban gardening could even be practised using RWH, but the town councils are allegedly not interested in such projects, especially in informal urban settlements, where investors are preferred.

Additionally, climate change is expected to have a negative effect on the use of RWH, according to experts, since more droughts and less rain are to be expected in the future. This aspect is particularly interesting as several interviewees state that climate change might pose a threat to large-scale water supply systems and that this is one of the main reasons for calling for alternative water sources and techniques. Finally, another opportunity is seen in the combined usage of RWH and groundwater sources. Water authority officials believe that mixing brackish groundwater with fresh rainwater could be useful in order to reduce the salinity of the groundwater.

As far as the RWH systems with ground catchments are concerned, local experts argue that they could be viable and beneficial. Even representatives on the supply side state that the collected water would be cheaper than tap water and it could be used for the livestock during the approximately four months of water scarcity in the dry season. In addition, it is said that ground catchment facilities would reduce the risk of overgrazing, if enough of them are available. It is also thought that the making of bricks could reduce land degradation and deforestation, since less wood from local trees would be used by the population to build their houses. Apart from the benefits of irrigation mentioned above, which are also associated with ground catchment systems, water authority officials believe that RWH on a larger scale could lead to a growth of towns.

Finally, it can be said that NamWater plays a crucial role when it comes to promoting or impeding a technique such as RWH. Several representatives of the utility explain that NamWater, as a bulk water supplier, does not want to be involved in RWH and that it does not belong to their strategic goals. Nevertheless, they would give assistance and support to any attempts to establish the method, as long as it is sufficient and beneficial for the population. Water authority officials also confirm that the government is considering supporting RWH. However, the main assessment criteria for the options remain in the simplicity as well as the costs of construction, operation, and maintenance. Other experts are quite pessimistic and say that RWH has been tried in the past and that it would not be reasonable to reconsider it, because it has already failed previously.

Figure 3.6 Rainwater harvesting pilot plant using polyethylene tanks in the village of Epyeshona, Okatana constituency, approximately 5 km north of Oshakati

Within the CuveWaters project, pilot plants for RHW have been proposed (Figure 3.6).[6] Several materials were supposed to be deployed for the tanks of these systems: polyethylene, ferro-cement, and concrete bricks. The harvested rainwater was not only supposed to be used for small-scale irrigation but also for the domestic purposes of single households in rural villages and was, fur-

[6] Four RHW pilot plants were constructed in the village of Epyeshona (Okatana Constituency, Oshana Region) after the interviews had been conducted (Zimmermann et al. 2010). The village community chose households during several workshops as sites for three roof catchment facilities with catchment areas between 90 and 110 m². The corresponding reservoirs have a capacity of 30 m³ each. A 120 m³ cistern and an 80 m³ pond were constructed for the ground catchment plant that supplies approximately six households. The institutional setting of this facility was developed by the users themselves in participatory workshops. Furthermore, the users were trained in basic gardening techniques. All in all, up to 24 technicians from the village received capacity building measures to build, operate, and maintain all the described RWH systems.

thermore, assumed to be of good quality, especially compared to traditional sources. In addition, a larger facility with a concrete-lined ground catchment and an underground reservoir was planned. The collected water was mainly supposed to be used for horticulture, which is why gardening plots which could be used by the surrounding households of a village should be created close to the tank.

3.3.7 Other water supply techniques

Other water supply techniques include views on potential but not implemented alternatives as well as options that are no longer in use. In addition, these techniques have only been mentioned by either one or a few interviewees, which is why they are summarised in one system variable. A historical example for the sophisticated use of local surface water is the so-called Stengel dam (Stengel 1963) mentioned above, which is named after the German engineer Heinz Walter Stengel. Oshana water is collected in a sump, from where it is pumped into a reservoir bordered by a circular dike with a height of up to 5 m and a diameter of 20-30 m. After two to three treatment steps, including chlorination, drinking water quality is achieved. The potable water would then be stored in an elevated tank. Since the 1950s, attempts have been made to store Oshana water for utilisation in the dry winter season, to alleviate the difficult water supply situation until the long-distance scheme has been installed (Logan 1981). Several dozens of such Stengel dams can still be found throughout the region, but they are all abandoned and ruinous. One of them supplied water to the Roman Catholic Mission in Okatana, including a hospital, a church, and a school, for approximately 20 years. Locals claim that these kinds of structures have not been used since Namibia became independent in 1990, but it can be assumed that the abandonment of the facilities even dates further than the 15-20 years ago, when the pipelines were built. Although evaporation losses can be mitigated by the structural design, namely by a smaller surface to depth ratio, the main problems remain evaporation and water quality issues, due to the open reservoir, as mentioned above.

Large dams are discussed as another option. According to officials on the supply side, feasibility studies were carried out in the northern region but no suitable sites for dams were found. Furthermore, representatives of this stakeholder group are aware of possible negative impacts of large dams, such as the displacement of people, ecological effects on natural habitats, or technical problems due to erosion, debris, and sediments. Evaporation losses are also said to be a reason why large dams are not viable.

Water sector officials report on large amounts of deep groundwater in the central northern region. They doubt that the exploitation of these aquifers would be feasible, for economic and technical reasons. It is said that the capital investments in pipelines to supply the remaining 10 % of the population that is not yet connected to the piped scheme are lower than those for wells. Furthermore, the disadvantageous dependency on the required Diesel pumps is highlighted. A quasi-combination of both techniques formerly mentioned, such as the artificial recharging of groundwater and/or subsurface dams, is also not considered to be feasible by representatives of the water supply utility, due to geological reasons, as examinations have shown. This also applies to sand dams, because the sand in the region is not suitable for this purpose, due to its fine particle size, as experts state.

One issue on the SADC agenda is a project for transferring water from the Congo River to the Kunene and the Zambezi, as MAWF officials report. It is said that pre-feasibility studies have been carried out and funded by the Namibian government since 2004. Representatives state that the Democratic Republic of Congo has already agreed to this transcontinental project.

Finally, external experts discussed the potential of small to medium-scale water treatment techniques such as sand filtration for surface water sources. Some experts say that it is not feasible to treat water by this means, due to the properties of the regional sand. Moreover, it requires a continuous inflow that is not available if sand filtration with oil drums is considered on the household level, due to the distances to lakes or earth dams. Thus, some experts proposed using ceramic water filters to purify Oshana water on a small-scale level.

3.3.8 Sanitation problems

The examination of regional water regimes would not be complete without a brief look at sanitation issues. The distribution and types of sanitary facilities in the region vary considerably, depending on the spatial category. Water authority officials report that, nationwide, the coverage on the supply side is around 90 %, whereas on the sanitation side it is only around 60 %. This also applies to central northern Namibia. According to representatives of the water utility, any measures or projects should focus on sanitation systems, because the development of the regional water supply is ahead of the development of sewage disposal. Water authority representatives also state that:

> *"There is more need [for development measures] on the sanitation side than on the supply system." (07a-WM-07)*

Government officials report that sanitary reticulation systems only exist in central areas of the regional cities. In Oshakati, for instance, only half of the households are connected to the central sewage system, according to municipal engineers. The sewers are connected to so-called oxidation ponds. Here, the waste water evaporates and solid waste is deposited. Two of these systems can be found in the city. A single installation consists of several ponds of up to 3 m in depth that are interconnected. Each pond serves for a different stage of the process. New wastewater is pumped constantly into the first pond. Sludge from the last pond is then removed and deposited next to the ponds as well as on nearby fields, where it is used as fertiliser.

Some ministry officials have never heard of any problem with the centralised sewage systems in the northern cities. Several interviewees, however, criticise the high water losses from the oxidation ponds, technical problems in operation and maintenance, security issues, high costs, a foreseeable capacity shortfall and also organisational aspects. With regard to the evaporation losses, they suggest that the water should be recycled and reused in a region that is mainly dependent on external water sources. Municipal technicians explain that water reuse, even on a small scale, could minimise the urban water consumption, as is the case in Windhoek, for instance. Water authority representatives also mention the wastewater from toilet flushing and showers as examples of squandering. They also see ecological problems in the salinity of the sludge that results from the treatment process. Municipal technicians report that the treatment facility is fenced and security problems are, thus, said to be negligible. Nevertheless, one pond contains fish, which attract people, despite possible health risks due to pollution. It is also said that children play next to the facilities. Furthermore, representatives on the supply side state that the open water is a breeding ground for mosquitoes. Given such issues, the mere odour nuisance seems to be a small problem. In general, sewage-based sanitation systems are very maintenance-intensive and, after a while, reinvestments are mandatory, according to technicians of the water supply utility. The main technical problem is the aging of the system, which necessitates repairs of damages and accounts for a large part of the operational costs, as municipal technicians state. Water authority officials say that the system is in poor conditions, due to maintenance problems, and extensive investments would be needed for modernisation. This is also exemplified by the drainage system of Oshakati's Town Council, which is not functioning properly. Moreover, municipal technicians report that they are insufficiently equipped with maintenance devices. There is, for instance, only one machine available for the clearance of blocked sewage mains. For a few external experts, sanitation is not a problem as long as the population of the cities does not grow. On the other hand, officials of the municipal administration stress that the capacity of the oxidation ponds would not be sufficient if all inhabitants were connected.

> *"The three oxidation ponds in Oshakati are only made for a population of about 3,000." (07a-AP-01).*

Financial problems arise from the fact that the centralised sewage system is only financed by a minority of residents, as political representatives state:

> *"Only 2,000 inhabitants of Oshakati pay for 43,000 people for the urban services; people of informal settlements don't use these services and hence don't pay." (07a-AP-01)*

In the peri-urban informal settlements of the cities, the situation is quite different, because they are not served by the large-scale sewerage. According to local people, the so-called flying toilet is the most common method and it is used by around 60 % of the population. This means that plastic bags or night buckets are used and then disposed of in the bushes the next day. The reason why such flying toilets prevail is not only the lack of sanitary facilities but also for security reasons, since it may be dangerous to leave a dwelling after dark, especially for women. At the same time, some inhabitants can afford a pit latrine on their plot. In most cases, these latrines were built with the assistance of several development projects[7], as locals report. Construction was accompanied by training measures for the users that addressed the operation and maintenance of the facilities. A headman explains that the latrine on his plot was built in the mid 1990's and that it was jointly funded by him and the municipality after he had applied for it. According to the headman, not everybody could afford to build a pit latrine and not everybody who could afford it applied for this programme. Nevertheless, the projects were very popular among the residents, as locals report. It was said that, after 15 years, the latrine would have to be replaced, but then self-financed. Water authority officials report that not only private water taps but also latrines are shared by surrounding residents. Approximately 15 people use one facility, as inhabitants estimate. By now, all such projects have

[7] Pit latrines were, for instance, built by the Danish organisations IBIS (formerly known as World University Service, WUS) and DANIDA (e. g. within OHSIP, Oshakati Human Settlement Improvement Project), by FINNIDA, and with assistance from South Africa and the Namibian Rural Development Centres (07a-WU-03).

been phased out, due to the lack of funding on both the donors' and the recipients' sides. Former staff members also report that the projects were not finished properly, due to organisational issues.

High-ranking ministerial and municipal officials consider the sanitary conditions as the major problem of the informal settlements in the regional cities, especially in terms of risks for health and ecosystems. Water users confirm this.

> *"Sanitation is a very big problem especially concerning health risks and hazards." (MAWF official, 07a-WM-08)*

> *"[The] lack of sanitation infrastructure is a risk for the ecosystem and for health." (MAWF official, 07a-WM-08)*

> *"Sanitation is the main problem in informal settlements." (Resident of an informal settlement, 07a-WU-03)*

Specifically, the hygienic conditions are described as terrible, for instance, in Pohamba, one of these settlements. This is due to the lack of sanitation facilities, according to political representatives in Oshakati. In the case of the pit latrines, the collected faeces may be a health threat, particularly in densely populated areas, because groundwater could be contaminated through seepage, as scientists state. Furthermore, heavy rainfall and floods from Oshanas can lead to a fill up or even spill over of the underground reservoirs, which are filled with sludge, according to residents. The flying toilets produce the same problem and, thus, bear the risk of infections and epidemics. The existing sanitary facilities are badly maintained and deteriorating, according to locals, although the operational costs are said to be very low. The investment costs for the construction of a pit latrine—approximately 5,000 N$—are considered to be too high for the users to pay at once. In general, the majority of people would prefer the installation of toilets, according to residents, but these are, in some cases, rejected for psychological or cultural reasons. For instance, pit latrines are sometimes not used because of their bad smell. Another perception of many people is that they should use "the toilet that God gave them", as locals report.

Some of the conditions described above for informal settlements also apply to rural areas, because they are not served by a sanitary sewer system, either. However, the population density is much lower outside the cities. Although pit latrines can occasionally be found here, such facilities are still the exception, according to local people.

> *"Sanitation is a big problem because rural sanitation does not exist." (MAWF official, 07a-WM-08)*

This is why high-ranking water authority representatives ask which technologies might be appropriate solutions for informal settlements as well as in urban and rural areas.

> *"The informal settlements in the cities of the northern region need appropriate sanitation systems." (Official of the water supply utility, 07b-WSU-01).*

Local politicians and municipal technicians argue in favour of the development of informal settlements by extending the large-scale sewage system. The explanation they give is quite tautological, as they justify their plans by saying that there are no sanitary services yet. Other options are not considered. Furthermore, pit latrines are said to have many disadvantages. Other reasons remain unmentioned but can be assumed. Regional political leaders, nevertheless, argue that the informal settlements have to be restructured to build the infrastructure, and municipal engineers are already discussing measures for implementation. These include the resettlement of the residents of newer informal districts once the expansion of these kinds of settlements is stopped. This is followed by a "cleaning" of the area for the construction of the infrastructure. Once the developed plots have been sold, private houses are supposed to be built. The described procedure is said to be:

> *"An optimal path to a long-term improvement […]." (Municipal engineer, 07a-AP-02)*

However, hindrances recognised by the planners are that residents are said to be unwilling to move, since they have already been living on their plots for a long time. Furthermore, it is understood that these people should receive subsidies for moving away from their plots. But neither money from the municipality nor space is said to be available for compensation or rehabilitation, for instance, in terms of alternative plot offers. Besides financial resources, capacity building is also needed, according to the mayor of Oshakati. Other cities, such as Ondangwa, are facing similar problems and are also looking for solutions, as municipal employees report. Former staff members of development projects estimate that a sewage system might only be realisable in new informal settlements. For existing parts of such districts, however, an implementation is not expected, due to the enormous efforts needed for planning and construction.

According to experts and water users but also supply side officials who are not even responsible for these issues, simple and decentralised solutions such as pit latrines have to be promoted, especially in peri-urban informal settlements, as well as in rural areas. However, these techniques are also said to have their disadvantages that mainly revolve around the mentioned problems of construction, investment, and groundwater contamination. A major reason why it is difficult for the poor to set up a pit latrine is that there is nowhere to obtain loans, according to the local population. The term “microcredit” is not known among locals.

> *“A solution would be the possibility of a debt for the high investment costs [of a pit latrine] and a paying back by slightly higher monthly fees but the municipality doesn’t support this idea.” (Former employee of a development project, 07a-WU-03)*

Sanitation centres are another option discussed by researchers for informal settlements. Such centres would offer services such as water closets and washing facilities for hygiene as well as for laundry to a larger group of residents in their catchment area. Beside these primary functions, equipment for the production of biogas could be installed optionally. The majority of locals endorse the concept of sanitation centres. They say that such a system would reduce the number of people “going to the bushes”, including the associated security problems mentioned above. Residents suggest that the centre should be owned by the community and not the municipality, but the latter should be responsible for the maintenance. Regarding the financing, it is said that a membership fee should be introduced but this should be affordable for the users. Water authority representatives, however, take an opposite view on this topic. They strongly advise focussing on individual solutions in informal urban areas.

> *“The problem of sanitation centres is that many people use them. Ownership, vandalism, maintenance, operation, payment, and cleaning are difficult to be solved.” (MAWF official, 07a-WM-10)*

In summary, ministry officials consider sanitation centres as “dead dugs”, because the issue of responsibility issues remains unresolved. They say that only private solutions could overcome this problem. Supply utility representatives warn against possible unhygienic conditions in public facilities. Furthermore, they state that local authorities in the north, such as the Town Council of Oshakati, dislike the existence of informal settlements and that, by building sanitation centres, these districts would be formalised indirectly. This has to be considered when projects are planned and has to be discussed with the respective authorities, as officials of the utility point out.

4 Systems analysis and simulation

The main drawback of verbal models such as the one presented in the previous section is their poor operability. Simulations for the construction of scenarios can only be run verbally but not in a system-analytical or methodically grounded way. This is why it seems reasonable to integrate Grounded Theory into systemic and cybernetic modelling approaches. It meets the necessary requirements for a combination with such methods. Several modelling techniques are used in this Chapter. After the identification of relevant system variables, their interdependencies and their roles within the system have to be analysed by using the so-called Sensitivity Model. In doing so, it is possible to identify outstanding variables that are important for understanding the system. Thereafter, the application of heterogeneity indicators that allow for the identification and assessment of different problem perceptions and world views within the interview survey is presented. It reveals which interdependencies in the system the interviewed stakeholders agree on and which they do not. In doing so, the interdependencies' polarities can be identified; this then serves as the basis for the analysis of feedback loops and cause-effect chains in the system. Finally, various water supply scenarios are simulated and subsequently assessed and compared in terms of systemic risks and viability indicators.

4.1 Sensitivity Model

4.1.1 Approach

There is a limited number of approaches that can be referred to as holistic because of their integrative character. For instance, Peter Checkland's Soft Systems Methodology (Checkland 2000), Jac Vennix' Group Model Building (Vennix 1999, Andersen et al. 2006), and Roland Scholz's Transdisciplinary Case Study Approach (Scholz et al. 2006) can be subsumed under these kinds of methodologies. They all have in common that so-called messy or ill-defined social problems are tackled by making use of group interviews, some kind of systems analysis, and an assessment of scenarios to achieve a desirable transition management (Zimmermann 2010a). However, it has been explained already in Chapter 3.1 why group interviews have been rejected.

In addition, there are purely quantitative methods, such as System Dynamics (Forrester 1961), which is based on cybernetic systems theory (cf. Chapter

2.1). Since, in the case of this study, the data is almost entirely qualitative, the Sensitivity Model (Vester 1980) is preferred to the former. This approach allows for the construction of a model of the deterministic system and comprises descriptive, analytical, as well as explanatory elements.

As mentioned in the methodological explanations in Section 3.1, the codes or concepts of the Grounded Theory are nothing else but the system variables of the Vester's Sensitivity Model that are, so to speak, crystallised by theoretical coding (Zimmermann 2010b). Hence, the method can be applied, based on this set of system elements. In fact, Vester suggests a check list to identify system variables (Vester 2000). However, since this way of finding system elements lacks an empirical foundation, Grounded Theory is used to fill in the methodological gap. The main components of Vester's approach are the analysis of the variables' interdependencies and the characterisation of their respective roles within the system (Vester 2000). The elements can be examined in terms of their specific properties as well as of relations and connections to other variables. These interdependencies represent flows of matter, energy, or information and can be assessed, based on empirical data from the interviews, by using a cross-impact matrix (CIM). In doing so, it is possible to interpret and categorise system variables based on their character or function within the system, which is an essential result of this method. According to four fundamental types, which are active, passive, critical or reinforcing, and buffering, ordinal rankings of the variables can be created. Thus, it is possible to identify outstanding variables (or codes) that are essential for the understanding as well as for the sustainability of the system, since not only weakest links but also driving forces, destabilising elements, systemic stabilisers, and indicators are recognised. By-products of this analysis are visualisations of the observed system and its subsystems, which are relevant for subsequent steps like simulations and policy tests.

Apart from identifying system variables, analysing their interdependencies is another essential task of modelling. This information can also be drawn from the interviews, at least in a qualitative way. In this context, interdependency means that an altering of one system variable leads to an alteration of another system variable. These interrelations can be recorded in the cross-impact matrix (Table 4.1). Each time an interviewee mentioned an interdependency, it was counted and recorded in the matrix. Thus, each number in the matrix represents the number of statements by all interviewees on a specific interdependency. The evaluation of the interview transcripts and the counting and recording of the interdependencies in the cross-impact matrix were conducted several times by different people (the author as well as student assistants), in order to make sure that the results are not biased by an individual perspective.

This way of evaluating the interdependencies, however, is not exactly the procedure that Vester (2000) suggested. He argued in favour of an assessment using values of 0, 1, 2, and 3, according to the specific proportionality or strength of an interrelation. Nevertheless, no advice was given on which theoretical or methodological basis the interdependencies had to be assessed. To ensure that the absolute number of statements does not bias the analysis and interpretation, the sensitivity analysis in this study was also conducted with a normalised matrix, to avoid misinterpretations (Table A.2). In this context, normalised means that each entry in the matrix was set to 1 if an interdependency was mentioned, no matter how often. Similar results of the absolute and the normalised matrices can be interpreted as a confirmation of the findings and corroborate their validity. Any inconsistencies in the results are highlighted below.

Table 4.1 Example of an interdependency in a cross-impact matrix. The alteration of system variable No. 6 leads to a non-specified further alteration of system variable No. 5.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**…**	**n**	**Activity**	**Passivity**	**Q-value**	**P-value**
1			1	1		1	1		1	5	2	2.50	10
2	1		1			1				3	2	1.50	6
3				1						1	2	0.50	2
4										0	3	0.00	0
5		1								1	1	1.00	1
6					1					1	2	0.50	2
7				1						1	1	1.00	1
⋮										⋮	⋮	⋮	⋮
n	1	1								2	1	2.00	2
Passivity	2	2	2	3	1	2	1	…	1				

Subsequently, the interrelations can be analysed and assessed by deriving several indicators. We can describe the cross-impact matrix as follows:

$$\begin{pmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & & & \\ a_{i1} & & a_{ij} & & \vdots \\ \vdots & & & \ddots & \\ a_{n1} & & \cdots & & a_{nn} \end{pmatrix} \qquad \text{(Formula 1)}$$

where:

a = number of mentioned interdependencies between two system variables

i = 1, 2, …, n (rows)

j = 1, 2, …, n (columns)

n = number of system variables

The activity α of a system variable i is then defined as:

$$\alpha_i = \sum_{j=1}^{n} a_{ij} \qquad \text{(Formula 2)}$$

The passivity β of a system variable j is then defined as:

$$\beta_j = \sum_{i=1}^{n} a_{ij} \qquad \text{(Formula 3)}$$

The Q-value Q of a system variable i is defined as the quotient of activity and passivity:

$$Q_i = \frac{\alpha_i}{\beta_i} \qquad \text{(Formula 4)}$$

The P-value P of a system variable i is defined as the product of activity and passivity:

$$P_i = \alpha_i \cdot \beta_i \qquad \text{(Formula 5)}$$

These indicators provide information about the extent to which a single system variable has an effect on the rest of the system (as in the case of activity) and to what extent the rest of the system has an effect on a single element (as in the case of passivity). Furthermore, Q- and P-value make it possible to characterise each system variable in terms of their roles within the system. This will be described below.

4.1.2 Results and discussion

The interdependencies of the system variables identified are now analysed by using the cross-impact matrix (Table 4.2).[8] In total, it contains 239 interdependencies consisting of 1290 propositions, i. e. meaningful declarative sentences or statements by the interviewees. After determining the indicators described above, rankings of system variables are generated. In doing so, it is possible to interpret and categorise system variables based on their character or function within the system, which is an essential result of this method.

The ranking of system variables by Q-value is shown in Table 4.3. If the Q-value of a system variable is above 1, the element tends to influence the rest of the system rather than being influenced by the rest of the system. If the Q-value is below 1, the variable is influenced by the system rather than influencing the system. In other words, the higher the Q-value of a system variable is, the more active is the element, and, vice versa, the lower the value is, the more passive it is. In this particular case, "Low level of education and understanding of water issues" (Q-value of 17.7), "Angolan water demand" (14.0), "Floods, droughts, and climate change" (12.5), "Salinity of groundwater" (5.67), "Scarcity of water resources" (4.29), as well as "Population growth and migration" (3.43) are significantly the most active variables within in the system. However, in the cases of "Angolan water demand", "Floods, droughts, and climate change", "Salinity of groundwater", as well as "Population growth and migration" the quotient of activity and passivity might indeed be high but the absolute activity value is comparably small. Hence, it is suggested to treat them as second order active variables. Only the remaining two of the mentioned variables (No. 26 and 14 in Table 4.3) are considered as first order active variables. They fulfil the necessity of a high Q-value and the sufficiency of a high activity. Furthermore, their role within the system can be interpreted as those variables that can be used for desirable systemic transformations or to control the system in terms of adjusting screws. This is, of course, only the case if a variable can be influenced at all, which possibly does not apply to the "Scarcity of water resources". Interestingly, the most promising system element in this context is a factor of the social (SC) dimension (Table 4.3), and not of the technical (TE) one.

[8] Figure A.1 shows a visualisation of the matrix in the form of a causal loop diagram.

Table 4.2 Full Cross-Impact Matrix (CIM) with absolute numbers of propositions

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Activity	Passivity	Q-value	P-value
1			1	1					2		4										5	10	18	8	19	2	3		4	42		5		7	12	2	1	146	57	2.56	8322
2	6								1																					15								22	47	0.47	1034
3				1							1								2			2		13	1					20		2		12	9			63	56	1.13	3528
4																								5	2					8		3		7				25	11	2.27	275
5															2		1							6	5					8		1		10				33	56	0.59	1848
6																						1		4	2					12		1		4	12			36	44	0.82	1584
7									1	1					1					7				12						2						1		25	48	0.52	1200
8																									1					2		1		1			1	6	20	0.30	120
9	8	14			5	7	12	4		2		5													6	3	11	4	1	2					4	15		103	58	1.78	5974
10			2				2		2		2	2																2								2		14	7	2.00	98
11			1						4	1												8	8							1			5		3			31	20	1.55	620
12									9	2	2																											13	18	0.72	234
13																														8								8	9	0.89	72
14	8		11	3	8	7							1			1			2											8			6	5				60	14	4.29	840
15			3	2	12																																	17	3	5.67	51
16			10			1								11			1			1										1								25	2	12.50	50
17											4		1										6											13				24	36	0.67	864
18																			2														4					6	11	0.55	66
19																1																						1	11	0.09	11
20																								1								1						2	8	0.25	16
21	8						6		2													1								7								24	7	3.43	168
22	8		5				10		3		2						6				1				9	3						4	6	7		7		71	48	1.48	3408
23	7										1																							4				12	32	0.38	384
24																										2												2	49	0.04	98
25	5																											1	1	1								8	46	0.17	368
26		8	9	2	10	9	9	7	18	1	4	9										9					10	16	6			8	10	6	11	15		177	10	17.70	1770
27									1																				2	1					1			5	27	0.19	135
28	1		5	1	5	8		4	6			1																	5	3								39	27	1.44	1053
29		8							3			1													1		2	3										18	21	0.86	378
30				1																																		1	160	0.01	160
31																																1						1	16	0.06	16
32	6		9		10	12	9	5	6													5					1	1	2						1	9		76	63	1.21	4788
33																		9	3												9	9			1	7		38	31	1.23	1178
34		8			6												27	2	2											1		9				10		65	83	0.78	5395
35		1												3			1													6	5	9		1		9		35	55	0.64	1925
36																					1	12									1	9		6	1			30	77	0.39	2310
37		8											7																	12	1							28	2	14.00	56
Passivity	57	47	56	11	56	44	48	20	58	7	20	18	9	14	3	2	36	11	11	8	7	48	32	49	46	10	27	27	21	160	16	63	31	83	55	77	2				

Table 4.3 Ranking of system variables by Q-value, based on the absolute matrix

No.	Name of system variable	Dimension	Activity	Passivity	Q-value	P-value
26	Low level of education and understanding of water issues	SC	177	10	**17.70**	1770
37	Angolan water demand	EN	28	2	**14.00**	56
16	Floods, droughts, and climate change	EL	25	2	**12.50**	50
15	Salinity of groundwater	EL	17	3	**5.67**	51
14	Scarcity of water resources	EL	60	14	**4.29**	840
21	Population growth and migration	SC	24	7	**3.43**	168
1	Large-scale water supply	TE	146	57	**2.56**	8322
4	Shallow dug wells (Omuthima)	TE	25	11	**2.27**	275
10	Water supply and sanitation policies	PI	14	7	**2.00**	98
9	Governance and management problems	PI	103	58	**1.78**	5974
11	Land policies	PI	31	20	**1.55**	620
22	Urbanisation	SC	71	48	**1.48**	3408
28	Self-organisation and participation of users	SC	39	27	**1.44**	1053
33	Traditional crop farming	EN	38	31	**1.23**	1178
32	Subsistence and poverty	EN	76	63	**1.21**	4788
3	Oshanas and excavation dams (Omatale)	TE	63	56	**1.13**	3528
13	Inter-regional conflicts	PI	8	9	**0.89**	72
29	Misuse and vandalism	SC	18	21	**0.86**	378
6	Rainwater harvesting	TE	36	44	**0.82**	1584
34	Traditional livestock farming	EN	65	83	**0.78**	5395
12	Integration and decentralisation	PI	13	18	**0.72**	234
17	Poor quality and availability of grazing land	EL	24	36	**0.67**	864
35	Lack of irrigation and horticulture	EN	35	55	**0.64**	1925
5	Groundwater and dug wells (Oshikweyo)	TE	33	56	**0.59**	1848
18	Soil degradation	EL	6	11	**0.55**	66
7	Sanitation problems	TE	25	48	**0.52**	1200
2	Technical problems with the large-scale water supply system	TE	22	47	**0.47**	1034
36	Weak regional economy	EN	30	77	**0.39**	2310
23	Rural concentration and immobility	SC	12	32	**0.38**	384
8	Other water supply techniques	TE	6	20	**0.30**	120
20	Environmental pollution and risks for biodiversity	EL	2	8	**0.25**	16
27	Perception of water prices	SC	5	27	**0.19**	135
25	Disparities and exclusion	SC	8	46	**0.17**	368
19	Deforestation	EL	1	11	**0.09**	11
31	Security of food supply	SC	1	16	**0.06**	16
24	Health	SC	2	49	**0.04**	98
30	Security of water supply	SC	1	160	**0.01**	160

The system variables with the lowest Q-values and the highest passivities are "Security of water supply", "Health", and "Disparities and exclusion", which is why they should be considered as first order passive variables (cf. Vester 2000). They might play the role of indicators for the well-being, viability (Bossel 1999), or sustainability of the overall system.[9] This is due to the fact that they are heavily exposed to other system elements' influences and react very sensitively to their alterations. Passive variables could also be used for the regulation of feedback loops, e. g. as sensors within a closed loop control. Interestingly, systemic indicators mainly consist of social factors (SC). The passivities of the variables "Security of food supply" and "Deforestation" are significantly smaller. Thus, they are not treated as sustainability indicators below. Furthermore, the low Q-values of the variables "Perception of water prices", "Environmental pollution and risks for biodiversity", "Other water supply techniques", and "Rural concentration and immobility" cannot be confirmed by the normalised ranking (Table A.3). Finally, "Weak regional economy" and "Technical problems with the large-scale water supply system" can be considered as second order passive variables.

The ranking of system variables by P-value is shown in Table 4.4. As the product of activity and passivity, the P-value seems to indicate how relevant or important a system element is in terms of the interactions or interrelations among the variables. High P-values mean that a system element is strongly influenced by the rest of the system, because it influences the system to a great extent. Vice versa, low P-values indicate that a variable is neither strongly influenced by the system nor does it influence the rest of the system to a marked extent.

[9] A system is viable if it is able to maintain itself. The terms viability and sustainability are used interchangeably in this study. Nevertheless, this is only the case if it can be assumed that a system that is viable in the long run is also sustainable.

Table 4.4 Ranking of system variables by P-value, based on the absolute matrix

No.	Name of system variable	Dimension	Activity	Passivity	Q-value	P-value
1	Large-scale water supply	TE	146	57	2.56	**8322**
9	Governance and management problems	PI	103	58	1.78	**5974**
34	Traditional livestock farming	EN	65	83	0.78	**5395**
32	Subsistence and poverty	EN	76	63	1.21	**4788**
3	Oshanas and excavation dams (Omatale)	TE	63	56	1.13	**3528**
22	Urbanisation	SC	71	48	1.48	**3408**
36	Weak regional economy	EN	30	77	0.39	**2310**
35	Lack of irrigation and horticulture	EN	35	55	0.64	**1925**
5	Groundwater and dug wells (Oshikweyo)	TE	33	56	0.59	**1848**
26	Low level of education and understanding of water issues	SC	177	10	17.70	**1770**
6	Rainwater harvesting	TE	36	44	0.82	**1584**
7	Sanitation problems	TE	25	48	0.52	**1200**
33	Traditional crop farming	EN	38	31	1.23	**1178**
28	Self-organisation and participation of users	SC	39	27	1.44	**1053**
2	Technical problems with the large-scale water supply system	TE	22	47	0.47	**1034**
17	Poor quality and availability of grazing land	EL	24	36	0.67	**864**
14	Scarcity of water resources	EL	60	14	4.29	**840**
11	Land policies	PI	31	20	1.55	**620**
23	Rural concentration and immobility	SC	12	32	0.38	**384**
29	Misuse and vandalism	SC	18	21	0.86	**378**
25	Disparities and exclusion	SC	8	46	0.17	**368**
4	Shallow dug wells (Omuthima)	TE	25	11	2.27	**275**
12	Integration and decentralisation	PI	13	18	0.72	**234**
21	Population growth and migration	SC	24	7	3.43	**168**
30	Security of water supply	SC	1	160	0.01	**160**
27	Perception of water prices	SC	5	27	0.19	**135**
8	Other water supply techniques	TE	6	20	0.30	**120**
10	Water supply and sanitation policies	PI	14	7	2.00	**98**
24	Health	SC	2	49	0.04	**98**
13	Inter-regional conflicts	PI	8	9	0.89	**72**
18	Soil degradation	EL	6	11	0.55	**66**
37	Angolan water demand	EN	28	2	14.00	**56**
15	Salinity of groundwater	EL	17	3	5.67	**51**
16	Floods, droughts, and climate change	EL	25	2	12.50	**50**
20	Environmental pollution and risks for biodiversity	EL	2	8	0.25	**16**
31	Security of food supply	SC	1	16	0.06	**16**
19	Deforestation	EL	1	11	0.09	**11**

The system variables with the highest P-values in absolute terms as well as in the normalised ranking (Table A.4) are “Large-scale water supply” (P-value of 8322), “Governance and management problems” (5974), “Traditional livestock farming” (5395), “Subsistence and poverty” (4788), “Oshanas and excavation dams (Omatale)” (3528), as well as “Urbanisation” (3408). It is not evident whether these elements involve any risks but they might be factors that cause erratic systemic changes and unpredictable behaviour. This might, eventually, jeopardise the systemic equilibrium as well, i. e., the resilience of the overall system. How this can be handled and interpreted will be discussed in Chapter 5.

In terms of the lower part of the P-value ranking, a clear line cannot be drawn. This is why another instrument is introduced at this point that visualises the indicators. For this purpose, activity and passivity of each system variable are located in a two-dimensional space (Figure 4.1). In doing so, clusters of system elements with similar roles can be detected. Amongst other features, the cluster of variables on the lower left stands out. These are elements with activity and passivity values less than around 40 and, thus, with low P-values. Although the clustering process was carried out without methodological support, the elements can be assigned to a buffering role within the system, which means that they enforce systemic resilience and counteract or balance out destabilising elements. Hence, they might also counteract efforts for systemic transformations. Nevertheless, it can be argued whether low P-values really indicate the buffering capacity of a system variable or only their irrelevance regarding the whole system. Additionally, earlier mentioned results of Q- and P-value analyses can also be verified, i. e. critical system variables (No. 1, 9, 34, 32, 3, and 22), active (No. 26 and 14) and passive ones (No. 30, 24, and 25). The special role of the system elements No. 5, 6, 7, 33, and 35 will be discussed in Chapter 5 in detail. All results can be confirmed by the corresponding normalised diagram (Figure A.2).

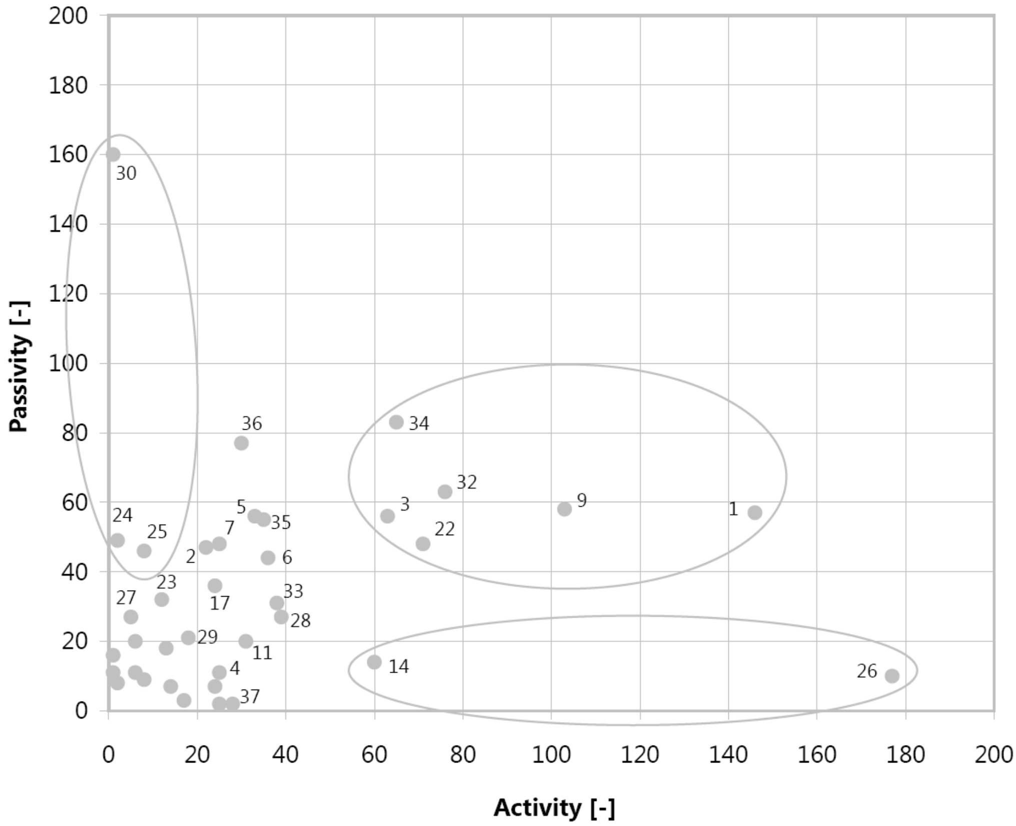

Figure 4.1 Location of system variables in the activity and passivity diagram of the absolute matrix

4.2 Heterogeneity of interdependencies

4.2.1 Approach

Interviewees' statements on any interdependency between two system variables can be diverse, due to different perceptions, world views or intentions. Hence, an indicator to measure the hetero- or homogeneity of the statements on a specific interdependency had to be developed (Zimmermann, Urban 2012). The indicator should be able to represent the relation of similar and contrary statements concerning a specific interdependency. Furthermore, it should be able to compare the hetero- or homogeneity of all interdependencies. For this purpose, it is necessary to count how many statements assign a specific interdependency as being positively related (if A increases → B increases; or if A decreases → B decreases) or negatively related (if A increases → B decreases; or if A decreases → B increases). Hereupon, both quantities make up a quotient, in which the smaller number is the numerator and the larger one the denominator. In doing so, the indicator takes values between "0" and "1", where "0" implies that the statements are (perfectly) homogeneous and "1" that 50 % of the interviewees hold a view which is contrary to the other half (perfectly heterogeneous). Which direction a system variable takes when it increases or decreases is defined in Table 4.5.

Table 4.5 Definition of the system variables' direction

No.	Name of system variable	Dimension	Increase of system variable means
1	Large-scale water supply	TE	Extension of the large-scale system and more usage of tapwater
2	Technical problems with the large-scale water supply system	TE	More technical problems with the large-scale water supply system
3	Oshanas and excavation dams (Omatale)	TE	More Omatale and more usage
4	Shallow dug wells (Omuthima)	TE	More Omuthima and more usage
5	Groundwater and dug wells (Oshikweyo)	TE	More Oshikweyo and more usage of groundwater
6	Rainwater harvesting	TE	More rainwater harvesting and usage of rainwater
7	Sanitation problems	TE	Less sanitary facilities and deteriorated sanitation
8	Other water supply techniques	TE	More of other water supply techniques and more usage
9	Governance and management problems	PI	More governance and management problems
10	Water supply and sanitation policies	PI	Better qualitiy of the implementation of water supply and sanitation policies
11	Land policies	PI	More regulation and interventions by the government
12	Integration and decentralisation	PI	More integration and decentralisation and better quality of implementation
13	Inter-regional conflicts	PI	More inter-regional conflicts
14	Scarcity of water resources	EL	Less availability of water resources
15	Salinity of groundwater	EL	More salinity of groundwater
16	Floods, droughts, and climate change	EL	More floods, droughts, and climate change
17	Poor quality and availability of grazing land	EL	Less quality and availability of grazing land
18	Soil degradation	EL	More soil degradation
19	Deforestation	EL	More deforestation
20	Environmental pollution and risks for biodiversity	EL	More environmental pollution and risks for biodiversity

21	Population growth and migration	SC	More population growth and migration
22	Urbanisation	SC	More urbanisation
23	Rural concentration and immobility	SC	More rural concentration and immobility
24	Health	SC	Improved health situation of water users and population
25	Disparities and exclusion	SC	More disparities and exclusion
26	Low level of education and understanding of water issues	SC	Lower level of education and worse understanding of water issues
27	Perception of water prices	SC	More appropriate perception of water prices
28	Self-organisation and participation of users	SC	More self-organisation and participation of users
29	Misuse and vandalism	SC	More misuse and vandalism
30	Security of water supply	SC	Higher security of water supply
31	Security of food supply	SC	Higher security of food supply
32	Subsistence and poverty	EN	More subsistence and poverty
33	Traditional crop farming	EN	More traditional crop farming
34	Traditional livestock farming	EN	More traditional livestock farming
35	Lack of irrigation and horticulture	EN	Less irrigation and horticulture
36	Weak regional economy	EN	Weaker regional economy
37	Angolan water demand	EN	More Angolan water demand

It is suggested to locate each interdependency in a two-dimensional coordinate system, in which the abscissa represents the described heterogeneity quotient (HQ), and the ordinate the absolute number of statements concerning an interdependency (Zimmermann, Urban 2012). This is done in order to differentiate between similar hetero- or homogeneity ratios, since those interdependencies with a larger number of statements are assumed to be more relevant to the interviewees than those with smaller numbers.

In addition, the heterogeneity difference (HD) can be used as an indicator not only for the hetero- or homogeneity of the statements on a specific interdependency but also for its polarity (Zimmermann, Urban 2012). The indicator is calculated by the difference of the numbers of statements on a specific interdependency (the numerator and the denominator mentioned above) multiplied by its polarity, which represents whether an interdependency is assigned as being positively ("+1") or negatively related ("-1"). The polarity is defined by the fraction of statements which forms the majority of all statements on a specific interdependency (Zimmermann, Urban 2012).

For the analysis below, it is suggested to use a reduced model or CIM in order to reduce the complexity to a certain extent. Interdependencies with three or less statements have been masked out; only those with four or more statements remain in the matrix. On the basis of the interview transcripts, 1,121 propositions (or statements) on 130 relevant interdependencies are considered below. This means that still 86.9 % of all statements on interdependencies are taken into account, whereas only 54.4 % of all interdependencies have to be regarded (Table 4.6).

Table 4.6 Reduction of information in the model depending on the number of propositions masked out

Interdependencies with propositions	Propositions		Interdependencies		System variables	
	Number	Percentage	Number	Percentage	Number	Percentage
> 0	1,290	100.0%	239	100.0%	37	100.0%
> 1	1,230	95.3%	178	74.5%	37	100.0%
> 2	1,160	89.9%	143	59.8%	35	94.6%
> 3	1,121	86.9%	130	54.4%	35	94.6%
> 4	1,065	82.6%	116	48.5%	35	94.6%
> 5	985	76.4%	100	41.8%	35	94.6%
> 6	889	68.9%	84	35.1%	35	94.6%
> 7	805	62.4%	72	30.1%	33	89.2%
> 8	661	51.2%	54	22.6%	28	75.7%
> 9	499	38.7%	36	15.1%	25	67.6%
> 10	409	31.7%	27	11.3%	24	64.9%
> 11	365	28.3%	23	9.6%	21	56.8%
> 12	245	19.0%	13	5.4%	13	35.1%
> 13	219	17.0%	11	4.6%	12	32.4%
> 14	205	15.9%	10	4.2%	12	32.4%
> 15	160	12.4%	7	2.9%	9	24.3%

4.2.2 Results and discussion

Generally, the interview statements on interdependencies are rather homogenous, since 83.1 % of all 130 relevant interdependencies have a heterogeneity quotient of 0.2 or less, 65.4 % even have one of 0 (Figure 4.2). This means that the interviewed stakeholders are in complete agreement about nearly two thirds and almost in agreement about more than four fifths of the system's interdependencies. Furthermore, only ten interdependencies (7.7 %) have 15 or more statements.

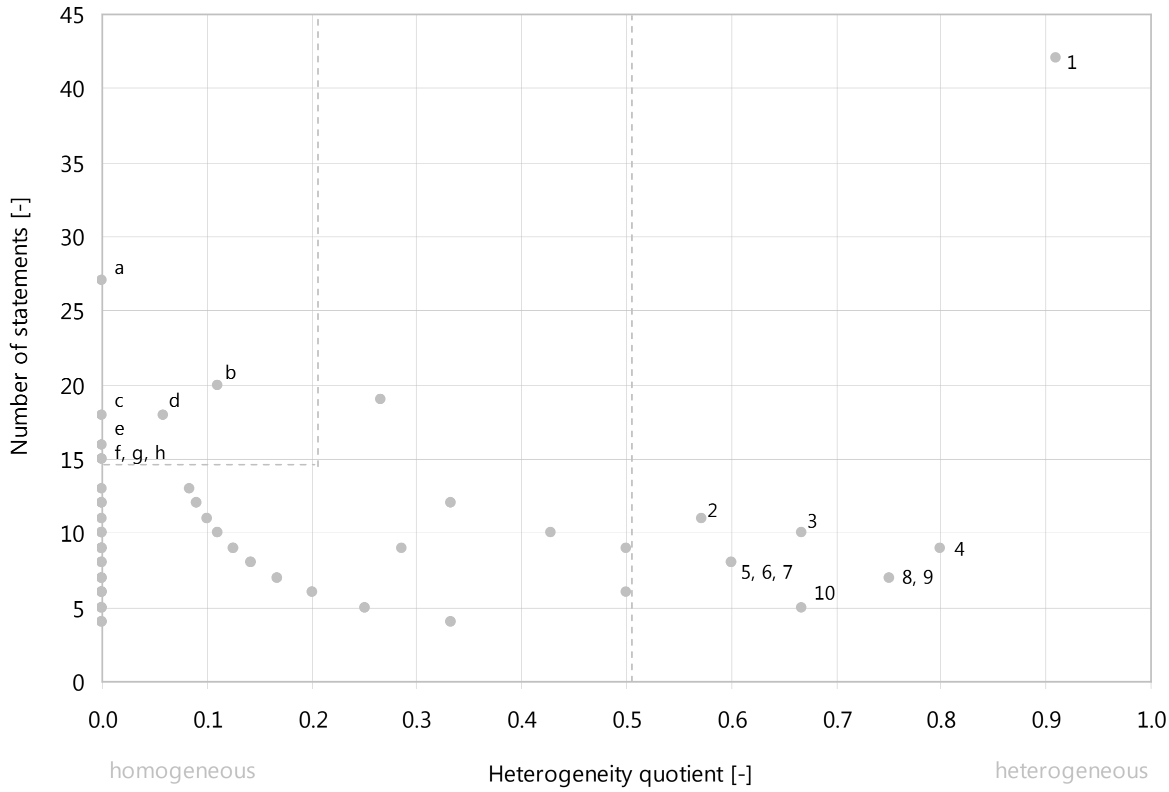

Figure 4.2 Heterogeneity quotient of interdependencies and number of statements

Those interdependencies with a HQ of 0.2 or smaller and a number of at least 15 statements are defined as the most homogeneous ones (Figure 4.2). These thresholds are set arbitrarily to filter out a reasonable number of outstanding interdependencies. The eight most outstanding homogeneous interdependencies are shown in Table 4.7. They make up 6.2 % of all relevant interdependencies. The table not only contains the total number of interview statements on a specific interdependency, as well as its HQ, but also the numbers of each of the numerators and the denominators, as well as the polarity.

Table 4.7 Outstanding homogeneous interdependencies

Designation	Cause	Effect	Number of statements	Numerator	Denominator	Polarity	Heterogeneity quotient (HQ)
a	Traditional livestock farming	Poor quality and availability of grazing land	27	0	27	+1	0.00
b	Oshanas and excavation dams	Security of water supply	20	2	18	+1	0.11
c	Low level of education and understanding of water issues	Governance and management problems	18	0	18	+1	0.00
d	Large scale water supply	Rural concentration and Immobility	18	1	17	+1	0.06
e	Low level of education and understanding of water issues	Self-organisation and participation of users	16	0	16	+1	0.00
f	Technical problems with the large-scale water supply system	Security of water supply	15	0	15	-1	0.00
g	Governance and management problems	Weak regional economy	15	0	15	+1	0.00
h	Low level of education and understanding of water issues	Weak regional economy	15	0	15	+1	0.00

Table 4.7 reveals that the homogeneous interdependency with the most statements (27) is that the traditional livestock farming in the region reduces the quality and availability of grazing land (a). Furthermore, it is said that the security of water supply is improved by Oshanas and excavation dams (b) but impaired by technical problems of the large-scale water supply system (f). In addition, it is said that the latter factor leads to a concentration and immobility of the rural population (d). The interviewees also stated that a higher level of education and understanding of water issues among all stakeholder groups would reduce governance and management problems (c) as well as informal organisational structures among users (e) ("Self-organisation and participation of users") and would also boost the regional economy (h). Governance and management problems are also said to have a direct negative impact on the regional economy (g).

Those interdependencies with a HQ of more than 0.5 are (arbitrarily) defined as heterogeneous (Figure 4.2). A HQ of more than 0.5 means that the fraction of statements that is assigned to the minority group amounts to more than one third of all statements on a specific interdependency. The ten most outstanding heterogeneous interdependencies are shown in Table 4.8. They make up 7.7 % of all relevant interdependencies.

Table 4.8 Outstanding heterogeneous interdependencies

Designation	Cause	Effect	Number of statements	Numerator	Denominator	Polarity	Heterogeneity quotient (HQ)
1	Large scale water supply	Security of water supply	42	20	22	+1	0.91
2	Floods, droughts, and climate change	Scarcity of water resources	11	4	7	+1	0.57
3	Large scale water supply	Urbanisation	10	4	6	+1	0.67
4	Traditional crop farming	Security of food supply	9	4	5	-1	0.80
5	Large scale water supply	Health	8	3	5	+1	0.60
6	Groundwater and dug wells (Oshikweyo)	Security of water supply	8	3	5	-1	0.60
7	Land policies	Urbanisation	8	3	5	-1	0.60
8	Urbanisation	Weak regional economy	7	3	4	+1	0.75
9	Angolan water demand	Inter-regional conflicts	7	3	4	+1	0.75
10	Large scale water supply	Population growth and migration	5	2	3	+1	0.67

Table 4.8 reveals that the interviewees do not agree whether the large-scale water supply system improves or impairs the regional water supply security (1), which is quite remarkable. This interdependency has by far the largest number of statements in the study (42). It is also not clear among the interviewees if the large-scale system fosters or limits urbanisation in the region (3), if it improves or impairs the health of the users (5), and if it fosters or limits population growth and migration into the region (10). There is also no agreement in which way floods, droughts, and climate change affect the availability of water resources (2) and in which way traditional crop farming affects the security of food supply (4). Furthermore, it is not clear whether traditional dug wells improve or impair the water supply security (6), whether the Angolan water demand fuels or defuses inter-regional conflicts (9), whether applicable land policies foster or limit urbanisation (7), and whether urbanisation, in turn, boosts or weakens the regional economy (8).

The previous results can be confirmed by using the HD (Figure 4.3). If an interdependency is located close to one of the angle bisectors, it can be designated as homogeneous. If it is located close to the ordinate, it can be designated as heterogeneous, since positively and negatively directed statements balance each other out to a greater or lesser extent. In contrast to the HQ, the polarity of the interdependencies is being visualised. The analysis of the interdependencies' polarity will be the starting point for further steps.

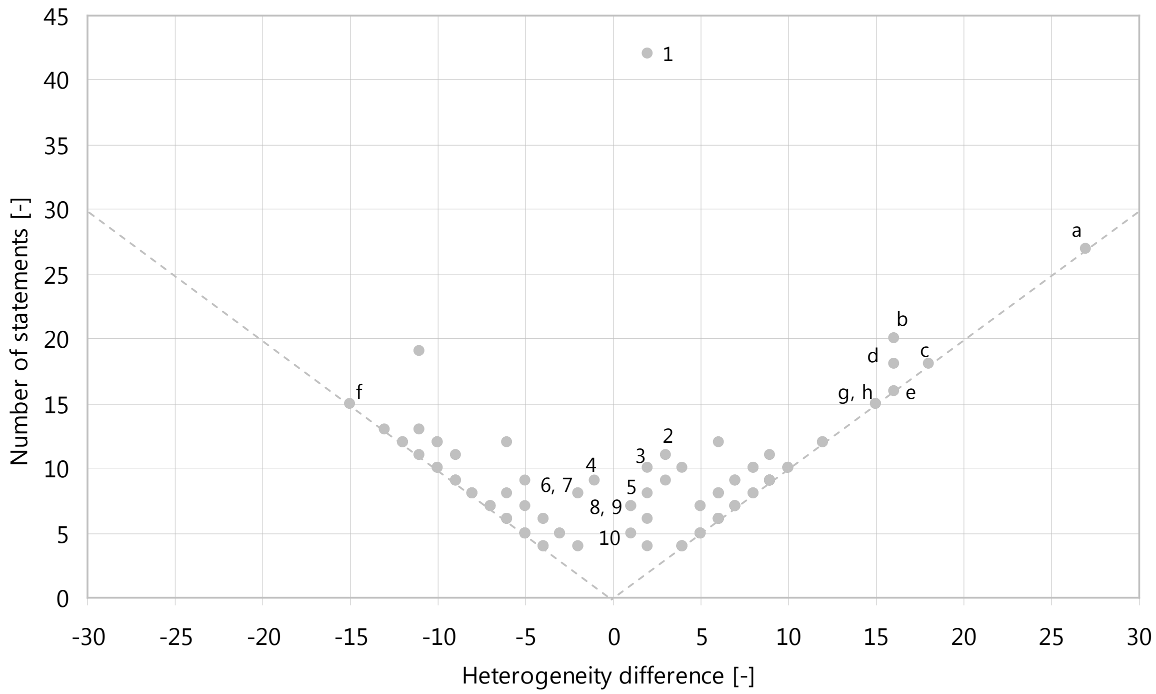

Figure 4.3 Heterogeneity difference (HD) of interdependencies and number of statements

Regarding both indicators, the interdependency between the variable "Large scale water supply" and the variable "Disparities and exclusion" (HQ: 0.27; HD: -11) is in an exposed position, since it has the relatively high number of 19 statements and cannot be clearly assigned as being hetero- or homogeneous. It does not seem to be clear among the interviewees whether the large-scale water supply system prevents disparities among and the exclusion of users, or even contributes to it.

4.3 Feedback loops

4.3.1 Approach

The number of feedback loops and, thus, the computational efforts increase exponentially, the more interdependencies and system variables are taken into consideration. Hence, the amount of data has to be reduced in a reasonable manner in order to filter out relevant feedback loops for further analysis. For this purpose, it has to be specified how to carry out the data reduction. Generally, there are two ways to reduce the amount of data. One way is to reduce the number of interdependencies in the CIM to the ones that are more relevant, in order to reduce the number of potential feedback loops before they are computed. In this context, interdependencies with more statements are supposed to be more relevant than those with fewer statements (Table 4.6). Hence, interdependencies with smaller numbers of statements can be masked out of the CIM. The second way is to filter out those feedback loops (after they have been computed) that are shorter than a defined threshold, i. e. feedback loops which consist of a certain number of variables that is smaller than a defined limit value. This is due to the assumption that the feedback signal or impulse of longer feedback loops is more likely to be weaker than that of shorter loops. Both ways of data reduction will be applied, depending on the actual resulting number of feedback loops.

Furthermore, as discussed earlier, system variables which have been assigned as being outstanding by the sensitivity model should still be present in a reduced CIM. This pertains especially to critical system variables but, to a certain extent, also to active and passive ones. Extremely active or passive variables are less likely to be part of a feedback loop, since they are exogenous or systemic dead ends. This is why influenceable system elements as well as second order passive variables should be favoured for closed loop control. Apart from this, the hetero- or homogeneity of interdependencies, however, will only be considered after the identification of relevant feedback loops.

The starting point of the analysis of feedback loops are the interdependencies' polarities. The feedback loops have been identified by using the Vensim software from Ventana Systems. Vensim is meant for System Dynamics calculations but is also able to analyse causal loop diagrams. In order to do so, the CIM has to be reproduced in the software in the form of a directed graph consisting of nodes, which represent system variables, and vertices, which represent interdependencies. Several instances of the CIM have been built in which different numbers of interdependencies with few statements have been masked out in order to keep track of the resulting amount of data (i. e. the number of feedback loops) and information losses. The identified feedback loops were then exported as a spreadsheet and analysed in an external application.

Three indicators were used in order to assess the feedback loops. The complexity level is the minimum number of statements of the interdependencies involved in a feedback loop. Secondly, the sum of heterogeneity quotients (HQ sum) of the interdependencies involved in a feedback loop can be compared to the HQ sum of loops consisting of the same number of variables (cf. Chapter 4.2). This can be interpreted as an indicator for the heterogeneity of the entire feedback loop, i. e. the uncertainty whether a loop is positive or negative. Finally, the sum of the P-values of variables involved in a feedback loop (P-value sum) can be compared to the P-value sum of loops consisting of the same number of variables (cf. Chapter 4.1). This can be interpreted as an indicator for the criticality of the whole feedback loop, especially if it is a positive one. It has to be noted that the HQ sum as well as the P-value sum can only be used to compare feedback loops of the same length.

4.3.2 Results and discussion

Five instances of the CIM were implemented using the mentioned software. In the most complex instance, only interdependencies with four or more statements were taken into account. Interdependencies with only three or less statements were masked out (Table 4.6). In the most simplified instance used, interdependencies with eight or more statements were taken into account. Interdependencies with seven or less statements were masked out. The following Table 4.9 shows the number of specific feedback loops of selected system variables, depending on the complexity level described.

Table 4.9 Number of feedback loops or role (source, sink, non-existent) of system variables, depending on the complexity level of the model

No.	Name of system variable	Interdependencies with more propositions than				
		> 7	> 6	> 5	> 4	> 3
1	Large-scale water supply	5	10	137	462	4957
2	Technical problems with the large-scale water supply system	0	0	49	110	1014
3	Oshanas and excavation dams (Omatale)	5	7	27	163	2535
4	Shallow dug wells (Omuthima)	Source	Source	Source	Source	Source
5	Groundwater and dug wells (Oshikweyo)	3	3	18	175	2043
6	Rainwater harvesting	2	4	20	54	1548
7	Sanitation problems	0	0	0	0	0
8	Other water supply techniques	non-existent	Sink	Sink	Sink	Sink
9	Governance and management problems	0	0	62	204	4135
10	Water supply and sanitation policies	non-existent	non-existent	non-existent	non-existent	non-existent
11	Land policies	Source	Source	Source	Source	4112
12	Integration and decentralisation	0	0	0	1	1
13	Inter-regional conflicts	Source	0	0	0	0
14	Scarcity of water resources	0	0	0	0	0
15	Salinity of groundwater	Source	Source	Source	Source	Source
16	Floods, droughts, and climate change	Source	Source	Source	Source	Source
17	Poor quality and availability of grazing land	1	1	59	150	3565
18	Soil degradation	Sink	Sink	Sink	Sink	Sink
19	Deforestation	non-existent	non-existent	non-existent	non-existent	non-existent
20	Environmental pollution and risks for biodiversity	non-existent	Sink	Sink	Sink	Sink
21	Population growth and migration	Source	Source	Source	1	1
22	Urbanisation	5	14	126	421	4539
23	Rural concentration and immobility	Sink	1	40	100	1516
24	Health	Sink	Sink	Sink	Sink	Sink
25	Disparities and exclusion	Sink	Sink	Sink	Sink	Sink
26	Low level of education and understanding of water issues	Source	Source	Source	Source	Source
27	Perception of water prices	Sink	Sink	Sink	Sink	Sink
28	Self-organisation and participation of users	Source	0	0	0	1759
29	Misuse and vandalism	Source	Source	0	0	208
30	Security of water supply	Sink	Sink	Sink	Sink	Sink
31	Security of food supply	Sink	Sink	Sink	Sink	Sink
32	Subsistence and poverty	12	18	150	478	4964
33	Traditional crop farming	0	0	47	87	1516

34	Traditional livestock farming	7	15	136	414	4853
35	Lack of irrigation and horticulture	8	12	85	274	3280
36	Weak regional economy	9	18	140	402	4209
37	Angolan water demand	Source	Source	Source	Source	Source

As mentioned earlier, it can be seen that the number of feedback loops increases exponentially the more interdependencies are involved. However, the data contains redundancies, since only specific feedback loops are counted. This means that one and the same feedback loop is counted as many times as the number of system variables involved. Although remarkable feedback loops can be filtered out by using indicators, they have to be examined and assessed manually, one by one. This is why it seems reasonable to set the upper complexity level of the model to six or more statements per interdependency. Furthermore, only feedback loops consisting of six or less variables were taken into consideration. This limit value was chosen arbitrarily but it allows interdependencies with six statements to be included in the considerations without creating too large amounts of data. In the case of the system variable “Large-scale water supply”, for instance, 61 of a total of 137 feedback loops consist of six or less variables. The remaining 76 feedback loops consist of seven or more variables. Furthermore, only 14 of the 37 system variables are part of a feedback loop on the chosen complexity level (six or more statements per interdependency). The rest is either a source or sink of the system (which means that a system variable is only influencing the rest of the system or it is only influenced by it) or is connected to such a systemic dead end (cf. Chapter 4.4). Two system variables are completely non-existent (“Water supply and sanitation policies” and “Deforestation”), due to the fact that they are represented by interdependencies with only three or less statements.

Under the given conditions, a total number of 98 feedback loops can be identified, of which 70 are positive and only 28 are negative (Table 4.10). The clear preponderance of positive feedback loops can be interpreted as an indication of the instability of the whole system. Including those feedback loops that are not covered by the criteria explained above might reduce the imbalance to a certain extent. But the identified feedback loops are still supposed to be more relevant and valid. In addition, 81 of the 98 feedback loops are water-related, since they include at least one water-related system variable of the technical dimension. The remaining 17 feedback loops are non-water-related. Regarding the water-related feedback loops, 26 are negative and 55 positive. The imbalance becomes even clearer when looking at the non-water-related feedback loops. Here, only two are negative and 15 are positive.

Table 4.10 Number and length of water-related and non-water-related feedback loops (with six or more statements per interdependency and consisting of six or less variables)

	Loops with X variables	Water-related feedback loops (WR)	Sum WR	Non-water-related feedback loops (NWR)	Sum NWR	Total
Negative feedback loops	2		26	2	2	28
	3	3				
	4	7				
	5	7				
	6	9				
Positive feedback loops	2	3	55	2	15	70
	3	4		4		
	4	10		5		
	5	14		3		
	6	24		1		
Total			81		17	

The system variables involved in the largest number of feedback loops consisting of interdependencies with six or more statements are "Subsistence and poverty" (73) and "Weak regional economy" (67) followed by "Traditional livestock farming" (62), "Large-scale water supply" (61) and "Urbanisation" (56) (Table 4.11). The system variable "Oshanas and excavation dams (Omatale)" is the only one that is included in more negative (5) than positive (4) feedback loops. The system variable "Rural concentration and immobility" is involved in as many negative as positive feedback loops (4). All other variables are part of more positive than negative feedback loops. The variable "Large-scale water supply", for instance, is involved in 40 positive and 21 negative feedback loops. The system variables "Groundwater and dug wells (Oshikweyo)" (5) and "Rainwater harvesting" (8) are only included in positive feedback loops. The variables "Traditional crop farming" and "Lack of irrigation and horticulture" are part of much more positive than negative feedback loops.

Table 4.11 Number of positive and negative feedback loops of specific system variables

No.	Name of system variable	Number of feedback loops (interdependencies > 5, variables < 7)		
		Negative feedback loops	Positive feedback loops	Total
1	Large-scale water supply	21	40	61
2	Technical problems with the large-scale water supply system	5	12	17
3	Oshanas and excavation dams (Omatale)	5	4	9
5	Groundwater and dug wells (Oshikweyo)	0	5	5
6	Rainwater harvesting	0	8	8
9	Governance and management problems	8	21	29
17	Poor quality and availability of grazing land	5	10	15
22	Urbanisation	16	40	56
23	Rural concentration and immobility	4	4	8
32	Subsistence and poverty	19	54	73
33	Traditional crop farming	2	14	16
34	Traditional livestock farming	19	43	62
35	Lack of irrigation and horticulture	6	27	33
36	Weak regional economy	20	47	67

4.3.2.1 Water-related feedback loops

Five negative and eleven positive water-related feedback loops consisting of interdependencies with seven or more statements are presented below. Only examples of loops with seven or more statements were chosen, because the large numbers of loops with fewer statements mainly represent variations of the archetypes presented below.

The variable “Large-scale water supply” is included in two positive feedback loops consisting of two components (Figure 4.4 and 4.5). The interviewees do not seem to completely agree on the self-reinforcing nature of the interrelation between the variables “Large-scale water supply” and “Urbanisation”, due to the very high HQ sum of 0.81 (compared to other feedback loops consisting of two variables). However, the very high P-value sum of 11,730 indicates the feedback loop’s criticality for the whole system. Apart from this, the interviewees are very much in agreement on the self-reinforcing nature of the interrelation between the variables "Large-scale water supply" and "Rural concentration and immobility", as the HQ sum is very low (0.06).

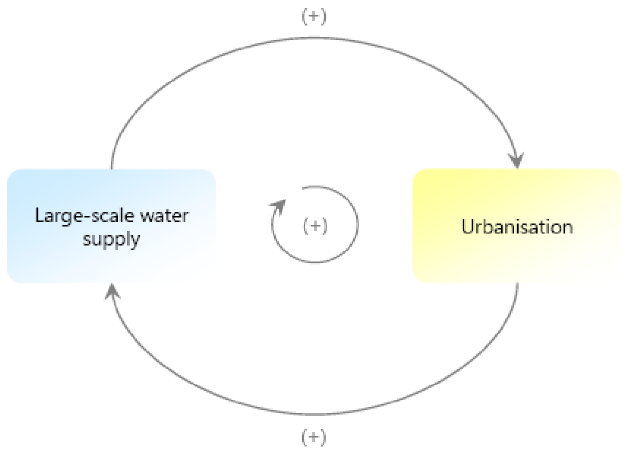

Figure 4.4 Positive feedback loop including the variable "Large-scale water supply" and consisting of two variables (FL1)

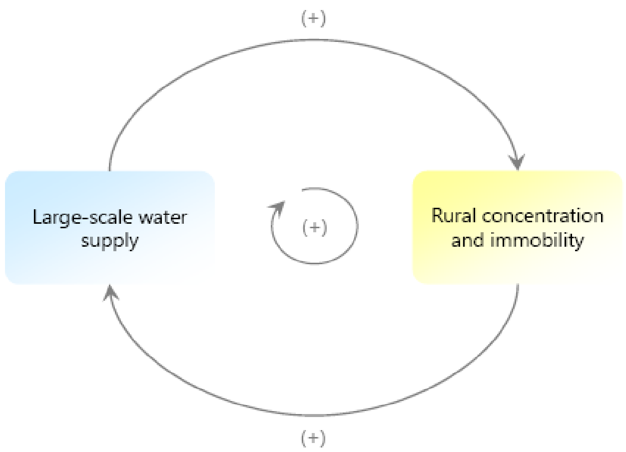

Figure 4.5 Positive feedback loop including the variable "Large-scale water supply" and consisting of two variables (FL2)

Only two negative feedback loops involving the variable "Large-scale water supply" can be identified at the chosen complexity level (Figure 4.6 and 4.7). Both are identical except that the longer feedback loop has a bypass via the variable "Subsistence and poverty". Apart from this, the processes described are similar and seem to have a resilient nature. The interviewees state that the variable "Large-scale water supply" contributes directly (e. g. through the open canal) or indirectly (e. g. through providing tap water to farmers in rural areas) to traditional livestock farming. This, for instance, reinforces subsistence and poverty and keeps the regional economy down which, in turn, slows down urbanisation as well as the growth of the large-scale water supply system and vice versa. The very low HQ sum (0.14) of the feedback loop consisting of four variables indicates that the interviewees agree very strongly on these interrelations. Furthermore, the very high P-value sum of 19,435 (also of the shorter of both loops) shows the criticality of these feedback loops.

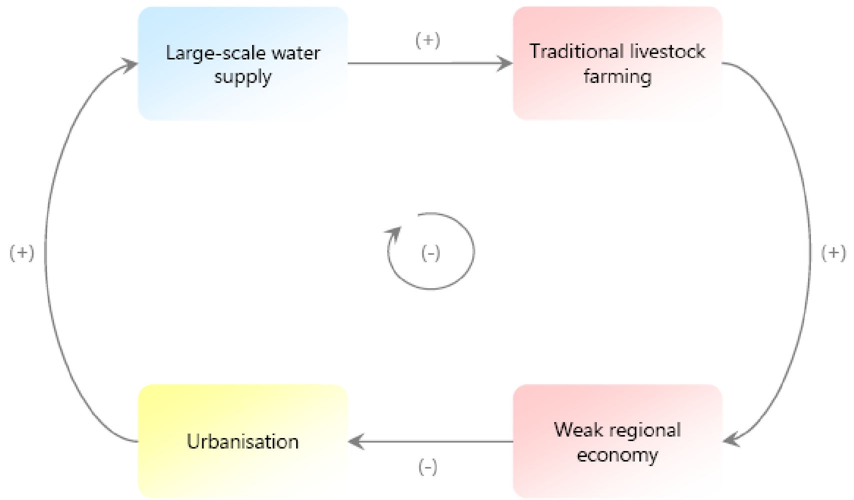

Figure 4.6 Negative feedback loop including the variable "Large-scale water supply" and consisting of four variables (FL3a)

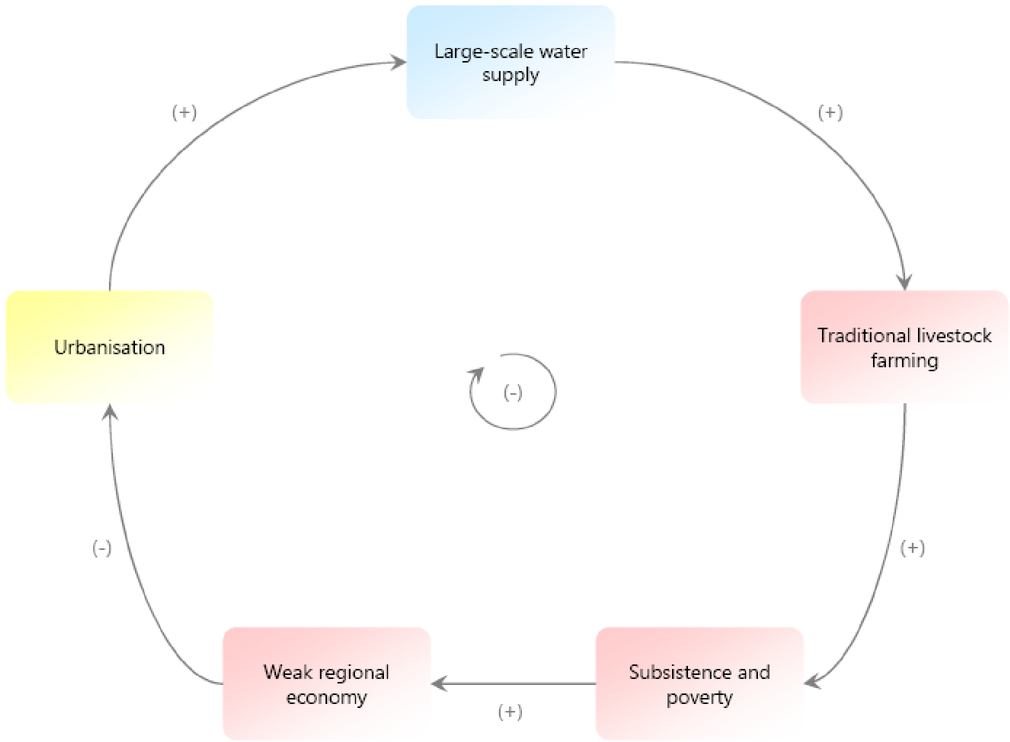

Figure 4.7 Negative feedback loops including the variable "Large-scale water supply" and consisting of five variables (FL3b)

Two positive feedback loops involving "Large-scale water supply" and consisting of four or five variables can be identified that are quite similar to the negative loops mentioned above (Figure 4.8 and 4.9). An increase of the variable "Large-scale water supply", for instance, leads to a smaller lack of irrigation and horticulture as well as less subsistence and poverty. This strengthens the regional economy, increases urbanisation and, eventually, reinforces the large-scale water supply system and vice versa. When considering regulation measures, it has to be taken into account that all mentioned processes of the feedback loops involving the variable "Large-scale water supply" take place at the same time and might counteract each other.

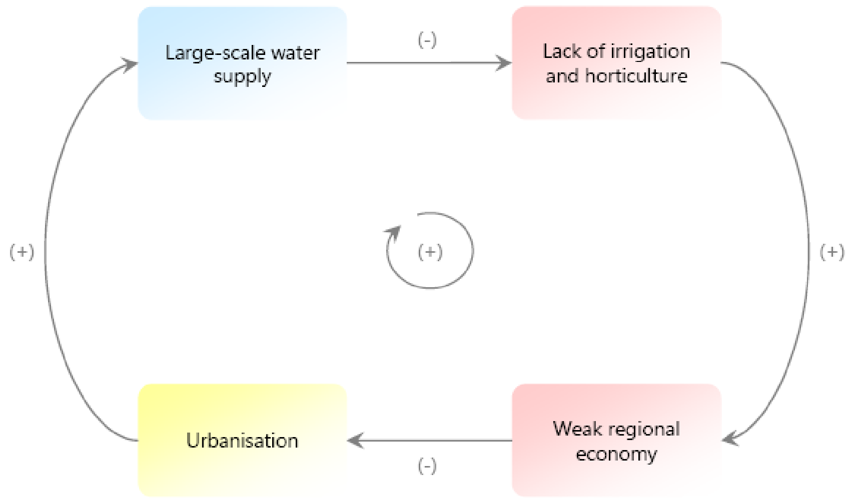

Figure 4.8 Positive feedback loop including the variable “Large-scale water supply” and consisting of four variables (FL4a)

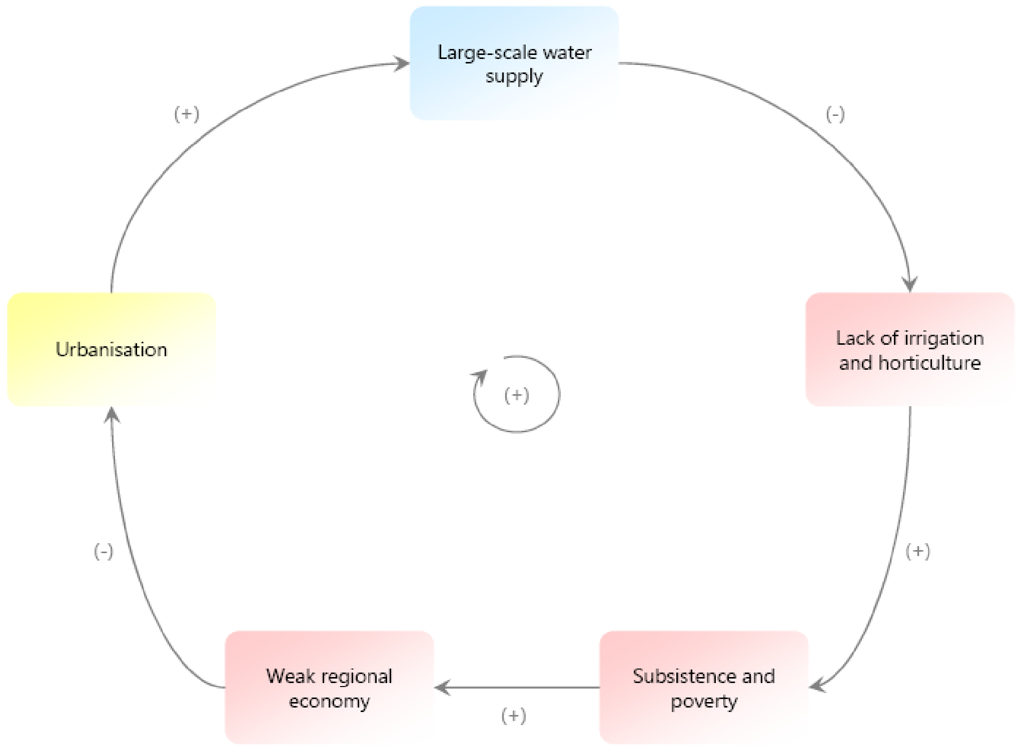

Figure 4.9 Positive feedback loop including the variable “Large-scale water supply” and consisting of five variables (FL4b)

An examination of the feedback loops containing alternative water supply techniques reveals the presence of two feedback loops, each consisting of three variables, which are quite similar but have an opposite sign (Figure 4.10 and 4.11). Using more Oshanas and excavation dams (Omatale), for instance, would reduce the lack of irrigation and horticulture and, in turn, also subsistence and poverty. This leads to a lower utilisation of Oshanas and excavation dams (and vice versa) and, thus, a balancing feedback. Unlike the case described, a self-reinforcing feedback can be observed when replacing Oshanas and excavation dams with rainwater harvesting in the otherwise identical feedback loop. This is due to the fact that less subsistence and poverty is said to lead to more rainwater harvesting and vice versa. Nevertheless, the latter feedback loop has a very high HQ sum of 0.42 and, furthermore, a very low P-value sum of 8,297 which is why it might be considered as leverage to initiate transitions.

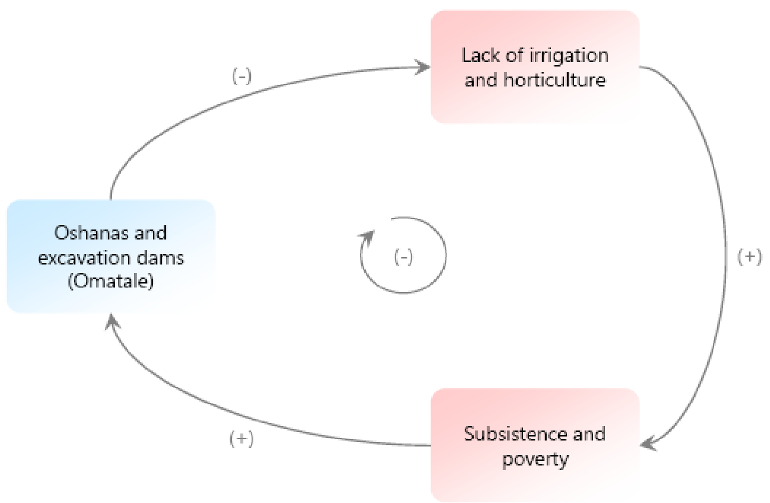

Figure 4.10 Negative feedback loop including alternative water supply technique and consisting of three variables (FA1a)

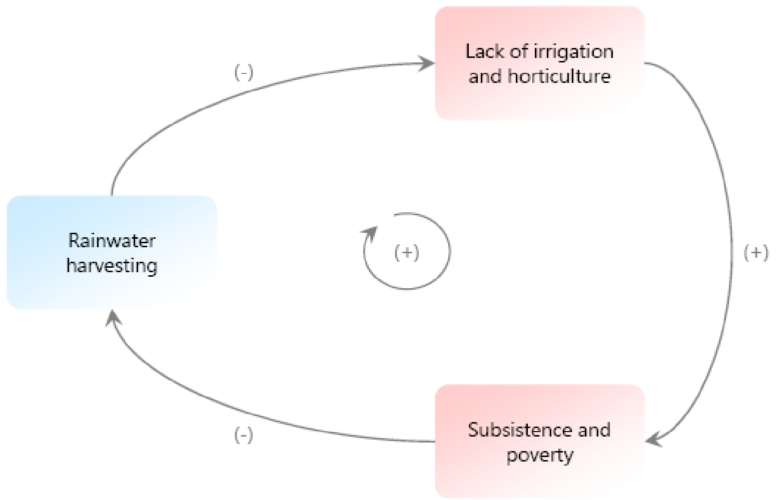

Figure 4.11 Positive feedback loop including alternative water supply technique and consisting of three variables (FA2a)

The following two feedback loops consisting of four variables are a variation of the two loops mentioned above. The only difference to the latter is a bypass via the variable "Weak regional economy" (Figure 4.12 and 4.13). Again, the feedback loop containing rainwater harvesting has a very high HQ sum of 0.55 and, furthermore, a very low P-value sum of 10,607, which underpins the above-mentioned conclusion.

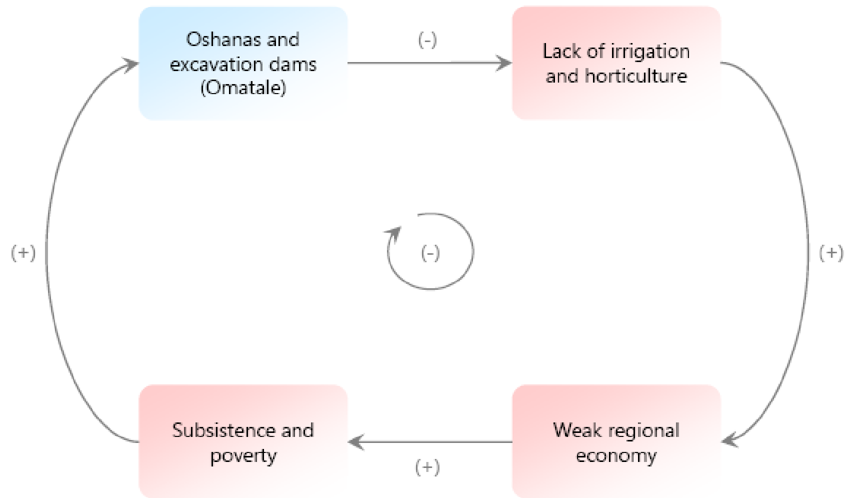

Figure 4.12 Negative feedback loop including alternative water supply technique and consisting of four variables (FA1b)

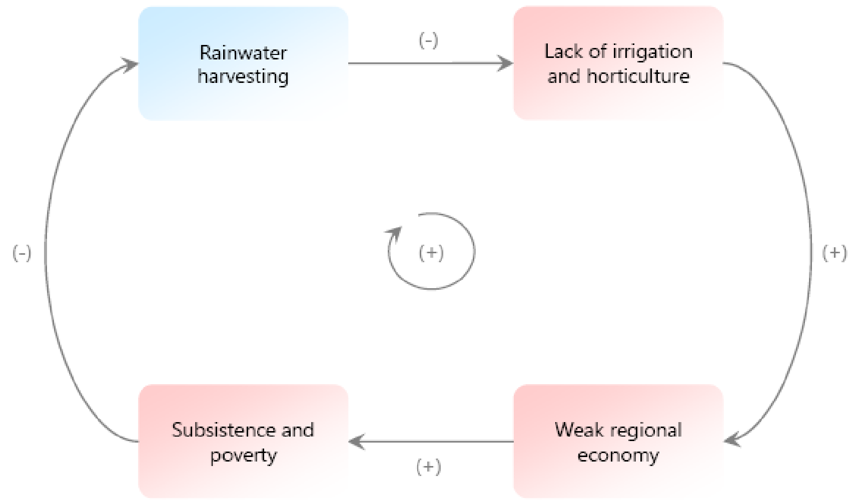

Figure 4.13 Positive feedback loop including alternative water supply technique and consisting of four variables (FA2b)

In addition, Oshanas and excavation dams (Omatale) are involved in a positive feedback loop consisting of three variables (Figure 4.14). Interestingly, Groundwater and dug wells (Oshikweyo) can replace Oshanas in the otherwise identical feedback loop without changing its self-reinforcing nature, which is why they can be considered as interchangeable in this case (Figure 4.15). An increase in one or the other variable would intensify traditional livestock farming and, in turn, lead to more subsistence and poverty which, eventually, reinforces the alternative water supply technique and vice versa. Since the feedback loop containing Oshanas and excavation dams (Omatale) has a very high P-value sum of 13,711, both should be handled with caution when considering them for regulation measures. Additionally, the feedback loop containing Groundwater and dug wells (Oshikweyo) has a very high HQ sum of 0.54.

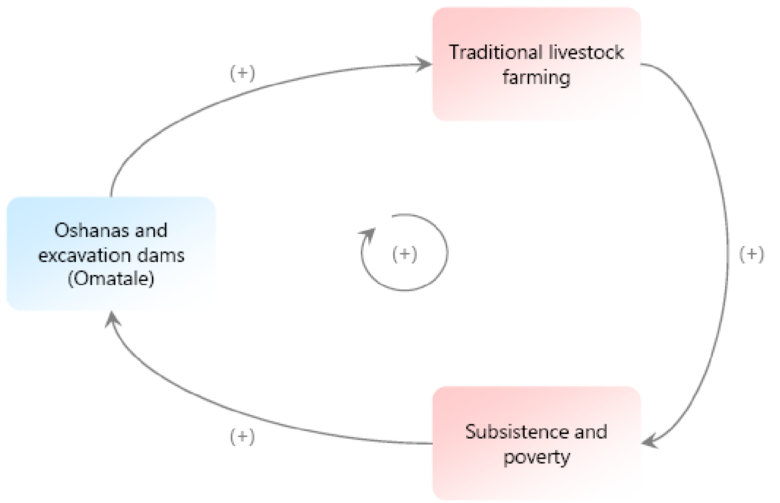

Figure 4.14 Positive feedback loop including alternative water supply technique and consisting of three variables (FA3a)

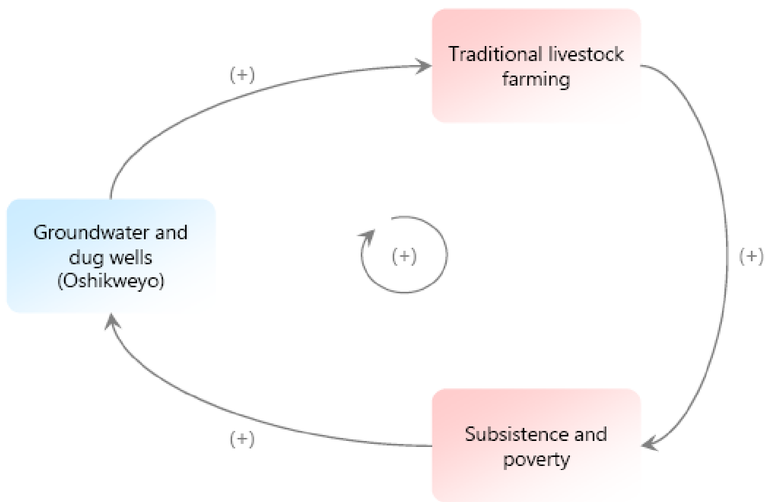

Figure 4.15 Positive feedback loop including alternative water supply technique and consisting of three variables (FA4a)

Again, a variation of the feedback loops just mentioned with a bypass via the variable "Weak regional economy" can be observed (Figure 4.16 and 4.17). Once more, the feedback loop consisting of four variables which involves Groundwater and dug wells (Oshikweyo) has a very high HQ sum of 0.66.

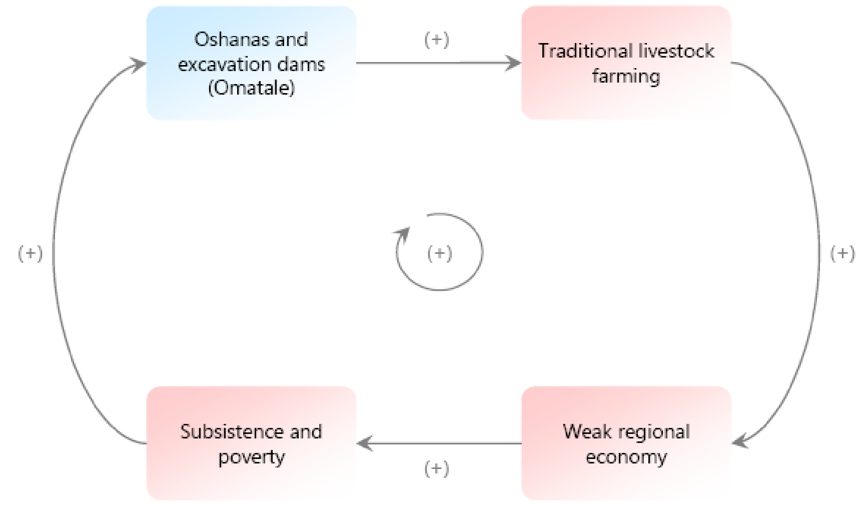

Figure 4.16 Positive feedback loop including alternative water supply technique and consisting of four variables (FA3b)

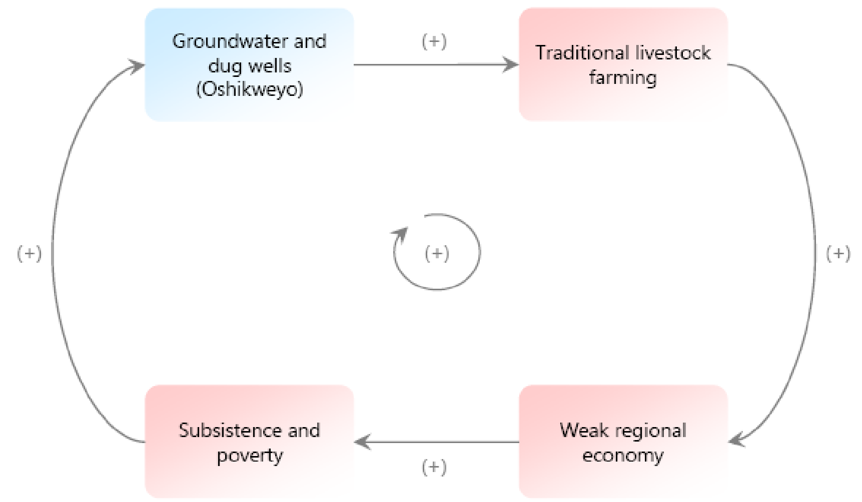

Figure 4.17 Positive feedback loop including alternative water supply technique and consisting of four variables (FA4b)

Finally, two feedback loops of opposite sign and consisting of six variables involve alternative water supply techniques (Figure 4.18 and 4.19). The loop containing Oshanas and excavation dams (Omatale) has a balancing nature and the loop containing rainwater harvesting a self-reinforcing. For instance, an increase in the utilisation of Oshanas and excavation dams (Omatale) would reduce the lack of irrigation and horticulture, which, in turn, strengthens the regional economy. A more productive regional economy would increase urbanisation, which, in turn, reduces traditional livestock farming. Less traditional livestock farming leads to less subsistence and poverty and, eventually, a decrease in the utilisation of Oshanas and excavation dams (Omatale). Nevertheless, the positive feedback loops involving Oshanas and excavation dams (Omatale) mentioned above should be taken into account when considering this variable for regulation measures. Replacing Oshanas with the variable "Rainwater harvesting" in the otherwise identical feedback loop induces a self-reinforcing feedback. Again, this is due to the fact that less subsistence and poverty is said to lead to more rainwater harvesting and vice versa.

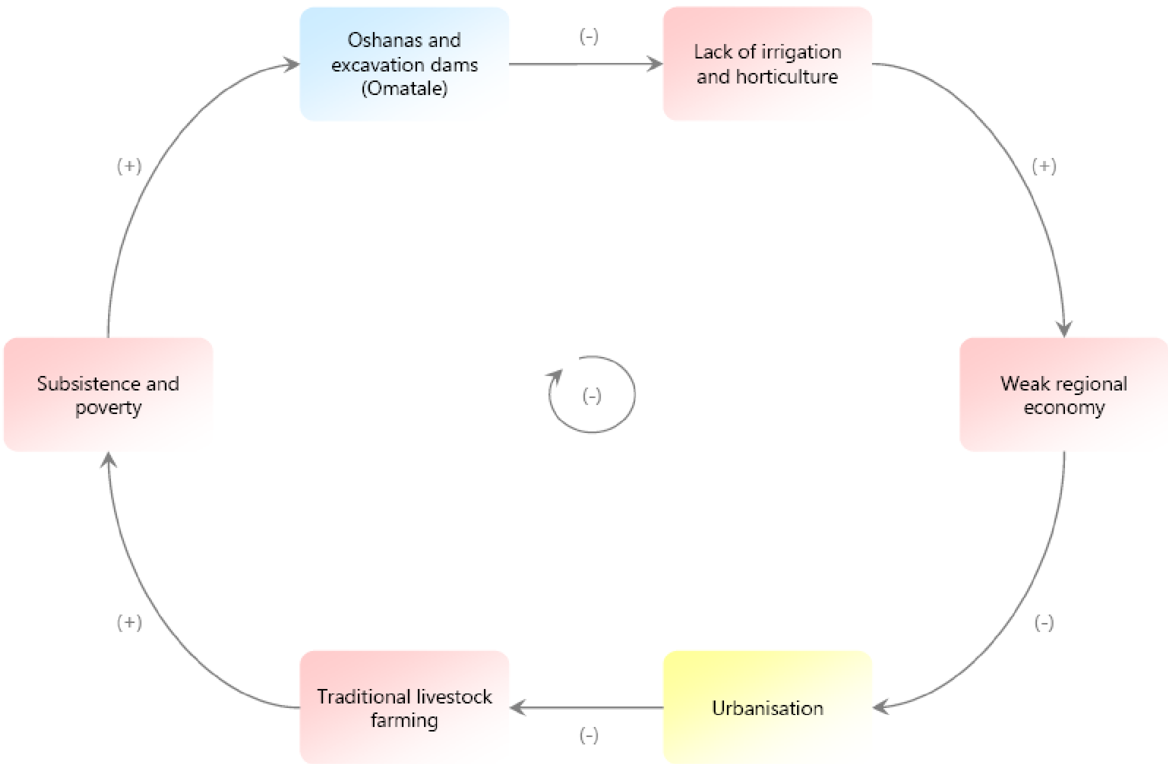

Figure 4.18 Negative feedback loop including alternative water supply technique and consisting of six variables (FA5)

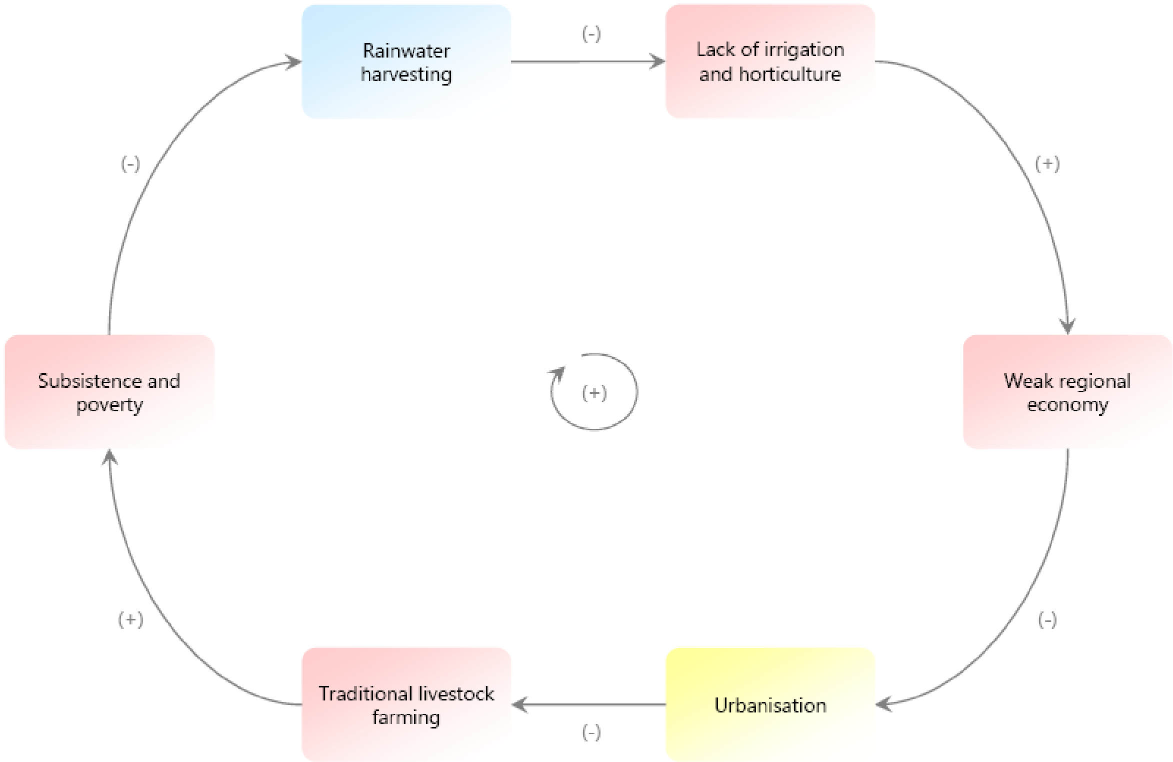

Figure 4.19 Positive feedback loop including alternative water supply technique and consisting of six variables (FA6)

4.3.2.2 Non-water-related feedback loops

Five non-water-related feedback loops consisting of interdependencies with seven or more statements have been identified, of which two are negative and three positive. The first negative feedback loop presented is the interrelation between the variables “Traditional livestock farming” and “Poor quality and availability of grazing land” (Figure 4.20). The interviewees state that more traditional livestock farming leads to a lower quality and availability of grazing land which, in turn, weakens traditional livestock farming and vice versa. This can be seen as a textbook example of a balancing feedback loop. Furthermore, the interviewees agreed unanimously on this interrelation, since its HQ sum is zero. A positive feedback loop between the variables “Subsistence and poverty” and “Weak regional economy” has also been identified (Figure 4.21). Its self-reinforcing nature can be interpreted as a vicious circle if it is directed downwards, i. e. more subsistence and poverty leads to a weaker regional economy, which, in turn, increases subsistence and poverty. In the other direction, the feedback loop might be an economic booster.

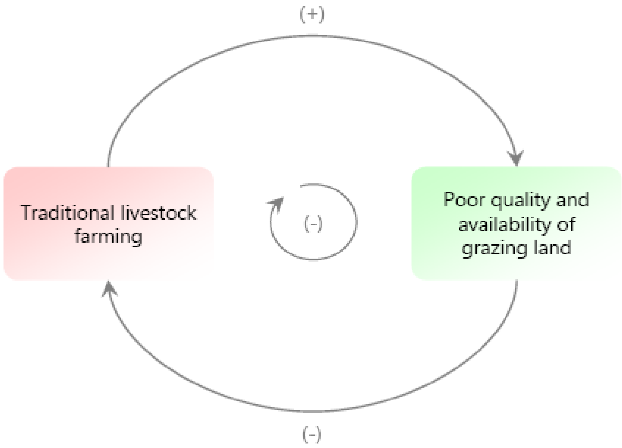

Figure 4.20 Negative feedback loop consisting of two non-water-related variables (FN1)

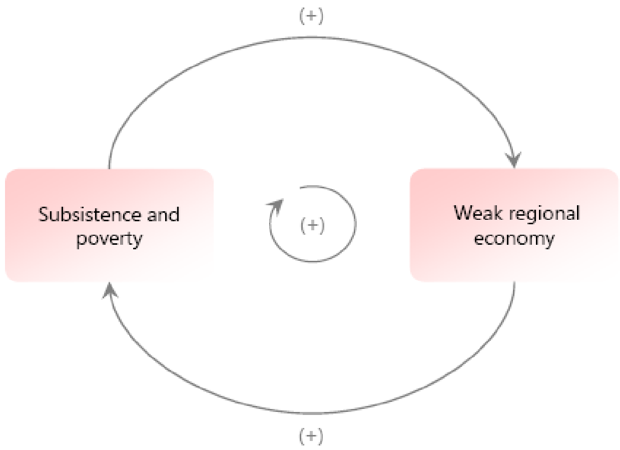

Figure 4.21 Positive feedback loop consisting of two non-water-related variables (FN2)

The second negative feedback loop consists of the variables “Urbanisation” and “Weak regional economy” (Figure 4.22). The interviewees do not seem to agree substantially on this interrelation, because its HQ sum is very high (0.75). At the same time, the feedback loop has a very low P-value sum of 5,718.

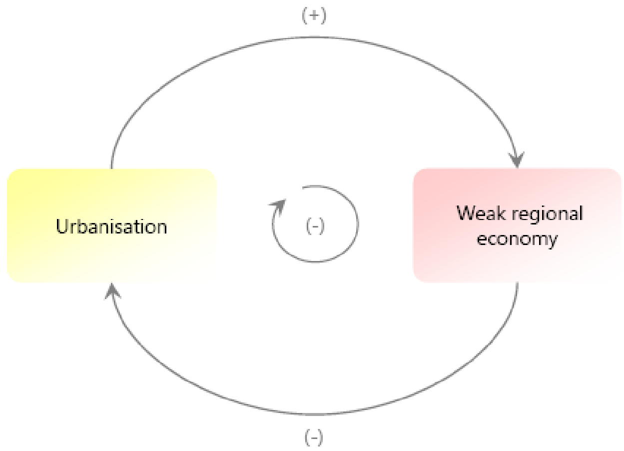

Figure 4.22 Negative feedback loop consisting of two non-water-related variables and including the variable "Urbanisation" (FN3)

The variable "Urbanisation" is, furthermore, involved in two positive feedback loops (Figure 4.23 and 4.24) consisting of three or four components. Both loops are closely related to each other, since three of four variables are identical. It is said that more urbanisation, for instance, leads to less traditional livestock farming and, in turn, also to less subsistence and poverty. This strengthens the regional economy and, in turn, increases urbanisation and vice versa. The interviewees agree completely on these feedback loops since their HQ sums are both zero. These self-reinforcing processes have to be taken into account when considering urbanisation as a regulation measure to strengthen the regional economy.

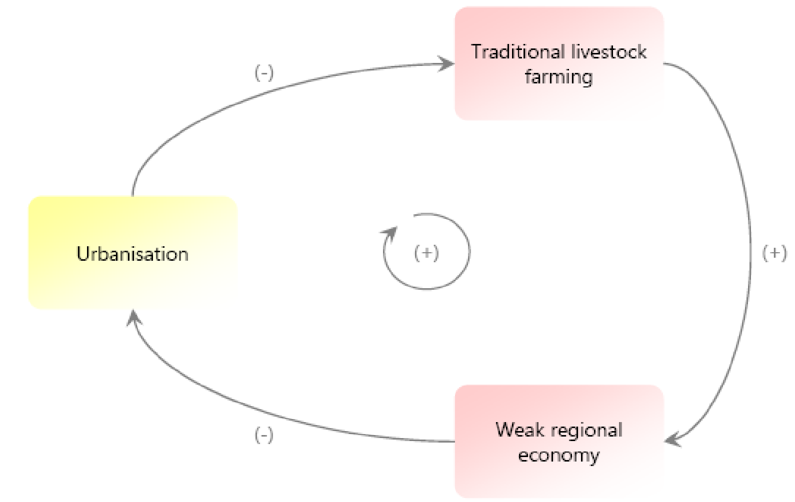

Figure 4.23 Positive feedback loop consisting of three non-water-related variables and including the variable “Urbanisation” (FN4a)

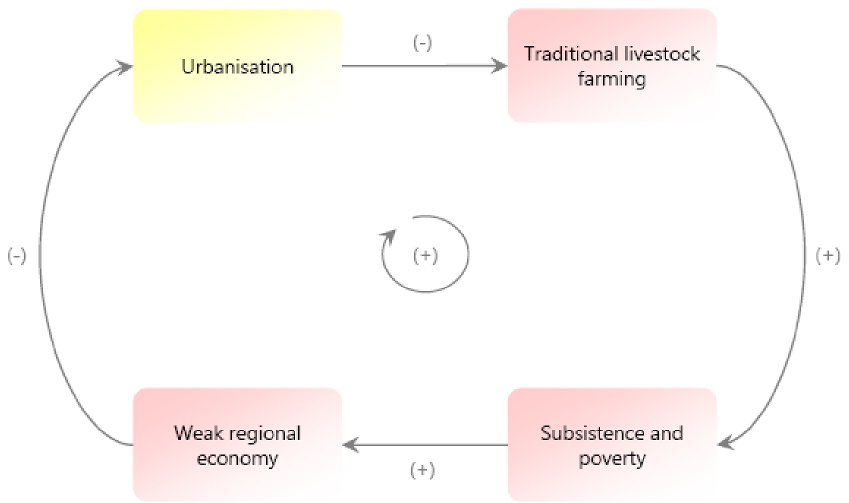

Figure 4.24 Positive feedback loop consisting of four non-water-related variables and including the variable “Urbanisation” (FN4b)

4.4 Cause-effect chains

4.4.1 Approach

After having identified the system variables involved in feedback loops, the remaining variables have to be analysed. These remaining variables can be systemic sources, systemic sinks, part of a cause-effect chain, or non-existent (Table 4.9). Sources have effects, which means that they influence a number of other system variables directly and indirectly. The goal of this section is to analyse which other elements are affected and how they are affected. At the same time, sinks have causes, which means that they are influenced by a number of other system variables, directly and indirectly. The task is now to find out by which other elements they are affected and how they are affected. All these findings are relevant when it is intended to influence specific system variables or parts of the system in a purposeful way by making use of cause-effect chains or so-called open loops.

As in the case of the feedback loops, the software Vensim has been used to identify and analyse cause-effect chains of sources and sinks, or so-called effects trees and causes trees. Only directly or indirectly affected system variables after two steps in a cause-effect chain were considered, since it is more likely that a cause-effect chain derives from or leads to a feedback loop, the longer the chain. Again, the model consisting of interdependencies with at least six statements has been used to analyse cause-effect chains.

4.4.2 Results and discussion

Table 4.12 surveys the sources with the most effects (in terms of system variables) and the sinks with the most causes in the model with the chosen complexity level. Effects trees of systemic sources and causes trees of systemic sinks are discussed in detail below.

Table 4.12 Number of direct and indirect causes or effects of specific system variables

No.	Name of system variable	Causes		Effects	
		Direct	Indirect	Direct	Indirect
4	Shallow dug wells (Omuthima)			2	5
8	Other water supply techniques	1			
16	Floods, droughts, and climate change			2	9
21	Population growth and migration			3	8
24	Health	4	11		
25	Disparities and exclusion	3	13		
26	Low level of education and understanding of water issues			17	25
27	Perception of water prices	2	4		
30	Security of water supply	11	17		
37	Angolan water demand			3	2

4.4.2.1 Effects trees of systemic sources

No other system variable influences as many factors in open loops as “Low level of education and understanding of water issues” (Figure 4.25). This correlates with the highest Q-value (17.7, absolute; 5.0, normalised) and activity (177, absolute; 20, normalised) of all system variables (cf. Chapter 4.1.2). It directly affects 17 other variables and 25 indirectly on 70 different pathways when considering two steps in the effects tree. Thus, most indirectly affected system variables are influenced several times. System variables in parentheses indicate the fact that they appear somewhere else in the diagram. In terms of an interdependency’s polarity, the variables most negatively influenced are “Other water supply techniques” and “Large-scale water supply”. A lower level of education is said to directly impede “Other water supply techniques” (and vice versa). Furthermore, it indirectly decreases the variable on three different pathways. Apart from this, a lower level of education indirectly also leads to a deterioration and/or shrinkage of the large-scale water supply system (on four pathways). It must be remembered that a negatively related interdependency or effect also implies the corresponding interrelation with opposite sign (e. g. a higher level of education leads to an improvement and/or expansion of the large-scale water supply system).

System variables most positively influenced by “Low level of education and understanding of water issues” (in terms of the interdependencies’ polarity) have to be highlighted as well. A lower level of education is said to weaken the regional economy (directly and indirectly on five different pathways with one additional negatively related indirect effect), to worsen technical problems with the large-scale water supply system (directly and indirectly on three pathways), and to increase the usage of Oshanas and excavation dams (Omatale) (directly and indirectly on three pathways) as well as the usage of Groundwater and dug wells (Oshikweyo) (directly and indirectly on three pathways but additionally one negatively related indirect affect) and vice versa. Furthermore, it is said to increase subsistence and poverty as well as traditional livestock farming (both directly and indirectly on four pathways but one negatively related indirect effect).

Figure 4.25 Effects tree of the system variable "Low level of education and understanding of water issues" (created with Vensim)

Another system variable with a conspicuously large number of open loop effects is “Population growth and migration” (Figure 4.26). The variable directly affects three other variables and eight indirectly on nine different pathways, when considering two steps in the effects tree. Two variables are affected twice, namely “Security of water supply” and “Health”. Interestingly, the effects cancel each other out in both cases, which means that each variable is positively as well as negatively affected at the same time. The water supply security is reduced by more population growth and migration but also improved through the large-scale water supply system and vice versa. The variable “Health” is, for instance, worsened by more population growth and migration, through the lack of sanitary infrastructure, but also improved through the large-scale water supply system.

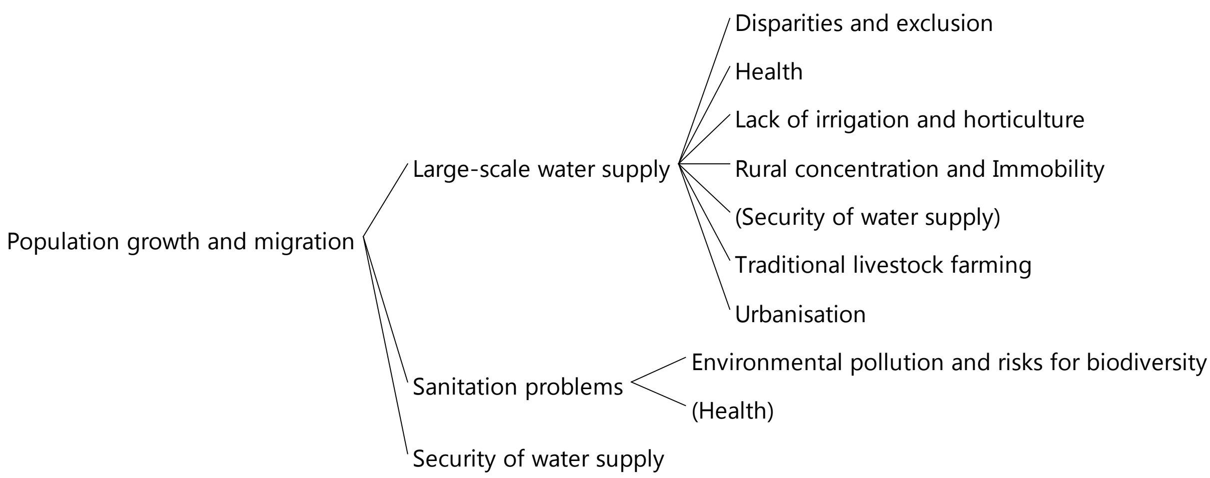

Figure 4.26 Effects tree of the system variable “Population growth and migration” (created with Vensim)

The system variable “Floods, droughts, and climate change” is also a variable with a conspicuously large number of open loop effects (Figure 4.27). It has also been identified earlier as one of the most active system elements (cf. Chapter 4.1.2). The variable directly affects two other variables and nine indirectly on ten different pathways when considering two steps in the effects tree. Two water-related effects are striking here. More floods, droughts, and climate change will directly and indirectly reduce the usage of Oshanas and excavation dams (Omatale) and vice versa. Furthermore, the water supply security is, for instance, said to be reduced (indirectly on two pathways) if the region has to face more floods, droughts, and climate change.

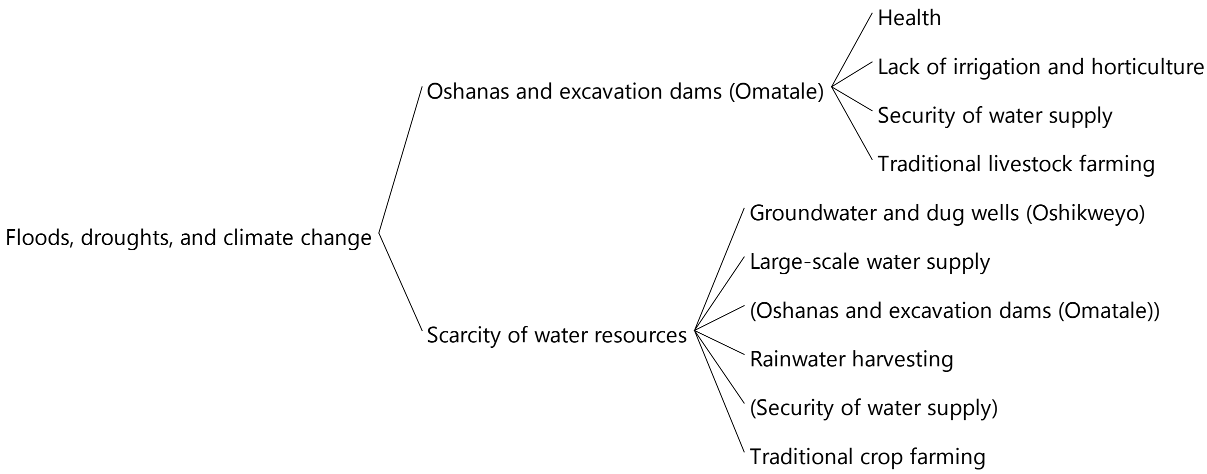

Figure 4.27 Effects tree of the system variable "Floods, droughts, and climate change" (created with Vensim)

Finally, two water-related effects trees are presented. The variable "Angolan water demand" directly affects three other variables and two indirectly on three different pathways when considering two steps in the effects tree (Figure 4.28). Again, the variable has previously been identified as very active (cf. Chapter 4.1.2). Interestingly, the water supply security is affected most (directly and indirectly on two pathways). All three effects are negatively related, which means that a higher Angolan water demand is said to reduce the water supply security and vice versa. Additionally, the variable "Shallow dug wells (Omuthima)" directly affects two other variables and five indirectly on five different pathways when considering two steps in the effects tree (Figure 4.29). However, there is no outstanding system variable that is affected several times in this case.

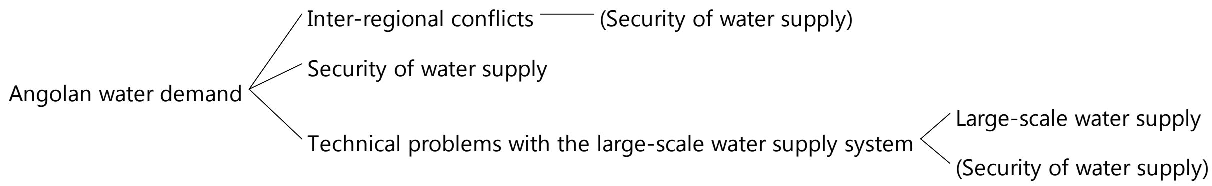

Figure 4.28 Effects tree of the system variable "Angolan water demand" (created with Vensim)

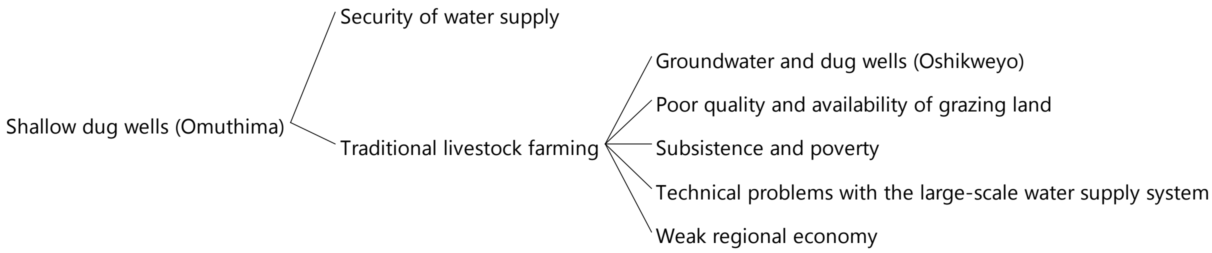

Figure 4.29 Effects tree of the system variable "Shallow dug wells (Omuthima)" (created with Vensim)

4.4.2.2 Causes trees of systemic sinks

No other system variable is influenced by as many factors in open loops as "Security of water supply". This correlates with the lowest Q-value (0.01) and highest passivity (160) of all system variables (cf. Chapter 4.1.2). The variable is directly affected by eleven other variables and indirectly by 17 on 32 different pathways when considering two steps in the causes tree (Figure 4.30). The most outstanding negatively related cause is the scarcity of water resources (directly and indirectly on four pathways but with one positively related indirect cause). The interviewees stated that more availability of water resources improves the water supply security and vice versa. Apart from this, two additional negatively related causes have to be highlighted. As identified earlier, the Angolan water demand is said to negatively affect the water supply security (directly and indirectly on two pathways). In addition, governance and management problems reduce the water supply security (indirectly on three pathways). Besides these major causes, other negatively related causes comprise "Technical problems with the large-scale water supply system", "Subsistence and poverty", "Traditional livestock farming", and "Floods, droughts, and climate change".

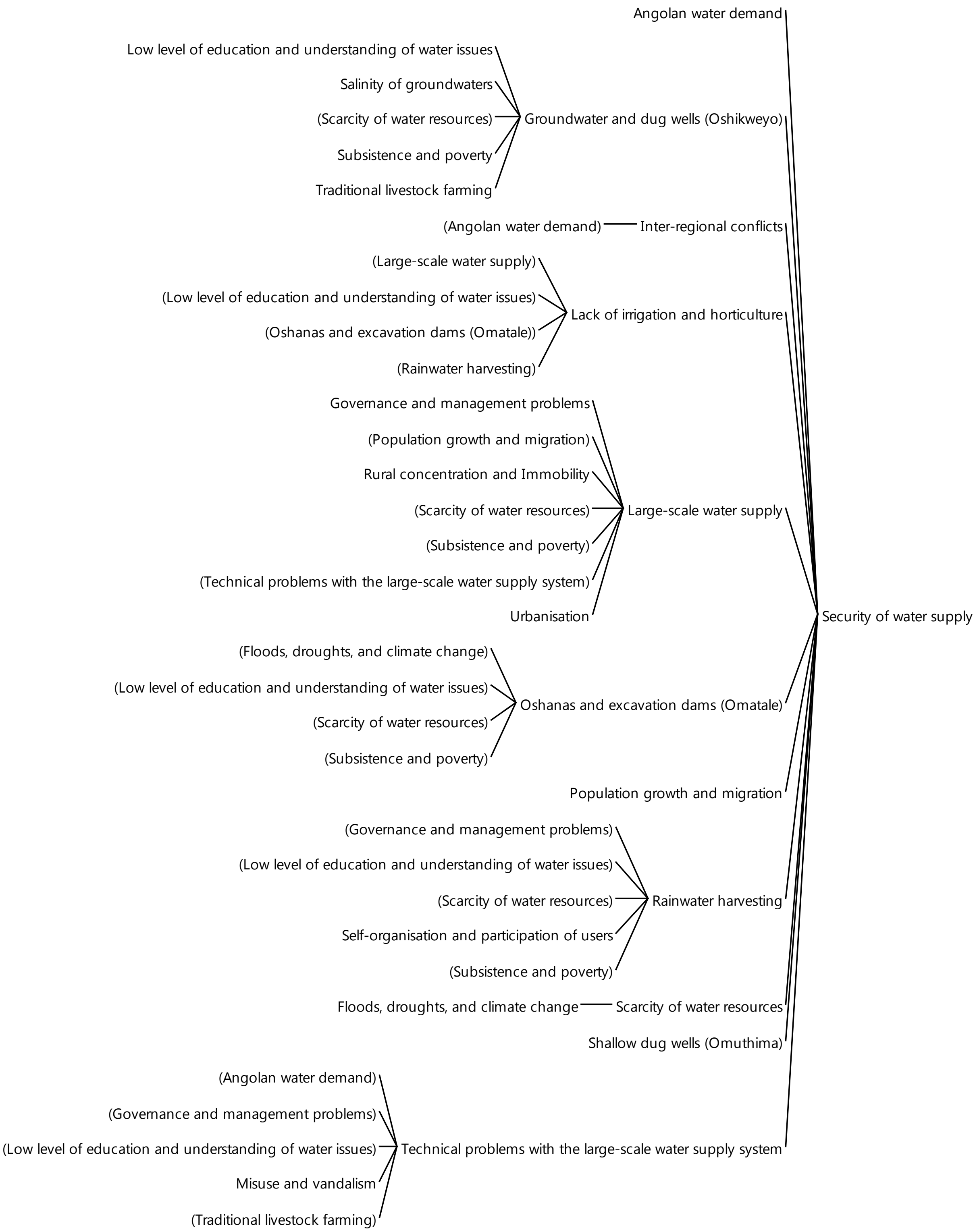

Figure 4.30 Causes tree of the system variable „Security of water supply" (created with Vensim)

The system variable which is influenced by the second largest number of causes in open loops is “Health”. It has already been identified as one of the most passive variables of all system elements (cf. Chapter 4.1.2). The variable is directly affected by four other variables and indirectly by eleven on 21 different pathways when considering two steps in the causes tree (Figure 4.31). The most outstanding negatively related cause is subsistence and poverty (indirectly on four pathways). No other variable is said to deteriorate the health situation of the population as much as this one. Another outstanding negatively related cause is “Low level of education and understanding of water issues” (indirectly on three pathways). Thus, no other system element is said to improve the health situation as much as a higher level of education. Both findings seem to be obvious, yet they are remarkable since the four direct causes of the variable “Health” are technical water-related elements.

Figure 4.31 Causes tree of the system variable „Health" (created with Vensim)

The system variable which is influenced by the third largest number of causes in open loops is "Disparities and exclusion". It was previously identified as a very passive system element (cf. Chapter 4.1.2). The variable is directly affected by three other variables and indirectly by 13 on 15 different pathways when considering two steps in the causes tree (Figure 4.32). Two positively related causes are somewhat outstanding here. More governance and management problems are said to increase disparities and exclusion directly and indirectly (and vice versa). Furthermore, the interviewees stated that problems with disparities and exclusion are indirectly magnified (on two pathways) by more subsistence and poverty.

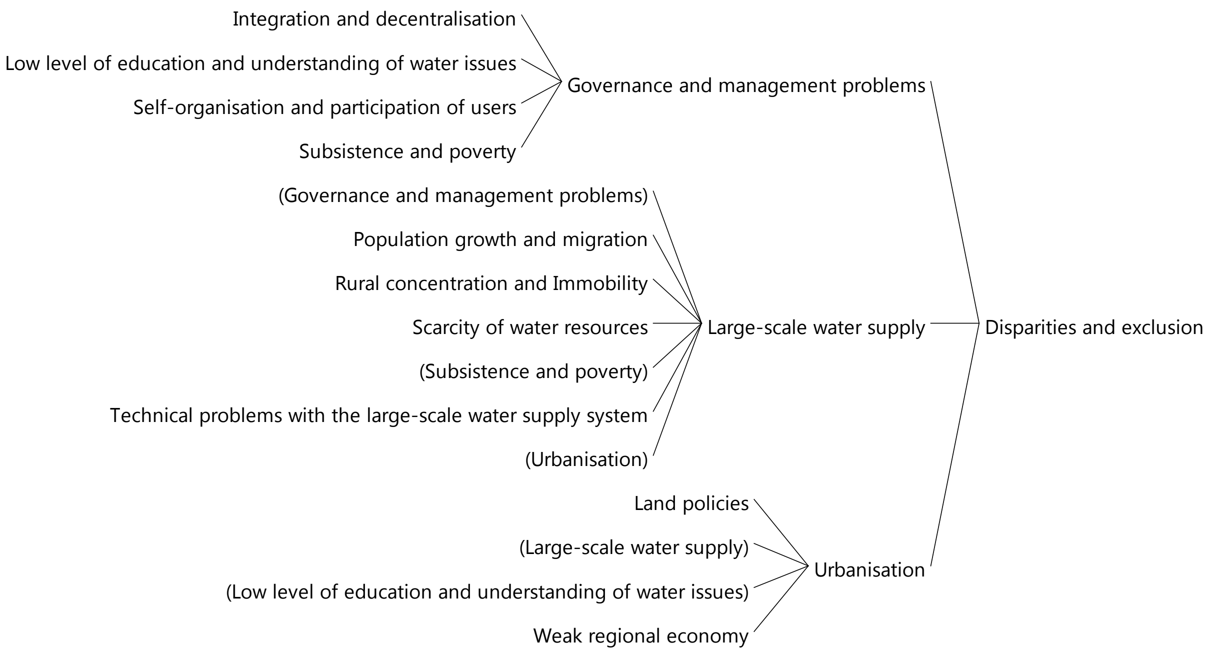

Figure 4.32 Causes tree of the system variable „Disparities and exclusion" (created with Vensim)

Finally, two water-related causes trees are presented. The variable "Perception of water prices" is directly affected by two other variables and indirectly by four on four different pathways when considering two steps in the causes tree (Figure 4.33). Only the negatively related cause "Low level of education and understanding of water issues" becomes apparent here. A higher level of education is said to directly and indirectly improve the perception of water prices and vice versa. Apart from this, the variable "Other water supply techniques" is also affected by the negatively related interdependency with the "Low level of education and understanding of water issues" (Figure 4.34). Since it is actually not a tree, no indirect causes occur in this case.

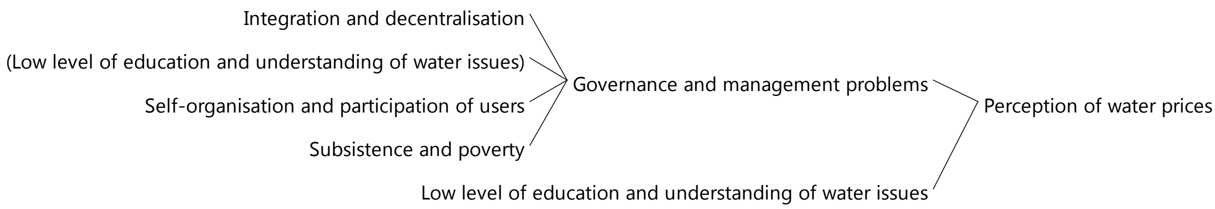

Figure 4.33 Causes tree of the system variable „Perception of water prices" (created with Vensim)

Figure 4.34 Causes tree of the system variable „Other water supply techniques" (created with Vensim)

4.5 Simulation of scenarios

4.5.1 Approach

In this study, a simulation is mainly understood as sensitivity analyses of groups of closely related variables in order to find out how they influence the rest of the system when their influence or weight increases or when they are completely removed from the model. Hence, interesting scenarios are those that comprise a group of system variables, since their involvement in the system is not evident. In contrast, the involvement of single variables can be seen directly, according to their corresponding rows or columns in the CIM.

The goal of this section is to identify stable and unstable system variables within scenarios. The results can be interpreted in terms of risks due to the instability of undesirable variables, on the one hand, and in terms of resiliency in the case of stable variables and/or scenarios, on the other. When inspecting the HD, the sum of columns can be interpreted as an indicator for the stability or instability of a system variable. This is due to the fact that the sum of the columns represents how a system variable is influenced by the rest of the system. In contrast to Vester, the polarity of interdependencies is considered here. The closer the sum is to zero, the more stable or resilient is the system variable, since it is affected by approximately as many positive interdependencies as negative ones. This means that the variable does not tend to change its state, or it does so only very slightly. The farther away the absolute value of the sum is from zero, the more unstable is the system variable, since it is unilaterally affected by either positive or negative interdependencies. This means that the variable tends (more or less) to increase or decrease, which might be either precarious or desirable. Especially in the case of variables that have been characterised as "critical" by the Sensitivity Model, scenarios can be described as precarious. Methods of Multi Criteria Analysis (Zangemeister 1976, Saaty 1990) could be used for a sustainability assessment of the scenarios. However, system variables that have been characterised as passive and that may, therefore, serve as indicators, will be used to assess and compare scenarios in terms of their viability or sustainability.

Two cases are compared below: a normalised matrix consisting only of the interdependencies' polarity (cf. Table A.2) and a matrix with the interdependencies' HD (cf. Table 4.2). Since the computation is not excessively complex, the complexity level is set to interdependencies with four or more statements. What actually was done to simulate scenarios was that the interdependencies' polarities or HD's of the group of variables defining a scenario (their activities in the rows of the CIM) were added gradually to the sum of columns. As a consequence, changes to the rest of the system became visible. Since this gradual change is linear, four iterations were calculated to clarify the tendency. The number of iterations analysed is chosen arbitrarily but it seems to be sufficient to illustrate the tendency's direction and its slope. However, how long a process takes and whether it is actually linear or not cannot be derived either from the data collected or from the results of the simulations. Furthermore, time spans and intensities of processes cannot be quantified, of course. However, the scenarios can be compared qualitatively to each other, to draw conclusions. Water supply scenarios and scenarios of selected key variables are presented below.

4.5.2 Results and discussion

4.5.2.1 Baseline scenario

Calculating column sums of the CIM's heterogeneity differences (or polarities) without any changes to the original matrix results in the so-called baseline scenario. It shows whether system variables tend to increase or decrease when the conditions of the underlying model are not changed or when no simulations are carried out. This, of course, depends on the initial definition of each variable or its “polarity”. For this reason, issues that have been considered as problems by the majority of interviewees were defined negatively, e. g. “Sanitation problems” instead of “Sanitation”. However, the baseline scenario does not represent the status quo (or the current state of affairs) of the system, because it is not located in time and also comprises “spaces of possibilities” (potential or future states or consequences) mentioned by the interviewees. Outstandingly unstable variables of the HD baseline scenario will be analysed below. Differences between the normalised (using polarities) and the HD baseline scenario will be highlighted, if necessary.

The system variable “Weak regional economy” (No. 36) is much more influenced by positively related interdependencies than negatively related ones (Figure 4.35). No other variable has a higher increase in the baseline scenario than this one. This is remarkable, since the variable has been characterised as a second order indicator for the system’s sustainability (cf. Chapter 4.1.2). Further variables with exceptionally high sums of columns are “Sanitation problems” (7), “Governance and management problems” (9), “Subsistence and poverty” (32), “Technical problems with the large-scale water supply system” (2), “Poor quality and availability of grazing land” (17), and “Traditional livestock farming” (34). Governance and management problems have been characterised as a critical variable. Technical problems with the large-scale water supply system have been identified as a second order viability indicator. All these system variables are said to increase under the given circumstances. One task of the scenarios discussed below will be to find out whether there are conditions or policies that are able to mitigate the criticality of these unstable variables.

The system variable “Health” (24) is much more influenced by negatively related interdependencies than positively related ones. No other variable has a greater decrease in the baseline scenario. Additionally, the variable has been identified as a major sustainability indicator. Further variables with exceptionally negative sums of columns are, amongst others, “Perception of water prices” (27) and “Rainwater harvesting” (6). Both variables also decrease under the given circumstances.

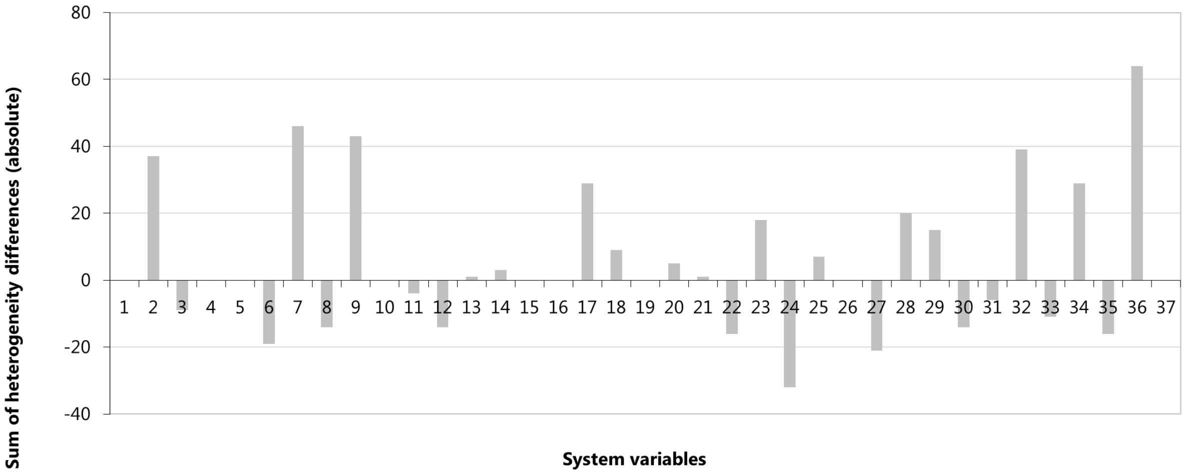

Figure 4.35 Baseline scenario using the sum of heterogeneity differences based on the absolute model

These results can be confirmed using the normalised baseline scenario (Figure 4.36), whereby some findings become more differentiated when using the HD baseline scenario. For instance, the outstanding instability of the variable "Poor quality and availability of grazing land" (17) does not become clear when analysing only the normalised baseline scenario. Slight differences can be observed, for instance, when looking at the column sums of the variables "Other water supply techniques" (8), "Perception of water prices" (27), and "Traditional crop farming" (33). This is due to the fact that they are influenced by a small number of interdependencies with a large number of propositions or vice versa.

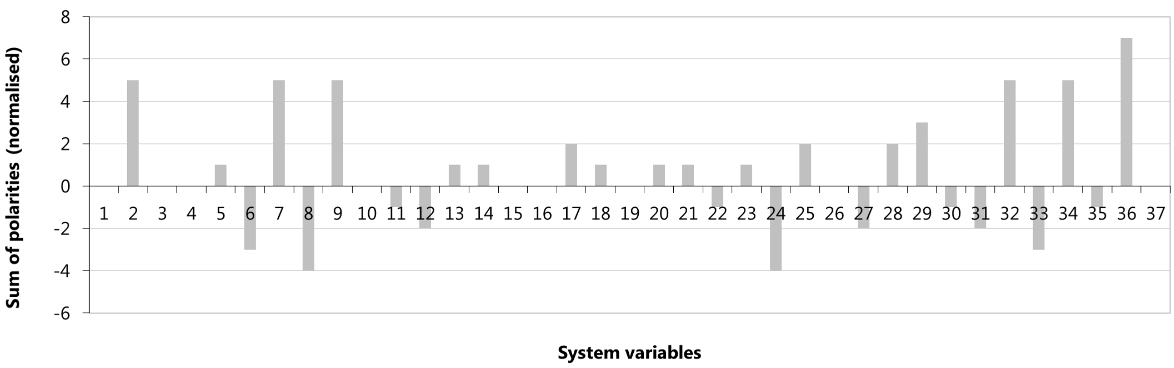

Figure 4.36 Baseline scenario using the sum of polarities based on the normalised model

4.5.2.2 Water supply scenarios

Four water supply scenarios are discussed below, of which two represent relatively centralised supply regimes (W1a and W1b) and the other two relatively decentralised ones (W2a and W2b). The first scenario W1a is characterised by a gradually increasing influence of the large-scale water supply system, representing its expansion. At the same time, the impacts of alternative water supply techniques (variables No. 3, 4, 5, and 6) on the rest of the system remain constant, as is the case in the baseline scenario. Thus, the scenario's defining variables are "Large-scale water supply" (1) and "Technical problems with the large-scale water supply system" (2). Both variables' impacts on the rest of the system are gradually increased in order to find out in which way the baseline scenario changes.

Figure 4.37 shows to what extent system elements are influenced by the variables defining the scenario. Thus, the elements' changing passivities or column sums in the CIM become visible. The largest increase rate can be observed in the system variable "Rural concentration and immobility" (No. 23, increase rate +16 per iteration), which has been identified as having a slightly high column sum in the baseline scenario (Figure 4.37). Furthermore, the high column sum of the variable "Traditional livestock farming" (34) is also increased in this scenario (by a growth rate of +7 per iteration). Thus, the criticality of this variable is even worsened by expanding the large-scale water supply system.

The negative column sum of the variable "Lack of irrigation and horticulture" (35) is greatly reduced in this scenario (by a rate of -10 per iteration). The desirable effect of reducing the lack of irrigation is therefore even enhanced here. Even higher decrease rates can be observed in the variables "Disparities and exclusion" (No. 25; -11 per iteration) and "Security of water supply" (No. 30; -13). Both variables have a slightly positive or negative column sum in the baseline scenario and move quickly into the negative range in this scenario. It can be assumed that this is a desirable effect in the case of the reduction of disparities and exclusion. The deteriorating water supply security, however, is a remarkable outcome of scenario W1a, since the variable has been characterised as passive (cf. Chapter 4.1.2) and, therefore, may serve as an indicator of the scenario's viability or sustainability.

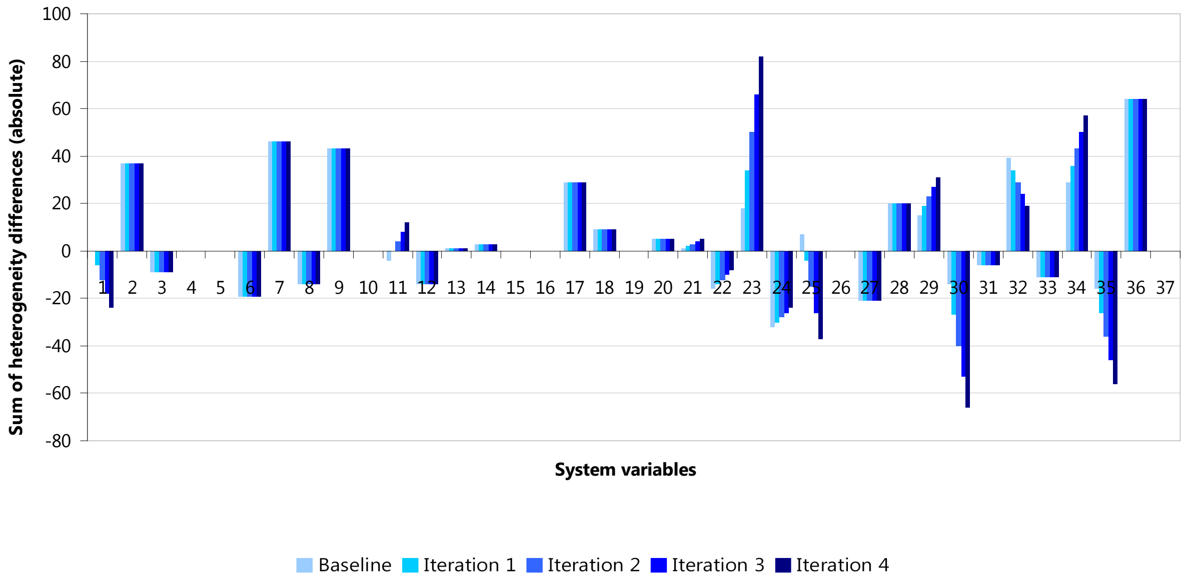

Figure 4.37 Water supply scenario W1a using the sum of heterogeneity differences based on the absolute model

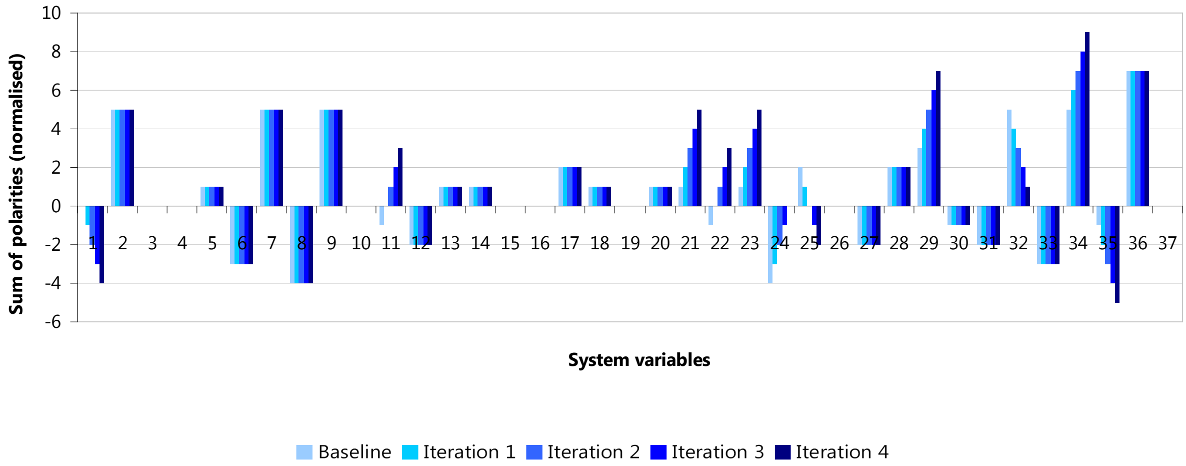

Figure 4.38 Water supply scenario W1a using the sum of polarities based on the normalised model

Significant differences between the normalised and the absolute scenario can be seen in the variables "Population growth and migration" (21) and "Security of water supply" (30) (Figure 4.38). The scenario's defining variables seem to contribute to population growth and migration much more in the normalised than in the absolute version. Furthermore, the phenomenon of the deteriorating water supply security cannot be observed in the normalised scenario. This is due to the fact that the influences of the scenario's defining variables cancel each other out in the normalised scenario. In the absolute scenario, the water supply security is mainly negatively affected by the variable "Technical problems with the large-scale water supply system" and its large absolute value.

The water supply scenario W1b is also characterised by the expansion of the large-scale water supply system (variables No. 1 and 2). In contrast to scenario W1a, the impacts of alternative water supply techniques on the rest of the system are completely removed or subtracted (variables No. 3, 4, 5, and 6), as if such techniques were non-existent. Hence, this scenario simulates a regional water supply regime which only consists of the large-scale one.

As in the case of scenario W1a, the variables "Rural concentration and immobility" (No. 23; +16) and "Traditional livestock farming" (No. 34; +7) have the highest increase rates (Figure 4.39). However, the baseline scenario's level of the variable "Traditional livestock farming" is only reached after four iterations, due to "missing" alternative water supply techniques. This might underpin their important role for traditional livestock farming.

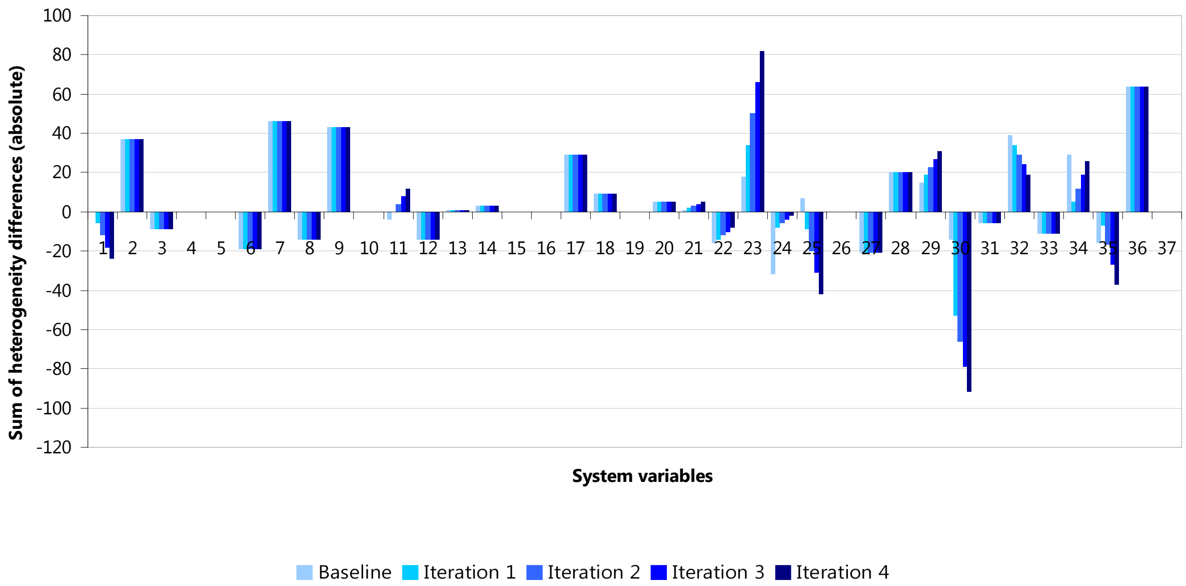

Figure 4.39 Water supply scenario W1b using the sum of heterogeneity differences based on the absolute model

According to scenario W1a, the variables “Disparities and exclusion” (No. 25; -11), “Security of water supply” (No. 30; -13), and “Lack of irrigation and horticulture” (No. 35; -10) have the highest decrease rates. However, the reduction of the water supply security is much more distinct in scenario W1b, due to the missing counteracting alternative water supply techniques. Furthermore, the reduction of the lack of irrigation and horticulture is not as pronounced as in scenario W1a, since the contribution of the alternative water supply techniques is absent.

As in scenario W1a, differences between the normalised and the absolute scenario can be seen in the variables “Population growth and migration” (21) and “Security of water supply” (30) (Figure 4.40). In contrast to scenario W1a, the variable “Health” (24) also becomes striking. Without the alternative water supply techniques’ negative effects on health, the system element reaches a much higher level in scenario W1b. This is quite remarkable, since the variable is another main viability indicator.

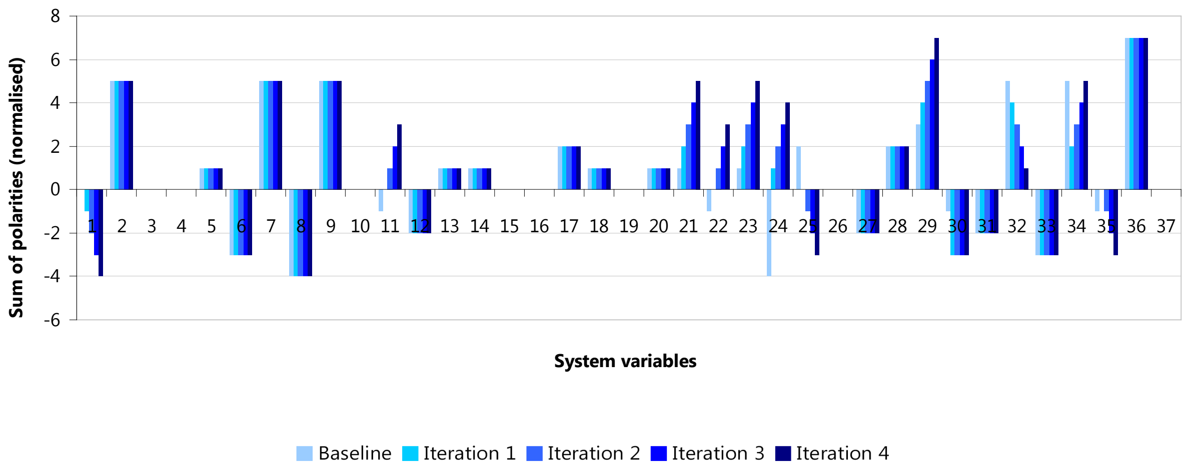

Figure 4.40 Water supply scenario W1b using the sum of polarities based on the normalised model

The water supply scenario W2a is characterised by a gradually increasing influence of alternative water supply techniques, representing their expansion. At the same time, the impacts of the large-scale water supply system (variables No. 1 and 2) on the rest of the system remain constant, as is the case in the baseline scenario. Thus, the scenario’s defining variables are “Oshanas and excavation dams (Omatale)" (3), "Shallow dug wells (Omuthima)" (4), "Groundwater and dug wells (Oshikweyo)" (5), and "Rainwater harvesting" (6).

The system variables with the highest increase rates are "Security of water supply" (No. 30; +26) and "Traditional livestock farming" (No. 34; +31) (Figure 4.41). The latter has already been identified as being critical and having a significantly high column sum in the baseline scenario. Furthermore, the reinforcing effect of alternative water supply techniques on traditional livestock farming could be proven indirectly in scenario W1b. In contrast to the large-scale water supply scenarios, the water supply security is significantly improved by alternative water supply techniques. This appears to be important, because the variable is a major indicator of the system's viability.

The system variables with the highest decrease rates are "Health" (No. 24; -22) and "Lack of irrigation and horticulture" (No. 35; -19). As in the case of the large-scale scenarios, alternative techniques might contribute to the reduction of the lack of irrigation and horticulture. A major drawback of alternative water supply techniques is, however, the deterioration of its consumers' health situation. Special attention has to be paid to this result, due to the variable's role as another major sustainability indicator. All outcomes of the absolute W2a scenario can be confirmed by the normalised one (Figure A.3).

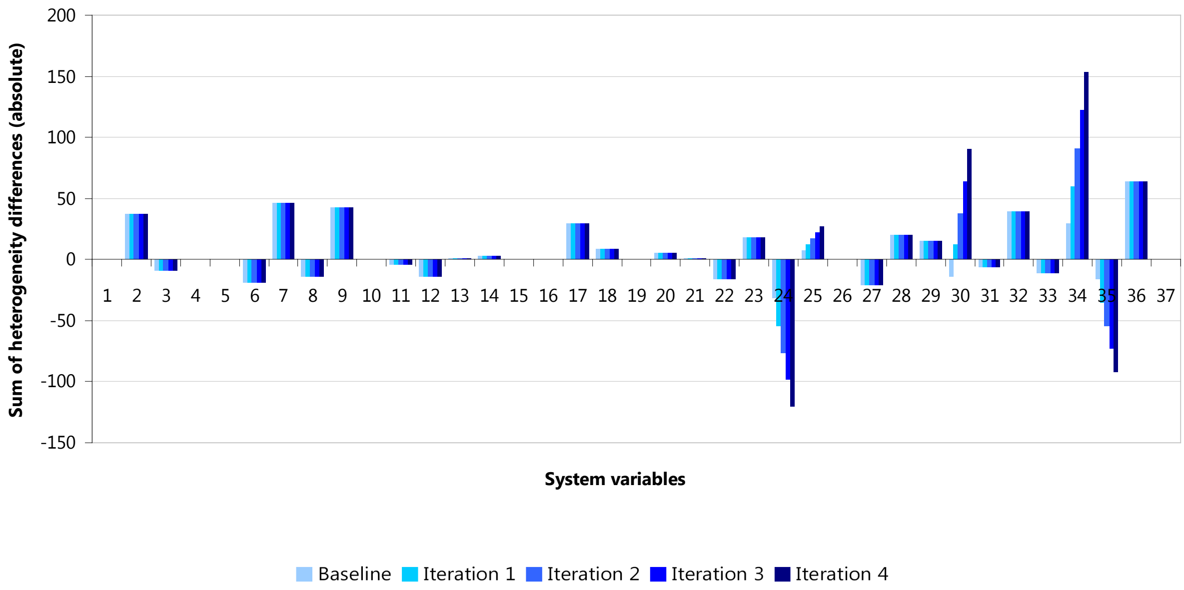

Figure 4.41 Water supply scenario W2a using the sum of heterogeneity differences based on the absolute model

Finally, the water supply scenario W2b is also characterised by the expansion of alternative water supply techniques (variables No. 3, 4, 5, and 6). In contrast to scenario W2a, the impacts of the large-scale water supply system on the rest of the system are completely removed or subtracted (variables No. 1 and 2), as if it was non-existent. Hence, this scenario simulates a regional water supply regime that only consists of alternative water supply techniques.

As in scenario W2a, the variables "Traditional livestock farming" (No. 34; +31) and "Security of water supply" (No. 30; +26) have the highest increase rates (Figure 4.42). Although the increase rate of the water supply security is the same as in scenario W2a, a slightly higher level of water supply security is obtained, due to corresponding disadvantages of the large-scale water supply system. Furthermore, the variables "Health" (No. 24; -22) and "Lack of irrigation and horticulture" (No. 35; -19) have the highest decrease rates, as is the case in scenario W2a. Finally, the only significant difference between the normalised and the absolute instance of scenario W2b is the increase rate of the variable "Security of water supply" (Figure 4.43). This is due to the fact that a major contribution to this increase can be traced back to the variable "Oshanas and excavation dams (Omatale)". In the normalised scenario, the effect does not become as visible as in the absolute one.

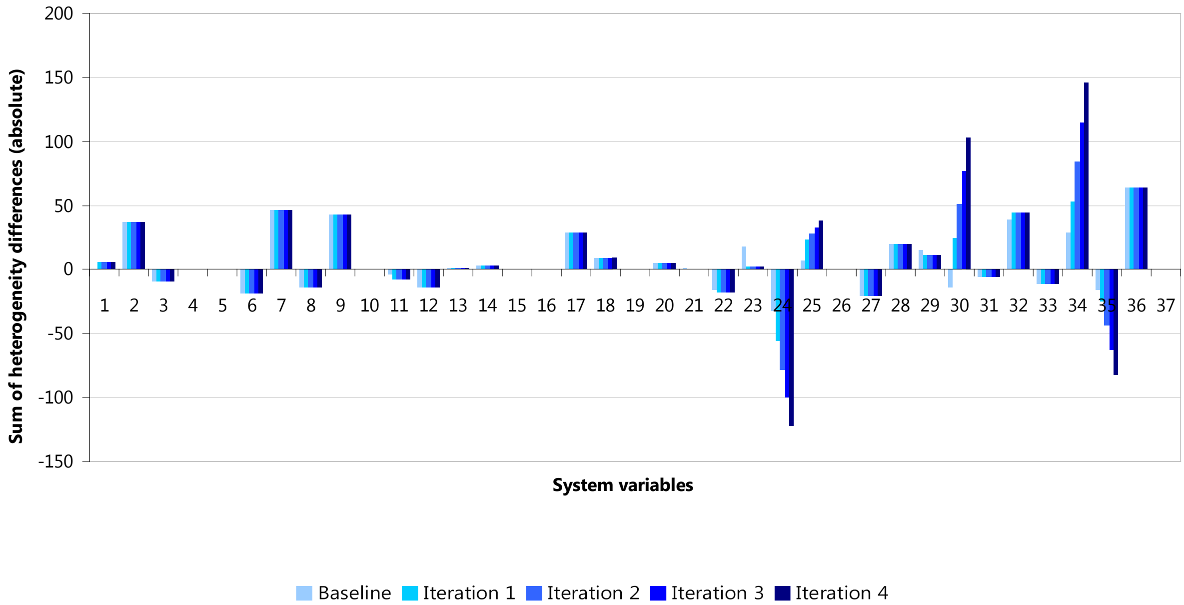

Figure 4.42 Water supply scenario W2b using the sum of heterogeneity differences based on the absolute model

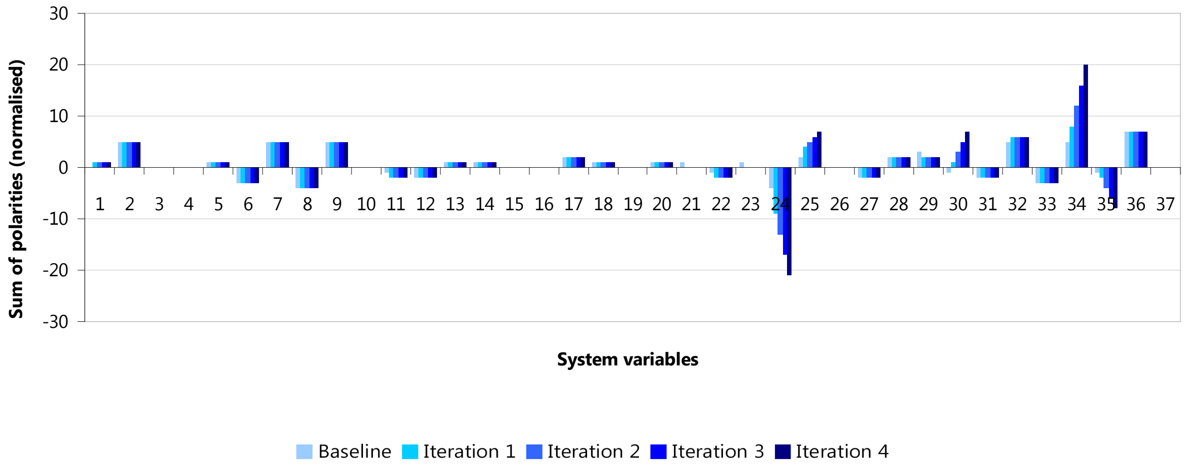

Figure 4.43 Water supply scenario W2b using the sum of polarities based on the normalised model

In conclusion, pair-wise comparisons of the scenarios W1a (Figure 4.37) and W2a (Figure 4.41) as well as W1b (Figure 4.39) and W2b (Figure 4.42) should reveal desirable consequences and risks of the different systemic arrangements or designs (large-scale vs. alternative water supply). Opposing effects can be observed in the system variables "Health" (No. 24), "Disparities and exclusion" (25), and "Security of water supply" (30). Remarkably, all three variables are major sustainability indicators of the system. The large-scale scenarios W1a and W1b (slightly) improve the health situation, whereas the alternative scenarios W2a and W2b both show a drastic deterioration of the viability indicator "Health". In contrast, the second main viability indicator, "Security of water supply", increases in both of the W2 scenarios, whereas it is reduced in the W1 scenarios. In terms of the third viability indicator, the W1 scenarios reduce disparities and exclusion, whereas the W2 scenarios even reinforce these undesirable aspects.

Furthermore, changes in system variables can be observed that only occur in one systemic design, while they remain constant in the other. Both W1 scenarios greatly increase rural concentration and immobility (23) while no change can be observed in the W2 scenarios. In addition, both large-scale scenarios slightly increase "Land policies" (11), urbanisation (22), as well as misuse and vandalism (29). The mentioned system variables did not make an appearance as outstandingly active or passive elements, except for the critical system variable "Urbanisation". Lastly, the W1 scenarios slightly decrease the variable

"Large-scale water supply" (1) as well as subsistence and poverty (32) which both have been identified as critical variables.

Finally, one effect can be observed that occurs similarly in the W1 and the W2 scenarios but to a different extent. Traditional livestock farming (34) is said to increase much more rapidly in the alternative water supply scenarios than is the case in the large-scale scenarios. This is of particular importance, due to the fact that "Traditional livestock farming" is one of the system's major critical variables. All results presented can be confirmed by using the corresponding normalised simulations.

4.5.2.3 Scenarios of selected key variables

In addition to the water supply scenarios presented, non-water-related scenarios were also simulated. These simulations comprise six scenarios that are defined by key variables of the system (Table 4.13). The results of the simulations will not be described in detail below.[10] Instead, only the direct consequences for any element of the water supply system, for critical variables or for viability indicators will be highlighted.

The scenario K1 is defined by ecological processes, namely an increase of the variables "Scarcity of water resources" (No. 14, identified as an active variable), "Salinity of groundwater" (15), and "Floods, droughts, and climate change" (16, active) (Table 4.13). Scenario K2 is shaped by traditional farming, in particular by an increase of the variables "Traditional crop farming" (33) as well as "Traditional livestock farming" (34, critical). Scenario K3 is characterised by processes concerning education and poverty, namely an increase of the variables "Low level of education and understanding of water issues" (26, active), "Misuse and vandalism" (29), and "Subsistence and poverty" (32, critical). Scenario K4 is defined by processes concerning organisation and management, in particular by an increase of the variables "Governance and management problems" (9, critical), "Integration and decentralisation" (12), and "Self-organisation and participation of users" (28, third order active). Scenario K5 is shaped by an increase of the variables "Population Growth" (21) and "Urbanisation" (22, third order active). Finally, scenario K6 is solely characterised by a

[10] The figures of the key variables' scenarios are attached in the appendix (Figure A.4 to A.15).

boost of the regional economy, i. e. a decrease of the variable “Weak regional economy” (36, second order passive).

Table 4.13 Increase (“+”) and decrease (“-”) of system variables in different scenarios of key factors. Variables in bold letters indicate an extraordinary growth or decline. Variables in brackets belong to the technological dimension.

	Scenario	Defining variables		Affected variables							
				Water-related variables		Critical variables		Viability indicators		Other variables	
		+	-	+	-	+	-	+	-	+	-
K1	Ecology	14 15 16			1 **3** **5** 6		(1) **(3)** 34		30		
K2	Traditional Farming	33 34		2 5		**32**		(2)	**36**		**17**
K3	Education and Poverty	26 29 32		2 3 5 **7**	1 6	(3) **9** 32 34	(1) 22	(2)	**36**		
K4	Organisation and Management	9 12 28		**2** 3 **7**	1	(3) **9**	(1)	**(2)** 25	**36**		
K5	Population Growth	21 22		**1** **7**	3		34	25	30		33
K6	Regional Economy		36			**22**	32 34				

No other non-water-related scenario influences as many variables of the water supply system as scenario K3 (“Education and poverty”) (Table 4.13). The variables “Technical problems with the large-scale water supply system” (2, passive), “Oshanas and excavation dams (Omatale)” (3, critical), “Groundwater and dug wells (Oshikweyo)” (5), and “Sanitation problems” (7) increase as a result of, generally speaking, less education and more poverty (and vice versa). At the same time, the variables “Large-scale water supply” (1, critical) and “Rainwater harvesting” (6) decline. This decrease is slight in the case of the large-scale water supply system and considerable for rainwater harvesting. The ecological scenario K1 affects four variables of the water supply system. While the variables “Large-scale water supply” (1, critical) and “Rainwater harvesting”

(6) decrease considerably, the alternative techniques “Oshanas and excavation dams (Omatale)” (3, critical) and “Groundwater and dug wells (Oshikweyo)” (5) undergo an extreme decline. Scenario K4 (“Organisation and management”) also affects four variables of the water supply system. More management problems drastically increase technical problems with the large-scale water supply system (2, passive), sanitation problems (7), and, also slightly, the usage of Oshanas and excavation dams (Omatale) (3, critical) (and vice versa). The large-scale water supply system (1, critical) decreases. Scenario K5 (“Population growth”) greatly fosters the variable “Large-scale water supply” (1) and extremely increases sanitation problems (7). Furthermore, the usage of Oshanas and excavation dams (Omatale) (3, critical) decreases slightly. Finally, groundwater and dug wells (Oshikweyo) are marginally promoted in scenario K2 (“Traditional Farming”). At the same time, technical problems with the large-scale water supply system (2, passive) also increase in this scenario.

Scenario K3 affects by far the largest number of critical variables. Apart from the previously mentioned critical water-related system elements, the variables “Governance and management problems” (9), “Subsistence and poverty” (32), and “Traditional livestock farming” (34) increase (considerably in the case of variable No. 9) and the variable “Urbanisation” (22) decreases. The critical variable “Traditional livestock farming” (34), furthermore, declines in the scenarios K1, K5, and K6. Apart from scenario K3, the variable “Subsistence and poverty” (32) is affected by the scenarios K2 and K6. While it increases considerably in scenario K2, it decreases in K6. As expected, governance and management problems (9) rise drastically in scenario K4. Finally, urbanisation processes (22) increase considerably in scenario K6.

In addition to the technical problems with the large-scale water supply system (2) mentioned previously, other systemic sustainability indicators are affected by the simulations. In particular, the regional economy (36) declines dramatically in the scenarios K2, K3, and K4. Furthermore, the water supply security (30) deteriorates in the scenarios K1 and K5. Finally, disparities and exclusion (25) increase in the scenarios K4 and K5. Thus, scenario K4 has the largest number of sustainability indicators of which two are considerably affected in a negative manner (No. 2 and 36). Apart from critical variables and indicators, other effects worth mentioning are that the quality and availability of grazing land (17) is clearly negatively affected in scenario K2, as expected, and that traditional crop farming (33) decreases in scenario K5.

5 Assessment and interpretation

5.1 Approach

The aim of this penultimate chapter is to summarise the results presented and to draw conclusions from them. While the previous section was focused on the outcomes of each modelling approach ("vertically"), the findings will now be assessed and interpreted for each relevant system variable ("horizontally"), in order to integrate specific results. For this purpose, three analytical dimensions have to be introduced. The first dimension deals with hazards and risks that are implied by the results. The second dimension comprises the results' implications regarding the regulation and transformation of the system. The third dimension includes the stakeholders' problem perceptions and power structures that enable or impede options for action, policies, or transitions.

First of all, system variables characterised as active or critical might pose hazards to the system, on the one hand, or might serve as systemic regulators, on the other hand (cf. Chapter 4.1.2). This depends on whether the variable can be influenced (at least partially) or not. In both cases, desirable or undesirable processes can occur. Some passive or critical variables might be vulnerable to undesirable processes. Some desirable processes might change passive or critical variables in a way that they can be referred to as forms of systemic regulation or transition. By using this concept, the prior findings can be structured and discussed in order to identify and assess systemic risks as well as options for action.

5.1.1 Hazards and risks

The aim of a qualitative risk assessment is to determine the risks of an observed system or actions within it, whereas a risk management also comprises the measures to eradicate or mitigate risks. The common (quantitative) definition of a risk within risk management is that it is the product of the probability of the occurrence of a hazardous event, on the one hand, and its damage, on the other (UNISDR 2009, DIN ISO 31000). Within vulnerability assessment, however, risks can be defined as the coincidence of hazard and vulnerability (Burton, Kates, White 1978; Wisner et al. 2004; UNESCO 2012). Since the quantification of neither the probability nor the damage is possible within the qualitative or semi-quantitative approach taken here, the latter definition will be used hereafter.

Hazards or threats can be defined as negative outcomes of future or potential situations (processes, events, activities, inactivities) that can lead to harm to persons or property (Sperber 2001, UNISDR 2009). The concept of vulnerability developed out of the discourse on poverty and has been used in development research since the 1980s (Chambers, Conway 1992; Bankoff, Frerks, Hilhorst 2004). Stakeholders (i. e. people, groups of people, organisations) are vulnerable when they are, on the one hand, exposed to stressors or shocks and, on the other hand, not able to cope with them (UNISDR 2009). Vulnerability can, therefore, be seen as the counterpart of resilience. The lack of resilience of certain stakeholders is, hence, a form of poverty. However, balancing feedback loops that stabilise undesirable conditions or processes are, in turn, an example of poverty sustaining resilience.

The desirability of conditions or processes is a matter of political or managerial decision- making with the participation of relevant stakeholders. Nonetheless, conditions or processes that bear potential risks can be defined as undesirable. Nevertheless, it has to be kept in mind that this is only based on reasonable assumptions and not on legitimisation by stakeholders. To assess the development of system elements as well as major feedback loops (only consisting of interdependencies with seven or more statements, Table 4.9), the impacts on the involved variables have to be rated in terms of their desirability. In this context, variables are desirable or undesirable, neutral, or influenceable. Four system elements can be clearly rated as desirable or undesirable depending on their increase or decrease: More irrigation, less poverty, a stronger regional economy, as well as a better quality and availability of grazing land are desirable (Table 5.1). The desirability of irrigation, for instance, might be argued but it also corresponds to national water policies (Government of the Republic of Namibia 2000 and 2008).

Furthermore, there are three neutral system variables which cannot be clearly rated in terms of their desirability; however, their consequences might be desirable or undesirable: Urbanisation, Rural concentration and immobility, as well as Traditional livestock farming. These elements are only desirable as long as they are stable (without being able to define a specific value). This is why they are rated as neutral in balancing feedback loops. In self-reinforcing feedback loops, they are rated as undesirable. In addition, they might also be influenceable through incentives, for instance, but not as directly as the following, final category of system variables.

Table 5.1 Influenceable, neutral, and undesirable system variables

	No.	Name of system variable	Dimension
Influenceable	1	Large-scale water supply	TE
	3	Oshanas and excavation dams (Omatale)	TE
	5	Groundwater and dug wells (Oshikweyo)	TE
	6	Rainwater harvesting	TE
Neutral	22	Urbanisation	SC
	23	Rural concentration and immobility	SC
	34	Traditional livestock farming	EN
Undesirable	17	Poor quality and availability of grazing land	EL
	32	Subsistence and poverty	EN
	35	Lack of irrigation and horticulture	EN
	36	Weak regional economy	EN

The final four variables are water supply techniques and are rated as influenceable, because they can be influenced directly by, for instance, policies or actions, which is why they are potential adjusting screws for the system: Large-scale water supply, Oshanas and excavation dams (Omatale), Groundwater and dug wells (Oshikweyo), as well as Rainwater harvesting.

5.1.2 Regulation and transformation

Balancing (negative) feedback loops can be used for closed loop control in order to regulate the (sub-) system (cf. Chapter 2.1). In doing so, its resilience is enhanced but it is not evident if this is desirable or undesirable. Depending on the desirability of the involved variables' conditions, the resilience can be rated as desirable or undesirable, since desirable or undesirable conditions are reinforced. In the worst case, sustainable transitions are prevented or at least hindered. Self-reinforcing (positive) feedback loops might be used to initiate transitions as long as they can be controlled and undesirable processes are not involved. Nevertheless, balancing feedback loops that reinforce undesirable resilience as well as self-reinforcing feedback loops that bear undesirable processes can be called vicious circles.

Furthermore, open loop control using cause-effect chains allows for regulation of the system. Influenceable causes of passive variables, as well as influenceable active variables, might be used to produce desirable effects. However, the causes of passive variables' undesirable conditions as well as active variables that cannot be influenced and involve undesirable consequences can also be seen as hazards. Apart from this, critical scenarios (cf. Chapter 4.5) contain system variables (critical ones or indicators) that tend to have an unstable behaviour, which might be undesirable. In turn, influenceable causes of these undesirable processes might be used to prevent or mitigate risks. Table 5.2 summarises this concept.

Table 5.2 Factors or processes that might pose risks, serve for regulation, or trigger transformation

	Hazards and risks	Regulation and transformation
Variables	Active or critical but not influenceable variables cause undesirable changes to passive or critical variables	Influenceable active or critical variables cause desirable changes to passive or critical variables (open loop control)
Negative (balancing) feedback loops	Undesirable resilience ("vicious circle")	Closed loop control, desirable resilience
Positive (self-reinforcing) feedback loops	Undesirable build-up or decay of processes ("vicious circle")	Desirable and controlled build-up of processes to initiate transitions
Causes trees	Causes of undesirable changes to passive variables	Regulation of passive variables (open loop control)
Effects trees	Undesirable effects of active variables	Desirable effects of active variables (open loop control)
Scenarios	Undesirable changes to critical and passive variables	Desirable changes to critical and passive variables through influenceable key variables (open loop control)

5.1.3 Perceptions and power

Finally, additional perceptions of the interviewees should be taken into consideration. In doing so, conclusions about underlying power structures and technological trajectories can be drawn that might enable or prevent systemic transitions. Apart from the statements on system variables and interdependencies, the stakeholders made personal comments representing their attitudes towards certain water supply techniques and/or options for action. It is not the aim of the study to answer the question of what the reasons for differing problem perceptions are. But an analysis of the correlation between heterogeneous statements and the affiliation to a certain stakeholder group might reveal additional insights. For this purpose, the interviewees again have to be differentiated between a supply side (WM, WSU, and AP, e. g. administration, politics, and NamWater), on the one hand, and a demand side (WU, EI, and SC, e. g. civil society, including users), on the other (cf. Chapter 3.3).

5.2 Potential regulators

5.2.1 Large-scale water supply

The large-scale water supply system is, as expected, the variable with the highest P-value (8322). The variable is constant in the current state of the system (baseline scenario) and, furthermore, involved in a large number of feedback loops (61, of which 40 are positive and 21 negative). It is part of six major feedback loops presented in Chapter 4.3.2 (FL1, FL2, FL4a, FL4b, FL3a, FL3b) that only consist of six or less variables as well as interdependencies with seven or more statements. Four of these six feedback loops bear undesirable implications (FL1, FL2, FL3a, FL3b) and two bear desirable ones (FL4a, FL4b). FL1 and FL2 are self-reinforcing feedback loops and might lead to unstable urbanisation as well as to rural concentration and immobility. FL3a and FL3b imply undesirable resiliencies regarding traditional livestock farming, subsistence and poverty, as well as the regional economy. However, both feedback loops might be used for regulation purposes after a transition to a more sustainable state of the system. This is especially the case when, among other things, the variables "Subsistence and poverty" as well as "Weak regional economy" have reached desirable states as a result of sustainable transformations. Apart from this, only FL4a and FL4b might bear desirable self-reinforcing processes regarding irrigation and horticulture, subsistence and poverty, as well as the regional economy if the large-scale system is promoted. Nevertheless, these potential stimuli for transitions might be counteracted by the undesirable processes mentioned before. Therefore, it might not be appropriate to use the large-scale water supply system as a means for sustainable transitions.

When looking at the direct effects of the large-scale system, the variable greatly reduces the lack of irrigation and horticulture, as well as disparities and exclusion (W1a, W1b). Furthermore, the large-scale water supply system is supposed to increase the water supply security and improve the users' health, but the interviewees do not agree on these effects to a significant extent. Nevertheless, all mentioned effects are desirable. Furthermore, some undesirable processes are noticeable. First of all, rural concentration and immobility greatly increases; this is even reinforced by the above-mentioned positive feedback loop. Traditional livestock farming also increases; this might be balanced out by the negative feedback loops mentioned above. Finally, urbanisation is fostered slightly but the interviewees did not agree on this very much.

Population growth is the biggest booster of the large-scale water supply system (K5). Urbanisation and "Rural concentration and immobility" are also supposed to foster an expansion of the large-scale system. The variable is mainly endangered by governance and management problems (K4) and indirectly by a low level of education. Other causes for deterioration are technical problems (W1), subsistence and poverty (K3), as well as a scarcity of water resources (K1).

With reference to the stakeholders' attitudes, a vast majority across sectors supported the large-scale water supply system (28 out of 31 statements). This tendency became even more evident within the interviewees on the supply side. Only two out of 26 interviewees argued against the large-scale system.

> *"Small scale technologies don't help very much; large-scale solutions are needed." (Namibian ministry official, 07a-AP-05)*

In the majority of cases, economic arguments were advanced in favour of the large-scale system:

> *"Any other technology has to be cheaper than the water supply from the Kunene delivered by NamWater with costs of 7 N$/m³." (MAWF official, 07b-WM-04)*

One reason why only three statements were made against the large-scale system might be that most of the interviewees on the demand side simply did not bring up this issue. In total, there were only five statements of the demand side, of which four argued in favour of the large-scale system. In conclusion, the interviewees' position can be interpreted as an indication of the system's underlying path dependency or resistance against any form of adaptation or transformation. The following statement gets to the heart of this issue:

> *"Clarification is needed of who will be in charge of the implemented technology; the problem now is that NamWater is able to do what they want; nobody else would have an influence into this decision if they wanted to implement new technologies." (MAWF official, 07a-WM-08)*

5.2.2 Oshanas and excavation dams (Omatale)

The critical system variable "Oshanas and excavation dams (Omatale)" decreases slightly in the current state of the system (baseline scenario). It is involved in five major feedback loops, of which two are self-reinforcing (FA3a, FA3b) and three balancing (FA1a, FA1b, FA5). Both positive feedback loops are undesirable, since they might lead to more traditional livestock farming, weaken the regional economy, and increase subsistence and poverty if Oshanas and excavation dams are promoted. The three negative feedback loops are undesirable, too, since they might only reinforce the current state of irrigation, the regional economy, as well as subsistence and poverty. For these reasons, the support of Oshanas and excavation dams cannot be recommended for interventions from a systemic point of view. However, the mentioned balancing feedback loops might be used for regulation purposes in the post-transition phase.

The only direct desirable effect of this variable is an increase of the water supply security (W2a, W2b). Irrigation and horticulture also increases, but it might be balanced out by the negative feedback loop mentioned above. Finally, the deterioration of the variable health as well as the increase of livestock farming are both undesirable processes.

Oshanas and excavation dams are extremely dependent on the availability of water resources (K1). Furthermore, urbanisation decreases the usage of this water resource (K5). Finally, a lower level of education and more poverty might lead to its increased utilisation (K3, K4). This is also the only interdependency on which the interviewees did not agree too much.

With respect to the alternative water supply technique of floodwater harvesting, a discussed about whether it is possible to avoid some of the undesirable consequences identified is required. This is the case in terms of the promotion of livestock farming and negative health impacts on users, since the harvested Oshana water is only intended for irrigation purposes. All balancing feedback loops mentioned above involve the variable "Lack of irrigation and horticulture". Hence, floodwater harvesting might contribute to improving the system's resilience. However, this influence should only be considered after a systemic transition, because the variables "Subsistence and poverty" and "Weak regional economy" are also involved in the feedback loops. Their consolidation is supposed to be undesirable. Apart from this, the great dependency of floodwater harvesting on the availability of surface water resources has to be kept in mind.

In terms of the interviewees' attitudes towards Oshanas and excavation dams, the picture appears to be less clear than in the case of the large-scale water supply system. A majority of 24 out of 33 statements argued in favour of the alternative technique. However, there were many more doubts about Oshanas and excavation dams among stakeholders on the supply side (8 out of 26), compared to the demand side (only one out of six).

> *"Pipeline water is too expensive to use it for all purposes; therefore, rural people demand for earth dams […]; hence, dams would be a good solution and an alternative source." (NamWater official, 07a-WSU-01)*

> *"Indeed the evaporation is quite high, but the improvement of the earth dams is good for the entire community, not just for some selected households." (Official of the Ministry of Regional Local Government, Housing & Rural Development, 07b-AP-01)*

One reason for the various assessment of Oshanas and excavation dams might be that the stakeholders had different ideas about this technique:

> *"One problem is that the definitions of earth dams differ between communities and government: The government thinks of big solutions whereas the communities think of smaller installations at specific places because they know about the geology." (Official of the Iishana Basin Management Committee, 07a-WM-05)*

5.2.3 Groundwater and dug wells (Oshikweyo)

The system variable "Groundwater and dug wells (Oshikweyo)" is virtually constant in the current state of the system (baseline scenario) and only included in two major feedback loops, both of which are self-reinforcing (FA3a, FA3b). Promoting this alternative water supply technique might lead to undesirable processes regarding livestock farming, the regional economy, and poverty.

More usage of groundwater and dug wells deteriorates the variable "Health" (W2a, W2b) and the water supply security. However, the interviewees did not agree on the latter interdependency. The variable is, furthermore, supposed to increase disparities and exclusion as well as traditional livestock farming. Especially the latter has to be taken into account, since it is part of the self-reinforcing feedback loop mentioned above. Nevertheless, all interdependencies mentioned are undesirable.

The scarcity of water resources and the salinity of the groundwater pose the greatest risks for the usage of groundwater and dug wells (K1). A lower level of education and more poverty (K3), as well as traditional livestock farming (K2), foster the usage of this traditional technique. "Subsistence and poverty" is supposed to have the same effect but the interviewees did not agree on this.

In terms of the groundwater desalination techniques presented in Chapter 3.3.5, it has to be discussed if they are able to avoid the mentioned undesirable effects of traditional groundwater usage. Primarily, decentralised desalination techniques might solve the problem that groundwater is saline in large parts of the region. If the treated groundwater is only used for the purpose of drinking water supply, undesirable processes such as the promotion of livestock farming and negative impacts on health connected to the usage of dug wells might be avoided. However, it is not clear whether desalination techniques would increase or decrease disparities and exclusion. Because subsistence and poverty are closely linked to traditional livestock farming in the identified feedback loops, desalinated water might also help to improve the livelihoods of its users. At the same time, subsistence and poverty influence the usage of treated groundwater, which raises the question of whether water users in remote rural areas can afford such purification methods.

The stakeholders' attitude towards the usage of groundwater and dug wells (Oshikweyo) is exceptional, compared to other options. The majority of interviewees on the supply side disapprove of these kinds of water supply techniques (19 out of 27). This applies to traditional techniques but also and especially for groundwater desalination. In general, economical and technical reasons were advanced in this context:

> *"It [using groundwater and/or desalination techniques] is economically not feasible; these technologies only mean more investments; still the people are not able to survive droughts or to feed their cattle." (MAWF official, 07a-WM-10)*

> *"In terms of desalination [techniques], there are maintenance problems […] and these technologies are not sustainable in most cases; […] a capacity building for operators would be needed and it must be a robust technique if it is supposed to be used in remote areas." (MAWF official, 07b-WM-04)*

The stakeholders on the demand side, however, argue in favour of the usage of groundwater and dug wells (5 out of 7), mainly due to the potential diversification of water sources. Nevertheless, any attempt to promote, for instance, groundwater desalination techniques will have to overcome the described resistance on the supply side.

5.2.4 Rainwater harvesting

The variable "Rainwater harvesting" appears in the middle of the Q- as well as P-value ranking and decreases in the current state of the system (baseline scenario). This system element is part of eight feedback loops, of which three are major ones. All three are self-reinforcing and have desirable outcomes (FA2a, FA2b, FA6). Promoting rainwater harvesting might lead to more irrigation and horticulture, boost the regional economy, mitigate subsistence and poverty, as well as reducing traditional livestock farming. The main reason for the absence of undesirable consequences is that the technique is not utilised for livestock watering, due to insufficient water quantities. Furthermore, rainwater harvesting is not as widely used as other alternative or traditional water supply techniques. It should, therefore, be considered as a major leverage and niche technology to initiate transitions.

Rainwater harvesting is supposed to increase irrigation and horticulture considerably and to increase the water supply security. However, not all interviewees agreed on the latter. In contrast to other alternative water supply techniques, it has only a slight, negative impact on the users' health. The self-organisation of users is supposed to foster rainwater harvesting. Governance and management problems, a scarcity of water resources (K1), a low level of education and a high level of poverty (K3) are supposed to impede the usage of rainwater harvesting. However, the interviewees did not fully agree on the effects of education as well as of poverty.

In total, the interviewees had a positive attitude towards rainwater harvesting (37 out of 50). The stakeholders on the demand side almost unanimously argued in favour of the technique (12 out of 13).

> *"The general problem is to be prepared for population growth and [an] increase of [water] demand under very restricted financial conditions; if one only relies on NamWater you have to face water shortages; hence, alternative technologies like rainwater harvesting are needed." (Municipal technician, 07a-AP-02)*

However, approximately one third of the supply side's statements disapproved of rainwater harvesting (12 out of 37). Some claimed that the regional precipitation is not sufficient; others fundamentally rejected small- or medium-scale techniques. The latter aspect might be the greatest obstacle for a comprehensive promotion of rainwater harvesting. Nevertheless, the potential for implementation seems to be much more promising, compared to other alternative water supply techniques, especially the usage and treatment of groundwater, when the stakeholders' attitudes are considered.

5.2.5 Low level of education and understanding of water issues

The "Low level of education and understanding of water issues" is the most active system variable (Q-value of 17.7; Activity of 177). Its decrease is clearly desirable and its increase undesirable. This exogenous variable appears to be constant in the current state of the system (baseline scenario), due to the fact that it is not influenced by other system variables. The low level of education must be seen as one of the major hazards to the system. However, the variable is proposed here as a regulator, because of its potential influenceability and activity.

A low level of education increases the usage of Oshanas and excavation dams (Omatale) as well as groundwater and dug wells (Oshikweyo), governance and management problems, the self-organisation and participation of users, subsistence and poverty, as well as traditional crop farming. In addition, a low level of education is supposed to hinder or weaken rainwater harvesting, irrigation and horticulture, the regional economy, urbanisation, the sanitary conditions, integration and decentralisation, as well as the perception of water prices. Indirect effects comprise a decrease of the variables "Other water supply techniques" and "Large-scale water supply" as well as an increase of technical problems with the large-scale water supply system and traditional livestock farming. Unlike the other effects, the interviewees did not fully agree on the effect on Oshanas and excavation dams.

In conclusion, measures to improve the level of education are proposed in terms of an open loop control of transition processes. Although not many statements were made in this regard, stakeholders on the supply as well as on the demand side unanimously declared themselves in favour of capacity development measures.

5.3 Systemic hazards

5.3.1 Traditional livestock farming

The variable "Traditional livestock farming" is one of the system's major critical variables. It is desirable as long as the number of livestock remains within certain limits, which, however, cannot be specified in this study. Hence, any erratic increase or decrease is undesirable. The variable increases considerably in the current state of the overall system (baseline scenario) and is involved in a large number of feedback loops (62), of which eleven are major ones. Traditional livestock farming is part of seven self-reinforcing feedback loops that bear undesirable consequences (FA3a, FA3b, FA4a, FA4b, FA6, FN4a, FN4b), including more poverty, a weaker regional economy, and partially unstable urbanisation, as well as less irrigation. However, measures or incentives to reduce livestock farming might have desirable consequences and would be self-reinforcing. Apart from this, traditional livestock farming is involved in three balancing feedback loops that are the cause of undesirable resilience (FL3a, FL3b, FA5), since, amongst others, poverty and regional economy would remain in their weak state. Nevertheless, these negative feedback loops might be used for regulation purposes in the post-transition phase. Finally, one feedback loop is a textbook example for self- regulation (FN1). The availability of grazing land limits traditional livestock farming.

The interviewees almost fully agreed on all causes and effects of traditional livestock farming. The variable is supposed to reduce the quality and availability of grazing land dramatically, to increase poverty, and, thus, to weaken the regional economy (K2), all of which are undesirable processes. Furthermore, traditional livestock farming directly fosters the usage of groundwater and dug wells (Oshikweyo) and indirectly reduces the water supply security by, for instance, causing technical problems with the large-scale water supply system.

The large-scale water supply system, as well as alternative water supply techniques, foster traditional livestock farming (W1a, W1b, W2a, W2b). However, the influence of alternative techniques on the variable is even greater. In particular, the usage of Oshanas and excavation dams, as well as groundwater and dug wells, is responsible for this effect. In addition, a lower level of education increases traditional livestock farming directly and indirectly (K3). A lower quality and availability of grazing land (K1), more urbanisation (K5), and a growing regional economy (K6) might reduce traditional livestock farming.

5.3.2 Subsistence and poverty

"Subsistence and poverty" is another major critical system variable. Its decrease is clearly desirable, whereas any increase is undesirable. The variable is involved in a large number of feedback loops (73), of which 14 are major ones. It is part of ten major self-reinforcing feedback loops (FL4b, FA2a, FA2b, FA3a, FA3b, FA4a, FA4b, FA6, FN2, FN4b) that bear undesirable processes if poverty increases. These processes comprise, for instance, a weaker regional economy, less irrigation, more traditional livestock farming, and unstable urbanisation. Measures to reduce poverty might be able to reverse these processes. Apart from this, the variable "Subsistence and poverty" is part of four balancing feedback loops that cause undesirable resilience (FL3b, FA1a, FA1b, FA5). Again, regional economy, irrigation, and traditional livestock farming tend to remain in their state. Nevertheless, these negative feedback loops might be used for regulation purposes in the post-transition phase.

Subsistence and poverty is increasing dramatically in the current state of the system (baseline scenario). This variable, for instance, causes organisational and financial problems for the large-scale water supply system, increases the usage of Oshanas and excavation dams (Omatale), reduces the usage of rainwater harvesting, worsens sanitary conditions, exacerbates governance and management problems, as well as weakening of the regional economy. However, the interviewees did not fully agree on the effects on the alternative water supply techniques mentioned. Furthermore, "Subsistence and poverty" is supposed to decrease the water supply security indirectly. In addition, no other variable indirectly deteriorates the water users' health as much as poverty does. Finally, this system element is said to magnify disparities and exclusion indirectly.

The large-scale water supply system reduces subsistence and poverty (W1a, W1b). Traditional farming (K2) and the lack of irrigation, a low level of education (K3), as well as a weak regional economy (K6) increase subsistence and poverty directly and indirectly. The interviewees agreed almost fully on all of these causes of subsistence and poverty.

5.3.3 Urbanisation

Urbanisation is also one of the system's major critical variables. As in the case of livestock farming, it is desirable as long as it remains within certain limits. Any unstable, uncontrolled, or erratic urbanisation is supposed to be undesirable. In the current state of the overall system, the variable is supposed to decrease (baseline scenario). "Urbanisation" is part of 56 feedback loops, of which ten are major ones. The variable is included in six major self-reinforcing feedback loops, of which five bear desirable consequences (FL4a, FL4b, FA6, FN4a, FN4b) and one is undesirable (FL1). Increasing urbanisation, amongst others, mitigates poverty, boosts the regional economy, and fosters irrigation. However, the feedback loops mentioned have to be handled with care, because they might induce an erratic growth of urbanisation. Furthermore, it is assumed that the variable is not suitable for interventions, due to its limited controllability. Apart from this, the self-reinforcing interdependency between urbanisation and the large-scale water supply system can be assessed as undesirable. Finally, the variable “Urbanisation” is involved in four balancing feedback loops that cause undesirable resilience (FL3a, FL3b, FA 5, FN3). These feedback loops again involve, for instance, the regional economy, traditional livestock farming, irrigation and horticulture, as well as subsistence and poverty. The interdependency between urbanisation and the regional economy can be seen as another example for self-regulation. Nevertheless, all negative feedback loops mentioned might be used for regulation purposes in the post-transition phase.

The variable “Urbanisation” fosters the large-scale water supply system, whereas it reduces the usage of Oshanas and excavation dams (Omatale). Urbanisation is furthermore supposed to worsen the sanitary conditions considerably, to deteriorate the quality and availability of grazing land, to increase disparities and exclusion, as well as to decrease traditional crop and livestock farming. However, the interviewees did not fully agree on the effects on grazing land and the regional economy. The main causes of urbanisation are a higher level of education (K3), a growing regional economy (K6), and poverty. The interviewees were not sure whether the large-scale water supply system fosters and whether land policies reduce urbanisation processes.

5.3.4 Governance and management problems

The variable “Governance and management problems” is the second most critical element of the system. In the normalised ranking, it is even the most critical one. Its increase is clearly undesirable and its decrease desirable. The variable appears to be increasing dramatically in the current state of the system (baseline scenario). Governance and management problems directly deteriorate the large-scale water supply system, rainwater harvesting, and sanitary conditions, increase technical problems with the large-scale water supply system, worsen the perception of water prices, and weaken the regional economy considerably. Furthermore, governance and management problems are supposed to indirectly reduce the water supply security as well as to directly and indirectly increase disparities and exclusion. Apart from this, governance and management problems are increasing drastically, due to a low level of education and, to a smaller extent, also due to poverty (K3). In addition, the variable increases considerably, due to decentralisation processes and informal organisation among water users (K4). The interviewees agreed completely on all mentioned interdependencies.

5.3.5 Scarcity of water resources

The "Scarcity of water resources" is one of the system's most active variables in the absolute ranking and even the most active one in the normalised ranking. It appears to be virtually constant in the current state of the system (baseline scenario), since it is hardly influenced by any other system element. The quantity of available water resources is desirable as long as it remains within certain limits. Scarcity and over-abundance are supposed to be undesirable. A scarcity of water resources poses risks for the large-scale water supply system, the security of water supply, the usage of rainwater harvesting, Oshanas and excavation dams (Omatale), as well as groundwater and dug wells (Oshikweyo) (K1). In addition, the scarcity of water resources is supposed to reduce traditional crop and livestock farming (K1). Only floods, droughts, and climate change are said to reduce the variable. However, the interviewees did not fully agree on this aspect.

5.3.6 Angolan water demand

"Angolan water demand" is the second most active variable in the absolute ranking. However, it is treated as a second order active variable, due to the relatively limited number of statements. The variable might be desirable as long as the water demand remains below a certain limit value and undesirable if it exceeds it. The Angolan water demand is exogenous and, therefore, appears to be constant in the current state of the system (baseline scenario). The variable directly increases technical problems with the large-scale water supply system and reduces the water supply security directly and indirectly. The interviewees were undecided about whether the Angolan water demand increases or reduces inter-regional conflicts.

5.3.7 Floods, droughts, and climate change

"Floods, droughts, and climate change" is one of the most active system elements but also treated as a second order active variable due to the relatively limited number of statements. Its increase is clearly undesirable and its decrease desirable. Due to its exogeneity, the system element "Floods, droughts, and climate change" appears to be constant in the current state of the system (baseline scenario). The variable reduces the usage of Oshanas and excavation dams (Omatale) directly and indirectly. A further indirect effect is the reduction of the water supply security. The interviewees were undecided whether floods, droughts, and climate change increase or reduce the availability of water resources.

5.3.8 Population growth and migration

"Population growth and migration" is a second order active variable. It is desirable as long as the growth rate remains within certain limits, which, however, cannot be specified here. The variable appears to be virtually constant in the current state of the system (baseline scenario), which is due to the fact that the system element is rather active. "Population growth and migration" boosts the large-scale water supply system, worsens sanitary conditions and reduces the water supply security (K5). In addition, the latter variable is also indirectly affected, as is the case with the variable "Health". Nevertheless, both indirect effects appear to be inconsistent. In conclusion, population growth and migration should be kept in view due to the fact that they can hardly be regulated.

5.4 Viability indicators

5.4.1 Security of water supply

"Security of water supply" is the variable with the lowest Q-value (0.01) as well as the highest passivity (160) and, therefore, the major (social) indicator for the system's viability. An increase of the variable is clearly desirable and a decrease undesirable. This system element is influenced by the largest number of causes and appears to be virtually constant, but with a slightly decreasing tendency in the current state of the system (baseline scenario). Technical problems with the large-scale water supply system (W1a, W1b) and, slightly, also with groundwater and dug wells (Oshikweyo) reduce the water supply security. The interviewees, however, did not fully agree on the latter aspect. Rainwater harvesting, shallow dug wells (Omuthima), and, especially, Oshanas and excavation dams (Omatale) are supposed to improve it (W2a, W2b). As mentioned before, the interviewees could not decide whether the large-scale water supply system improves or reduces the water supply security. Other direct causes that pose a risk for the variable are inter-regional conflicts, a scarcity of water resources (K1), population growth and migration (K5), irrigation and horticulture, as well as the Angolan water demand. Furthermore, the water supply security is reduced indirectly by governance and management problems, subsistence and poverty, traditional livestock farming, as well as floods, droughts, and climate change.

5.4.2 Health

"Health" is one of the most passive variables of all and another first order (social) indicator of the system's viability. As in the case of "Security of water supply", an increase of this system element is clearly desirable and a decrease undesirable. The variable is influenced by the second largest number of causes and appears to be decreasing slightly in the current state of the system (baseline scenario). Alternative water resources and techniques such as Oshanas and excavation dams (Omatale), as well as groundwater and dug wells (Oshikweyo), deteriorate the users' health considerably (W2a, W2b). Bad sanitary conditions decrease the variable even more, whereas the large-scale water supply system is supposed to improve the health situation (W1a, W1b). However, the interviewees did not agree on the latter. Apart from this, the most outstanding indirect causes that pose a risk to the users' health are a low level of education as well as poverty.

5.4.3 Disparities and exclusion

"Disparities and exclusion" is the third of three first order passive system elements and, hence, a (social) indicator for the system's viability. An increase of the variable is clearly undesirable and a decrease desirable. This system element, furthermore, contains the third largest number of causes and appears to be increasing slightly in the current state of the system (baseline scenario). Disparities and exclusions increase directly through urbanisation (K5) and the usage of groundwater and dug wells (Oshikweyo) (W2a, W2b) as well as directly and indirectly through governance and management problems (K4). The large-scale water supply system is supposed to reduce disparities and exclusions considerably (W1a, W1b).

5.4.4 Weak regional economy

The weak regional economy is a second order passive variable and, hence, an (economic) indicator of the system's viability. Its increase is clearly desirable and its decrease undesirable. This system element is involved in a large number of feedback loops (67), of which 18 are major ones. No other variable is part of as many major feedback loops as this one. Twelve major feedback loops are self-reinforcing (FL4a, FL4b, FA2a, FA2b, FA3a, FA3b, FA4a, FA4b, FA6, FN2, FN4a, FN4b), and are all undesirable, since the weak regional economy is increasing dramatically in the current state of the overall system (baseline scenario). This increase should not be confused with a positive growth rate. Instead, it shows that there are many more negatively related impacts on the regional economy than positively related ones. Amongst others, the downward spiral leads to more subsistence and poverty, less urbanisation, less irrigation and horticulture, as well as more traditional livestock farming. At first glance, one could think that measures to boost the economy might reverse the processes and serve as a stimulus for systemic transitions. However, the variable is influenced much more by the rest of the system than it influences the system by itself, due to its comparatively passive character. "Weak regional economy" is, furthermore, part of six major balancing feedback loops, all of which are causes of undesirable resilience (FL3a, FL3b, FA1a, FA1b, FA5, FN3). As mentioned in the context of other undesirable negative feedback loops, poverty, livestock farming, irrigation, and urbanisation remain in their undesirable states. Nevertheless, these balancing feedback loops might be used for regulation purposes in the post-transition phase. The interdependency between the regional economy as well as urbanisation (FN3) can be seen as an example of self-regulation.

A growing regional economy fosters urbanisation and reduces poverty as well as traditional livestock farming (K6). A low level of education weakens the regional economy considerably directly and indirectly (K3). Other reasons for a declining regional economy are subsistence and poverty (K3), governance and management problems (K4), traditional crop and livestock farming (K2), as well as a lack of irrigation and horticulture. The interviewees were undecided about whether urbanisation boosts or weakens the regional economy.

5.4.5 Technical problems with the large-scale water supply system

The variable "Technical problems with the large-scale water supply system" is part of 17 feedback loops, of which none are major ones. Furthermore, this system element is a second order passive variable and, therefore, one of the (technical) indicators for the system's viability. Its increase is clearly undesirable, whereas its decrease is desirable. Technical problems with the large-scale water supply system are increasing drastically in the current state of the overall system (baseline scenario). The variable has a negatively effect on the large-scale water supply system directly (W1a) and reduces the water supply security directly and indirectly. Governance and management problems are supposed to drastically worsen technical problems (K4). A low level of education increases the variable directly and indirectly (K3). Other reasons for technical problems include misuse and vandalism, Angolan water demand, and traditional livestock farming (K2). The interviewees agreed completely on all the mentioned interdependencies.

6 Conclusions

The water supply regime in central northern Namibia can be seen as a complex system of different interacting factors. Hence, it is appropriate to analyse not only isolated hydrological or technical aspects but to comprehend the whole system, in order to draw conclusions about an adapted water supply management. In this study, the stakeholders' perceptions of relevant system variables were identified (Chapter 3) and their interdependencies were assessed and interpreted (Chapters 4.1 and 4.2). Thus, it was possible to identify outstanding variables and processes that are essential for understanding the system, since not only potential regulators but also systemic hazards and viability indicators are revealed. These aspects will be recapitulated below, followed by a general discussion and critique of the study's results as well as the methodology applied. Additionally, open research questions will be identified. Finally, the whole study will be put into a broader context.

One of the main research questions was how the observed socio-technical system can be transformed in a sustainable manner and which key factors enable or impede such systemic transformations. To answer this question, theories and concepts of technological regimes, socio-technical transitions, systems theory, as well as cybernetics have been used. Two essential aspects were chosen as markers for sustainable transformation processes. On the one hand, the focus was on niche technologies, according to the multi-level perspective of transition theory. On the other, self-reinforcing feedback loops that accelerate a system's transition were sought. As long as these feedbacks can be controlled, they lead into a stabilisation phase after the acceleration.

The analysis showed that the water supply technique of rainwater harvesting might be the most promising niche technology that is able to initiate transformation processes with desirable outcomes (Chapter 5.2.4). However, the prevailing technological trajectories and power structures in the case study might be an obstacle for the promotion of this technique. Interestingly, all self-reinforcing feedback loops with the potential to induce transitions involve irrigation and horticulture. Apart from this, the balancing feedback loops in which floodwater harvesting is involved might only be used in order to stabilise the system in a post-transition phase and to strengthen its resilience (Chapter 5.2.2). Otherwise, undesirable conditions might be consolidated. The role of desalination techniques remains ambivalent and cannot be clearly assessed with the chosen methodology (Chapter 5.2.3). Nevertheless, the analysis does not recommend using the large-scale water supply system, Oshanas and excavation dams (Omatale), as well as groundwater and dug wells (Oshikweyo) as a means for sustainable transitions (Chapters 5.2.1, 5.2.2, and 5.2.3). In terms of open loop control using cause-effect chains, measures to improve the level of education are proposed (Chapter 5.2.5). Capacity development is supposed to have an extraordinary impact on a very large number of other system variables (Chapter 4.4).

Major hazards and risks to the system stem mainly from critical system variables, precarious feedback loops, and undesirable consequences of water supply scenarios (Chapter 5.3). Governance and management problems, traditional livestock farming, subsistence and poverty, as well as urbanisation have been identified as critical variables for the system (Chapter 4.1). Furthermore, some active variables have to be regarded with suspicion, due to their potential negative consequences, namely the low level of education and understanding of water issues, the scarcity of water resources, population growth and migration, Angolan water demand, as well as floods, droughts, and climate change (Chapter 4.4). Some self-reinforcing feedback loops bear undesirable consequences if they lead to an uncontrollable build-up or collapse of processes. Such feedback loops might induce more subsistence and poverty, a weaker regional economy, less irrigation and horticulture, more traditional livestock farming, as well as unstable urbanisation (Chapter 4.3). The latter effect and the large-scale water supply system even reinforce each other directly. Apart from this, some balancing feedback loops might cause undesirable resilience, which impedes any kind of development or transformation. Thus, subsistence and poverty, the regional economy, irrigation and horticulture, as well as traditional livestock farming might remain in their poor or undesirable conditions (Chapter 4.3). However, negative feedback loops might be used for regulation purposes in a post-transition phase.

Finally, the question about water supply scenarios that bear undesirable consequences is closely related to system variables with passive roles. Such indicators for the viability of the system are the security of water supply, health, disparities and exclusion, the regional economy, as well as technical problems with the large-scale water supply system (Chapter 5.4). The latter ones and, also slightly, groundwater and dug wells (Oshikweyo) reduce the water supply security (Chapter 4.5). Furthermore, the usage of Oshanas and excavation dams (Omatale) as well as groundwater and dug wells (Oshikweyo) foster traditional livestock farming and deteriorate the users' health considerably. In addition, Oshikweyo are supposed to increase disparities and exclusions.

In the end, the evaluation of the interviews allowed a description of the world views, perceptions, and opinions of all stakeholders questioned. In doing so, issues relevant for the assessment of the statements could be identified, e. g. dissensions, contradictions, agreements, valuations, priorities, and, of course, also unmentioned topics. Several aspects are striking, for instance, the clash of diametrically opposing views on large-scale water supply systems. Some interviewees take a rather sceptical view on technology while others remain technocratic. Interestingly, this is not influenced by their affiliation to a specific stakeholder group. Similar phenomena, but with opposite sign, can be observed in connection with alternative or traditional water supply techniques. Usually, this ties in well with the known controversy and argumentation patterns. Many interviewees emphasise the chances or risks of the various options, as they perceive them. In some cases, however, rather irrelevant or obviously incorrect arguments were put forward. Even more precarious is the fact that the rural poor did not have the required knowledge about more or less sophisticated alternative small-scale techniques, which is why their statements simply did not appear in this context. The interviewees' most important contribution, however, was highlighting the relevance of traditional water supply techniques as well as the significant role they play as a complement to the pipeline scheme. Not only were the differences regarding their specific properties and present usages demonstrated but also their historical development and change of use. Some of the interview statements also showed how changing usage patterns of such technologies can indicate a change in supply regimes and routines, as in the case of the abandoned Omuthima.

Following the summary of key results, theoretical and methodological aspects of the study will be critically reviewed. It has to be emphasised that the outcomes of the modelling approach used are highly specific for the chosen case study and, of course, cannot be generalised. Nevertheless, the developed methodology could be applied to comparable case studies, in order to validate its reliability. The validity of the results is ensured by the empirically grounded approach. However, the results may ultimately only be verified by an implementation of measures or policies derived from them and by scrutinising their success. Furthermore, the reproducibility of the results may not be complete, but key procedures of the evaluation, such as the cross-impact analysis, were also carried out, for comparison purposes, by several student assistants as well as the author. This yielded a reconfirmation of all major results.

A few words have to be devoted to the theories and methods used. Regarding the theory on technological transitions, not all aspects were fully taken into account. Only two, yet essential, facets were considered, namely niche technologies and self-reinforcing feedback loops that might induce transformation processes. Furthermore, Grounded Theory was only used to provide the foundation of the model, although it is capable of generating a conceptual theory about a substantive area on its own. However, it would not have been possible to generate a fully operable model without combining Grounded Theory with the modelling techniques used in the study. One of these techniques is the Sensitivity Model, which was also not applied exactly as proposed by its inventor. The main reason for this is that it lacks an empirical foundation in its original form, on the one hand, and that it does not provide a satisfactory scientific justification for the assessment of interdependencies in the cross-impact matrix, on the other. The proposed methodology attempted to compensate both drawbacks.

With respect to the system variables identified by theoretical coding, problems occurred with grasping issues, such as livelihoods, poverty, and subsistence, on the one hand, and organisation, management, decentralisation, and participation, on the other, as well as allocating them to a specific analytical dimension. This is due to the fact that the topics mentioned are distributed over several analytical dimensions and/or related to different stakeholders. In terms of the interdependencies' heterogeneity analysis, a customised method had to be developed, since no established tool met the requirements. This can be problematic because no previous research experience with it exists. In this context, it has to be emphasised that the sample might not be representative and the results of the heterogeneity analysis were therefore seen and used as indications of the interdependencies' properties in the case study. Nevertheless, the utility of this method outweighs its potential disadvantages within the modelling approach.

Regarding the analysis of feedback loops, the main drawback can be seen in the fact that only isolated loops were identified and assessed. Hence, statements about the stability of the coupled system as a whole are not possible. For this purpose, numerical or analytical calculations would have been necessary. Furthermore, only feedbacks consisting of interdependencies with more than six statements and consisting of less than seven variables were taken into account, mainly on account of the manageability of the large amount of data. In addition, the feedbacks could not be quantified regarding the involved interdependencies. Comparable constraints apply to the analysis of cause-effect chains, which included only two steps within open loops. In terms of the simulations, only direct effects of variables defining a scenario were investigated but pulse propagations could not be examined, for instance. Indirect effects were only considered by focussing on the simulated behaviour of critical variables.

The review of the methods used to date reveals a some open research questions. Nevertheless, three major strands of research topics are suggested that might be used as a starting point for further research, namely an epistemic one, an actor-oriented one, and a mathematical one. In the first place, the epistemic loop that has been opened up by the inductive approach can be closed by verifying the results. For instance, a deductive questionnaire could be used to verify the model, its variables and interdependencies as well as its heterogeneities. In this context, separate models of different stakeholder groups, such as the supply and demand side, as well as subsystems, could be examined. Last but not least, the technological and economical feasibility of the proposed techniques has to be scrutinised, especially when considering the implications of transition theory.

Secondly, an actor centred analysis of the governance system might be promising, since the results and theories already in use indicate that institutions, policies, actors, and their power play a significant role in connection with transformation processes. A policy analysis could clarify the stakeholders' options for action and decision-making processes in more detail. Thirdly and lastly, mathematical methods could be used to calculate the stability of the coupled overall system. This can be done analytically, for instance, by computing the Eigenvalue of the cross-impact matrix. Another mathematical research question would be to examine the correlation between system variables in terms of their interdependencies, in order to reduce the number of elements by merging those which have similar impacts on the rest of the system.

At the end of the thesis, a few words are devoted to the process of modelling, which is still the method of choice in water resources management. Whether a model provides a true picture or can offer any explanations depends on several factors. By integrating a large number of world views, not only one model of reality was built but, rather, a multitude of mental models of perceived and constructed realities. These perceptions are real in so far as people tend to take decisions and act, based on them. Since the heterogeneity of interview statements has been taken into account, it could be revealed on which interdependencies in the system the interviewed stakeholders agreed on and on which not. Thereupon, homogeneous interdependencies of interviewees, actors, or stakeholders can be interpreted as a kind of validation of the model that represents the underlying real-world problem. In contrast, heterogeneous statements can be interpreted as uncertainties in the model (from a modelling perspective) or as differently perceived problems and different world views (from a planning perspective). One possible reason for heterogeneities is that an interviewee might simply not know better, due to a lack of information or education. Another possibility is that a statement might represent a certain world view that clashes with other opinions on problems or systemic interdependencies.

In this context, who is constructing the model is of crucial importance, since the model-builder decides what is constructed and how it is constructed. Problems prevailing in an observed system are not necessarily evident or can be verified objectively. It is also not clear whose problems are supposed to be solved. External experts might perceive problems differently to internal stakeholders. Still, customary top-down approaches in engineering sciences tend to focus on problems that are quantifiable or that seem to be objective. However, the problem perceptions of all stakeholders have to be integrated, because their perceptions have real consequences, as has been demonstrated above. This can only be done in a participatory way. In this specific case, empirical methods of qualitative social research, such as interviews and participant observation, have been applied to understand and build a model of the perceived world views. In doing so, the application of inappropriate standard solutions to a given problem context can be avoided. In addition, it can be argued generally whether the term "problem" is appropriate at all, since it necessarily implies a solution, whereas the planning and management of water resources is more of an ongoing or perpetual process.

Furthermore, the proposed modelling concept is interdisciplinary. Contrary to conventional water management approaches, it does not refer only to natural sciences and engineering. By combining methods of qualitative social-empirical research and systems analysis, forms of knowledge and theories of both scientific cultures, positivism and constructivism, can be integrated. Otherwise it would not have been possible to identify cultural, social, or organisational topics such as the importance of traditional water supply techniques, the users' perceptions of water prices, their willingness to pay for the services, their understanding of the water supply system, and their traditional handling of water resources, crops, and livestock, etc. At the same time, interfaces between the approaches allowed for a seamless integration of social-empirical data and modelling. In particular, the processing within the systems analysis ensured the operability of the approach, which was essential for the simulation of scenarios, for instance.

Another important finding refers to the scope of the observed system. When dealing with systems that are intensely interrelated with historic path dependencies as well as with traditional and cultural entities, the question about their boundaries arises. As it was shown, it was not sufficient to analyse only the large technological system, not to mention the mere water utility, in order to understand and assess the current water supply regime, without considering alternative and traditional techniques. The scope of the examination had to be widened to the institutional and social environment of the observed system. Any reflections on sustainable planning and management would not be valid and comprehensive if such interdependencies are not taken into account. Furthermore, these explanations show that the system scope could only be determined a posteriori during the participatory process of data collection and analysis.

All the mentioned aspects make a considerable contribution to ensuring sustainable development. It comprises not only the ecological, economical, and technological dimension but also the social and political one, which is often not sufficiently considered in resource-driven approaches. This is due to the fact that engineers usually do not deal with issues such as perceptions, power, participation, or poverty. However, a methodological and theoretical integration is of particular importance to cover these topics and to fully comprehend socio-technical systems. The methodology developed in this thesis will be called Empirically Grounded Modelling.

List of references

ACACIA Project E1 (2004): Digital Atlas of Namibia. University of Heidelberg, University of Cologne, Directorate of Environmental Affairs, Ministry of Environment and Tourism, Republic of Namibia. http://www.uni-ko-eln.de/sfb389/e/e1/download/atlas_namibia/main_namibia_atlas.html (accessed July 6th, 2013).

Andersen, D. F.; Vennix, J. A. M.; Richardson, G. P.; Rouwette, E. A. J. A. (2006): Group Model Building: Problem Structuring, Policy Simulation and Decision Support. http://www.albany.edu/~gpr/JORS06.pdf (accessed May 23rd, 2011).

Araki, S. (2005): Change in Population and Land-Use Intensities in Several Villages of the Four Northern Regions of Namibia. African Study Monographs, Suppl. 30, 77-88, March 2005.

Argyris, C. (1994): Good communication that blocks learning. Harvard Business Review (July-August), 77-85.

Aristotle: Metaphysics. Various editions.

Bankoff, G.; Frerks, G.; Hilhorst, D. (2004): Mapping Vulnerability: Disasters, Development and People. Earth Scan, London.

Berkhout, F.; Smith, A.; Stirling, A. (2003): Socio-technological regimes and transition contexts. SPRU Electronic Working Paper Series No. 106, The Freeman Centre, University of Sussex.

Bertalanffy, L. von (1949): Zu einer allgemeinen Systemlehre. Biologia Generalis 1.

Bertalanffy, L. von (1969): General System Theory. George Braziller, New York.

Biswas, A. K. (2004): Integrated Water Resources Management: A Reassessment. Water International, Vol. 29, No. 2, 248-256, June 2004. International Water Resources Association. http://www.adb.org/Documents/Books/AWDO/2007/dp05.pdf (accessed August 5th, 2009).

Bleek, W. H. I. (1862): A Comparative Grammar of South African Languages. Trübner & Co., London.

Bossel, H. (1992a): Modellbildung und Simulation – Konzepte, Verfahren und Modelle zum Verhalten dynamischer Systeme. Vieweg, Braunschweig/Wiesbaden.

Bossel, H. (1992b): Simulation dynamischer Systeme. Grundwissen, Methoden, Programme. Vieweg, Braunschweig/Wiesbaden.

Bossel, H. (1999): Indicators for Sustainable Development – Theory, Method, Applications – A Report to the Balaton Group. International Institute for Sustainable Development (IISD), Winnipeg, Manitoba.

Bossel, H. (2004): Systeme, Dynamik, Simulation. Modellbildung, Analyse und Simulation komplexer Systeme. Books on Demand, Norderstedt.

Bots, P. W. G.; van Twist, M. J. W.; van Duin, J. H. R. (1999): Designing a Power Tool for Policy Analysts: Dynamic Actor Network Analysis. In: Nunamaker, J. F.; Sprague, R. H. (Edts.): Proceedings HICSS-32, IEEE-Press, Los Alamitos.

Boudon, R. (1979): La logique du social. Hachette, Paris.

Burger, P. (2005): Die Crux mit dem Zielwissen. Erkenntnisziele in transdisziplinärer Nachhaltigkeitsforschung und deren methodologische Implikationen. In: Technikfolgenabschätzung. Theorie und Praxis Nr. 2, 14. Jahrgang, Juni 2005, 50-56, Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe.

Burton, I.; Kates, R. W.; White, G. F. (1978): The Environment as Hazard. Oxford University Press, New York.

Central Intelligence Agency (CIA) (2013): The World Factbook. Africa. Namibia. Updated May 15th, 2013. https://www.cia.gov/library/publications/the-world-factbook/geos/wa.html (accessed July 6th, 2013).

Chambers, R.; Conway, G. (1992): Sustainable rural livelihoods: Practical concepts for the 21st century. IDS Discussion Paper 296, Brighton.

Checkland, P. (2000): Soft Systems Methodology: A Thirty Year Retrospective. In: Systems Research and Behavioral Science, Syst. Res. 17, 2000, S11–S58.

Deffner, J.; Mazambani, C.; Klintenberg, P.; Nantanga, K.; Moser-Norgaard, P.; Seely, M. (2008): Selected results from socio-ecological participatory situation assessments in two sites in Central Northern Namibia. CuveWaters Paper No 3, Institute for Social-Ecological Research, Frankfurt/Main. http://www.cuvewaters.net/ftp/cuve_3_deffner.pdf (accessed May 14th, 2009).

Deutsche Gesellschaft für International Zusammenarbeit (GIZ) (2012): Länder-Informations-Portal Namibia. Deutsche Gesellschaft für International Zusammenarbeit GmbH. Updated December 2012. http://liportal.giz.de/namibia/geschichte-staat.html?fs=9meta-navi-top%2Fkontakt.html%3Ffs%3D9 (accessed July 6th, 2013).

DIN ISO 31000 (2011-01): Risk management – Principles and guidelines (ISO 31000:2009).

Dosi, G. (1982): Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technical change. Research Policy, Vol. 11, 147-162.

Emery, F. E.; Trist. E. L. (1960): Socio-technical Systems. In: Management Sciences Models and Techniques, Vol. 2. London.

Forrester, J. W. (1961): Industrial Dynamics. Pegasus Communications, Waltham, MA.

Forrester, J. W. (1972): Der teuflische Regelkreis – das Globalmodell der Menschheitskrise. Deutsche Verlagsanstalt, Stuttgart.

Foucault, M. (1982): Subjekt und Macht. In: Defert, D.; Lagrange, F. (Edts.): Michel Foucault – Analytik der Macht. Suhrkamp, Frankfurt am Main, 2005, 240-263.

Fürst, D.; Scholles, F. (2001): Handbuch Theorien + Methoden der Raum- und Umweltplanung. Dortmunder Vertrieb für Bau- und Planungsliteratur, Dortmund.

Geels, F.; Kemp, R. (2000): Transities vanuit socio-technisch perspectief (Transitions from a socio-technical perspective). Background document for chapter 1. In: Rotmans et al. (Edts.): Transities en transitiesmanagement (Transitions and transition management). Maastricht, Netherlands.

Geels, F.; Monaghan, A.; Eames, M.; Steward, F. (2008): The feasibility of systems thinking in sustainable consumption and production policy: a report to the Department for Environment, Food and Rural Affairs. DEFRA, London.

Glaser, B. G.; Holton, J. (2004). Remodeling Grounded Theory. In: Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, Vol. 5, No. 2, Art. 4.

Glaser, B. G.; Strauss, A. L. (1967): The discovery of grounded theory. Aldine, Chicago.

Gleichmann, C. (1994): Returned exiles in Namibia. The dynamics of reintegration and political change. Diploma thesis at the University of Hamburg, 1994, unpublished.

Global Water Partnership (GWP) (2000): Integrated Water Resources Management. GWP Technical Committee (TEC) Background Paper No. 4. GWP, Stockholm.

Goldberg, G. (1989): Grundlagenstudie Namibia. Band 10: Sektorstudie Wasserwirtschaft. Erschließung und Bewirtschaftung von Grund- und Oberflächenwasser. Hannover, München.

Gould, J.; Nissen-Petersen, E. (2003): Rainwater Catchment Systems for Domestic Supply – Design, construction and implementation. ITDG Publishing, London.

Government of the Republic of Namibia (1956): The Water Act (Act 54 of 1956). Ministry of Agriculture, Water and Rural Development, Windhoek, Namibia.

Government of the Republic of Namibia (1997): Namibia Water Corporation Act (Act 12 of 1997). Government Gazette of the Republic of Namibia, Oct. 10th, 1997, Windhoek, Namibia.

Government of the Republic of Namibia (2000): National Water Policy White Paper. Policy Framework for Equitable, Efficient, and Sustainable Water Resources Management and Water Services. Ministry of Agriculture, Water and Rural Development, Windhoek, Namibia.

Government of the Republic of Namibia (2004): Water Resources Management Act (Act 24 of 2004). Government Gazette of the Republic of Namibia, Dec. 23th, 2004, Windhoek, Namibia.

Government of the Republic of Namibia (2008): Water Supply and Sanitation Policy. Ministry of Agriculture, Water and Forestry, Windhoek, Namibia.

Hangula, L. (1993): The Oshakati Human Settlement Improvement Project: The town of Oshakati: A historical background. Social Sciences Fivicion (SSD) Discussion Paper No. 2. Windhoek, Namibia.

Hartig, G. L. (1795): Anweisung zur Taxation der Forste oder zur Bestimmung des Holzertrags der Wälder. Georg-Ludwig-Hartig-Stiftung, Gießen

Hauff, V. (Ed.) (1987): Unsere gemeinsame Zukunft – der Brundtland-Bericht der Weltkommission für Umwelt und Entwicklung. Eggenkamp, Greven.

Heyns, P. (2005): Water institutional reforms in Namibia. In: Water Policy 7, 2005, 89-106.

Holling, C. S. (1973): Resilience and stability of ecological systems. In: Annual Review Ecological Systems, No. 4, 1-23.

Hughes, T. (1983): Networks of power, Electrification in Western society, 1880-1930. JHU Press, Baltimore.

Hughes, T. (1987): The evolution of large technological systems. In: Bijker, W. E.; Hughes, T. P.; Pinch, T. (Edts.): The social construction of technological systems. MIT Press, Boston.

Hughes, T. (1999): The evolution of large technological systems. In: Biagioli, M. (Ed.): The Science Studies Reader, New York, London, 1999, 201-223.

Iishana Sub-Basin Management Committee (IBMC) (2008): Raising of Awareness in the Iishana Sub-Basin. Ministry of Agriculture, Water and Forestry (MAWF), Namibia.

Informationsstelle südliches Afrika (ISSA) (2013): Länderprofil Namibia. Informationsstelle südliches Afrika e. V. http://www.issa-bonn.org/laender.htm (accessed July 6th, 2013).

International Conference on Water and Environment (ICWE) (1992): The Dublin Statement on Water and Sustainable Development. Development issues for the 21st century. 26-31 January 1992, Dublin, Ireland.

International Monetary Fund (IMF) (2013): Report for Selected Countries and Subjects. Namibia. http://www.imf.org/external/pubs/ft/weo/2013/01/weodata/weorept.aspx?pr.x=19&pr.y=1&sy=2009&ey=2012&scsm=1&ssd=1&sort=country&ds=.&br=1&c=728&s=NGDPD%2CNGDPDPC%2CPPPGDP%2CPPPPC%2CLP&grp=0&a=#download (accessed July 6th, 2013).

IWRM Joint Venture Consultants Namibia (no date): Integrated Water Resources Management – Cuvelai-Etosha River Basin. Ministry of Agriculture, Water and Forestry, Republic of Namibia, Windhoek, Namibia.

http://www.mawf.gov.na/Documents/IWRM%20Booklets/Cuvelai%20 Etosha%20Basin_RV2.pdf (accessed July 7th, 2013).

Jahn, T. (2005): Soziale Ökologie, kognitive Integration und Transdisziplinarität. In: Technikfolgenabschätzung. Theorie und Praxis Nr. 2, 14. Jahrgang, Juni 2005, 32-38. Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe.

Janis, I. L.; Mann, L. (1977): Decision Making – A Psychological Analysis of Conflict, Choice and Commitment. The Free Press, New York.

Joerges, B. (1988): Large technical systems. Concepts and issues. In: Mayntz, R.; Hughes, T. (Edts.): The Development of Large Technical Systems. Frankfurt/M., New York, 9-36.

Jörissen, J. et al. (1999): HGF-Projekt: Untersuchung zu einem integrativen Konzept nachhaltiger Entwicklung: Bestandsaufnahme, Problemanalyse, Weiterentwicklung. In: Abschlußbericht Band 3: Ein integratives Konzept nachhaltiger Entwicklung. Forschungszentrum Karlsruhe, Institut für Technikfolgenabschätzung (ITAS), Karlsruhe.

Kelle, U. (2005): “Emergence“ vs. “Forcing“ of Empirical Data? A Crucial Problem of “Grounded Theory“ Reconsidered. In: Forum Qualitative Sozialforschung / Forum Qualitative Social Research, 6(2), Art. 27.

Kemp, R.; Schot, J.; Hoogma, R. (1998): Regime shifts to sustainability through processes of niche formation: the approach of Strategic Niche Management. Technology Analysis and Strategic Management 10 (2), 175-195.

Klimoski, R. J.; Karol, B. L. (1976): The impact of trust on creative problem solving groups. In: Journal of Applied Psychology 61(5), 72-74.

Kluge, T.; Liehr, S.; Lux, A.; Moser, P.; Niemann, S.; Umlauf, N.; Urban, W. (2008). IWRM Concept for the Cuvelai Basin in Northern Namibia. In: Physics and Chemistry of the Earth, 33, 48-55.

Kössler, R.; Melber, H. (2004): Völkermord und Gedenken: Der Genozid an den Herero und Nama in Deutsch-Südwestafrika 1904-1908 (Genocide and memory: the genocide of the Herero and Nama in German South-West Africa, 1904-08). In: Fritz Bauer Institut (Ed.): Völkermord und Kriegsverbrechen in der ersten Hälfte des 20. Jahrhunderts. Jahrbuch 2004 zur Geschichte und Wirkung des Holocaust, 37-75. Campus, Frankfurt am Main, New York.

Koziol, M.; Veit, A.; Walther, J. (2006): Stehen wir vor einem Systemwechsel in der Wasserver- und Abwasserentsorgung? Sektorale Randbedingungen und Optionen im stadttechnischen Transformationsprozess. netWORKS-Papers. Deutsches Institut für Urbanistik, Berlin.

Kube, S. (1985): Chronik. In: Interessengemeinschaft deutschsprachiger Südwester (Ed.): 1884-1984. Vom Schutzgebiet bis Namibia. Windhoek, 1985, 255-341.

Lambert, J. H. (1782 and 1787): Logische und philosophische Abhandlungen, Vol. 1. In: Händle, F.; Jensen, S. (Edts.): Systemtheorie und Systemtechnik. Nymphenburger Verlagshandlung, Munich, 1974, 87-103.

Latour, B. (2007): Eine neue Soziologie für eine neue Gesellschaft – Einführung in die Akteur-Netzwerk-Theorie. Suhrkamp, Frankfurt am Main.

Logan, R. F. (1981): Namibia. In: De Blij, H. J.; Martin, E. B.; Ali Memon, P. (Edts.): African perspectives – an exchange of essays on the economic geography of nine African states. 173-192. Taylor & Francis.

Luhmann, N. (1984): Soziale Systeme. Suhrkamp, Berlin.

Madley, B. (2005): From Africa to Auschwitz: How German South West Africa Incubated Ideas and Methods Adopted and Developed by the Nazis in Eastern Europe. In: European History Quarterly, 35 (3), 429-464.

Marsh, A.; Seely, M. (Edts.) (1992): Oshanas - sustaining people, environment and development in central Owambo, Namibia. Desert Research Foundation of Namibia, Windhoek.

Matthies, M. (2003): Einführung in die Systemwissenschaft. Lecture notes (Vorlesungsskript), Institut für Umweltsystemforschung, Universität Osnabrück.

Mayntz, R. (1988): Zur Entwicklung technischer Infrastruktursysteme. In: Mayntz, R.; Rosewitz, B.; Schimank, U.; Stichweh, R. (Edts.): Differenzierung und Verselbständigung. Zur Entwicklung gesellschaftlicher Teilsysteme. Frankfurt/Main, New York, 233-260.

Mayntz, R.; Scharpf, F. W. (1995): Der Ansatz des akteurszentrierten Institutionalismus. In: Mayntz, R.; Scharpf, F. W. (Edts.): Gesellschaftliche Selbstregelung und politische Steuerung. Frankfurt/Main, New York, 40-72.

Meadows, D. H.; Meadows, D. L.; Randers, J.; Behrens III, W. W. (1972): The Limits to Growth. Universe Books, New York.

Mendelsohn, J.; Jarvis, A.; Roberts, C.; Robertson, T. (2003): Atlas of Namibia – A Portrait of the Land and its People. Ministry of Environment and Tourism of Namibia, Windhoek.

Ministry of Agriculture, Water and Rural Development (2000): National Water Policy White Paper. Policy Framework for Equitable, Efficient, and Sustainable Water Resources Management and Water Services. Ministry of Agriculture, Water and Rural Development, Republic of Namibia, Windhoek.

Mittelstraß, J. (2005): Methodische Transdisziplinarität. In: Technikfolgenabschätzung. Theorie und Praxis Nr. 2, 14. Jahrgang, Juni 2005, 18-23. Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe.

Monstadt, J.; Naumann, M. (2004): Neue Räume technischer Infrastruktursysteme – Forschungsstand und -perspektiven zu räumlichen Aspekten des Wandels der Strom- und Wasserversorgung in Deutschland. netWORKS – Papers, Heft 10, Berlin.

NamWater (2006): Official website of the Namibia Water Corporation Ltd. http://www.namwater.com.na (accessed May 8th, 2009).

National Planning Commission (2012): Namibia 2011 Population and Housing Census – Preliminary Results. Republic of Namibia, National Planning Commission (NPC), Windhoek, Namibia.

Nelson, R. R.; Winter, S. G. (1977): In search of a useful theory of innovation. Research Policy 6, 36-76.

Nelson, R. R.; Winter, S. G. (1982): An Evolutionary Theory of Economic Change. The Belknap Press of Harvard University Press, Cambridge, MA.

Niemann, S. (2000): Wasserversorgung und Wasserverwendung in Namibia. Nutzungstraditionen als Grundlage eines nachhaltigen Ressourcenverbrauches im ehemaligen Ovamboland (Water supply and usage in Namibia. Traditions of usage as a basis of a sustainable resource use in the former Ovamboland). In: Hamburger Beiträge zur Afrika-Kunde, Band 61. Deutsches Übersee-Institut, Institut für Afrika-Kunde, Hamburg, Germany.

Pack, L.; Pack, P. (2012): Stefan Loose Reiseführer Namibia. 6th edition, Dumont, Köln.

Parsons, T. (1937): The Structure of Social Action. Free Press.

Parsons, T. (1951): The social system. Ulan Press.

Pohl, C.; Hirsch-Hadorn, G. (2006): Gestaltungsprinzipien für die transdisziplinäre Forschung, ökom-Verl., Munich.

Rammert, W.; Schulz-Schaeffer, I. (2002): Technik und Handeln – Wenn soziales Handeln sich auf menschliches Verhalten und technische Abläufe verteilt. In: Rammert, W.; Schulz-Schaeffer, I. (Edts.): Können Maschienen handeln? Soziologische Beiträge zum Verhältnis von Mensch und Technik, 11-64. Campus, Frankfurt/Main. http://www2.tu-berlin.de/~soziologie/Crew/schulz-schaeffer/pdf/TechnikUndHandeln.pdf (accessed July 8th, 2009).

Reichelt, H. (1990): Grundlagenstudie Namibia. Band 15: Materielle Infrastruktur. Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn.

Rip, A.; Kemp, R. (1998): Technological Change. In: Rayner, S.; Malone, E. L. (Edts.): Human Choice and Climate Change. Battelle Press, Columbus, OH, 327-399.

Rogers, C. R.; Roethlisberger, F. J. (1988). Barriers and gateways to communication. In: Gabarro, J. J.: People – Managing your most important asset. Harvard Business Review, Special edition of articles, 19-25.

Ropohl, G. (1979): Eine Systemtheorie der Technik: Zur Grundlegung der Allgemeinen Technologie. Hanser, Munich, Vienna. 2nd ed., 1998.

Ropohl, G. (1999a): Allgemeine Technologie – Eine Systemtheorie der Technik. Fachbuchverlag Leipzig, Leipzig.

Ropohl, G. (1999b): Philosophy of Socio-Technical Systems. In: Phil & Tech 4:3, Spring 1999. http://scholar.lib.vt.edu/ejournals/SPT/v4_n3pdf/ROPOHL.PDF (accessed July 8th, 2009).

Ropohl, G. (2005): Allgemeine Systemtheorie als transdisziplinäre Integrationsmethode. In: Technikfolgenabschätzung. Theorie und Praxis Nr. 2, 14. Jahrgang, June 2005, 24-31. Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe.

Rotmans, J.; Kemp, R.; van Asselt, M. (2001): More evolution than revolution: transition management in public policy. Foresight, Vol. 3 Iss: 1, 15-31.

Saaty, T. L. (1990): Multicriteria decision making – the analytic hierarchy process. Planning, priority setting, resource allocation, 2nd Edition. RWS Publishing, Pittsburgh.

Schmidt, J. C. (2005): Dimensionen der Interdisziplinarität. Wege zu einer Wissenschaftstheorie der Interdisziplinarität. In: Technikfolgenabschätzung. Theorie und Praxis Nr. 2, 14. Jahrgang, Juni 2005, 12-17. Institut für Technikfolgenabschätzung und Systemanalyse, Forschungszentrum Karlsruhe.

Scholz, R. W.; Lang, D. J.; Wiek, A.; Walter, A. I.; Stauffacher, M. (2006): Transdisciplinary case studies as a means of sustainability learning – Historical framework and theory. In: International Journal of Sustainability in Higher Education, Vol. 7, No. 3, 2006, 226-251. Emerald Group Publishing Limited.

Schümer, M. (1977): Die angolanisch-südafrikanische Wirtschaftsverflechtung am Beispiel des Cunene-Projektes. In: Schümer, M.: Die Wirtschaft Angolas 1973-1976. Ansätze einer Entwicklungsstrategie der MPLA-Regierung. Arbeiten aus dem Institut für Afrika-Kunde, Vol. 12, Hamburg, 304-333.

Snellen, W. B.; Schrevel, A. (2004): IWRM for sustainable use of water – 50 years of international experience with the concept of integrated water management. Ministry of agriculture, nature and food quality, the Netherlands, Wageningen.

Sperber, W. H. (2001): Hazard identification: from a quantitative to a qualitative approach. Food Control 12, 223-228.

Stengel, H. W. (1963): Wasserwirtschaft in Südwestafrika. Afrika-Verlag Der Kreis, Windhoek.

Stern, C.; Lau, B. (1990): Namibian Water Resources and their Management. A preliminary history. Windhoek.

Strauss, A. L.; Corbin, J. (1990): Basics of Qualitative Research. Grounded Theory Procedures and Techniques. Sage, Newbury Park, Ca.

Sturm, M.; Zimmermann, M.; Schütz, K.; Urban, W.; Hartung, H. (2009). Rainwater Harvesting as an Alternative Water Resource in Rural Sites in Central Northern Namibia. In: Physics and Chemistry of the Earth, Vol. 34 (2009), Elsevier, 776-785.

The Namibian (2010): Namibia – Cabinet Approves Water Resources Management Bill. July 13th, 2010.

Transboundary Freshwater Dispute Database (2012): Transboundary Freshwater Dispute Database. Department of Geosciences, Oregon State University. http://www.transboundarywaters.orst.edu/publications/register/tables/IRB_africa.html (accessed August 16th, 2012).

UFZ – Helmholtz-Zentrum für Umweltforschung (2009): IWRM: Integriertes Wasserressourcen-Management: Von der Forschung zur Umsetzung. http://www.wasserressourcen-management.de/_media/IWRM_Broschuere_BMBF_19_03_2009.pdf (accessed May 15th, 2009).

United Nations Development Programme (UNDP) (2013): Human Development Report 2013. The Rise of the South. Human Progress in a Diverse World. United Nations Development Programme, New York.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2012): Managing Water under Uncertainty and Risk. The United Nations World Water Development Report 4. The United Nations Educational, Scientific and Cultural Organization, Paris, France.

United Nations International Strategy for Disaster Reduction (UNISDR) (2009): UNISDR Terminology on Disaster Risk Reduction. United Nations, Geneva, Switzerland.

van de Poel, I. R. (2003): The transformation of technological regimes. In: Research Policy 32, 49-68.

van de Poel, I. R.; Franssen, M. P. M. (2002): Understanding technical development: the concept of "Technological Regime". In: Int. J. Technology, Policy and Management, Vol. 2, No. 4, 355-360.

Vennix, J. A. M. (1999): Group model-building: tackling messy problems. In: System Dynamics Review, Vol. 15, No. 4 (Winter 1999), 379-401.

Vester, F. (1980): Neuland des Denkens – Vom technokratischen zum kybernetischen Zeitalter (New ground of thinking – From the technocratic to the cybernetic age). Deutsche Verlagsanstalt, Stuttgart.

Vester, F. (2000): Die Kunst vernetzt zu denken. Ideen und Werkzeuge für einen neuen Umgang mit Komplexität. Deutsche Verlagsanstalt, Stuttgart.

von Carlowitz, H. C. (2000): Sylvicultura oeconomica – Anweisung zur wilden Baum-Zucht (reprint of the 1713 edition, edited by K. Irmer and A. Kießling). TU Bergakademie Freiberg und Akademische Buchhandlung, Freiberg.

von Foerster, H. (1974): Cybernetics of Cybernetics. Urbana Illinois, University of Illinois.

von Foerster, H. (1995): Cybernetics of Cybernetics, The Control of Control and the Communication of Communication. Carl-Auer, Heidelberg.

Wiener, N. (1948): Cybernetics: Or Control and Communication in the Animal and the Machine. Paris, New York.

Wisner, B.; Blaikie, P.; Cannon, T.; Davis, I. (2004): At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, New York.

Zangemeister, C. (1976): Nutzwertanalyse in der Systemtechnik – Eine Methodik zur multidimensionalen Bewertung und Auswahl von Projektalternativen, Diss. Techn. Univ. Berlin 1970, 4th edition. Wittemann, Munich.

Zimmermann, M.; Urban, W. (2009). Wasserversorgungstechnische Lösungsansätze innerhalb des IWRM im Norden Namibias (Water supply solutions within the IWRM in northern Namibia). In: Linke, H. J. (Edt.): 1. Darmstädter Ingenieurkongress – Bau und Umwelt, 14-15 September 2009, Conference proceedings, Technische Universität Darmstadt.

Zimmermann, M. (2010a): Modellierung für eine nachhaltige Wasserversorgung im Norden Namibias (Modelling for a sustainable water supply in northern Namibia). In: Darmstädter Seminar Wasserversorgung und Grundwasserschutz – Neue Herausforderungen und Chancen in der Wasserversorgung, WAR-Schriftenreihe, Vol. 205, Technische Universität Darmstadt, 141-153.

Zimmermann, M. (2010b): The Coexistence of Traditional and Large-Scale Water Supply Systems in Central Northern Namibia. In: Journal of Namibian Studies, History – Politics – Culture, 7 (2010), Otjivanda Presse, Essen, Germany, 55-84.

Zimmermann, M.; Brenda, M.; Jokisch, A.; Urban, W. (2010): Appropriate Water Supply Techniques for Semi-Arid Regions – The Cuvelai-Etosha-Basin in Namibia. In: Steusloff, H. (Ed.): Integrated Water Resources Management Karlsruhe 2010, Conference Proceedings, 24-25 November 2010, 286-292. KIT Scientific Publishing, Karlsruhe.

Zimmermann, M. (2012): Water Resources Management in Central Northern Namibia Using Empirically Grounded Modelling. In: Journal of Water, Sanitation and Hygiene for Development, Vol. 02.2 (2012), 112-123, IWA Publishing, London.

Zimmermann, M.; Jokisch, A.; Deffner, J.; Brenda, M.; Urban, W. (2012): Stakeholder Participation and Capacity Development during the Implementation of Rainwater Harvesting Pilot Plants in Central Northern Namibia. In: Water Science and Technology: Water Supply, Vol. 12.4 (2012), 540-548, IWA Publishing, London.

Zimmermann, M.; Urban, W. (2012): The Analysis of Problem Perceptions and Systemic Interdependencies in the Case of the Water Supply Regime in Central Northern Namibia. In: Steusloff, H. (Ed.): Integrated Water Resources Management Karlsruhe 2012, Conference Proceedings, 21-22 November 2012, 252-259. KIT Scientific Publishing, Karlsruhe.

Appendix

Table A.1 List of interviews

Code of interview	Date of interview	Place of interview
07a-WM-01	17.08.2007	Pfungstadt
07a-WM-02	29.08.2007	Windhoek
07a-WM-03	30.08.2007	Windhoek
07a-WM-05	03.09.2007	Oshakati
07a-WM-07	04.09.2007	Oshakati
07a-WM-08	10.09.2007	Windhoek
07a-WM-09	10.09.2007	Windhoek
07a-WM-10	13.09.2007	Windhoek
07b-WM-01	02.08.2007	Windhoek
07b-WM-02	06.08.2007	Windhoek
07b-WM-03	07.08.2007	Windhoek
07b-WM-04	09.08.2007	Windhoek
07a-AP-01	04.09.2007	Oshakati
07a-AP-02	05.09.2007	Oshakati
07a-AP-03	05.09.2007	Oshakati
07a-AP-04	07.09.2007	Oshakati
07a-AP-05	13.09.2007	Windhoek
07b-AP-01	10.10.2007	Windhoek
07a-WU-01	05.09.2007	Oshakati
07a-WU-02	06.09.2007	Oshakati
07a-WU-03	04.09.2007	Oshakati
09-WU-01	21.11.2009	Oshakati
09-WU-02	26.10.-30.11.2009	Epyeshona, Oshakati
09-WU-03	26.10.-29.11.2009	Epyeshona
09-WU-04	08.11.2009	Etunda
09-WU-05	26.10.-29.11.2009	Epyeshona
09-WU-06	9.-29.11.2009	Epyeshona
09-WU-07	9.-29.11.2009	Epyeshona
09-WU-08	9.-29.11.2009	Epyeshona
09-WU-09	9.-29.11.2009	Epyeshona
09-WU-10	26.10.-30.11.2009	Epyeshona
09-WU-11	21.11.2009	Amutanga
09-WU-12	24.11.2009	Epyeshona
09-WU-13	18.11.2009	Oshakati
09-WU-14	2.-30.11.2009	Epyeshona
09-WU-15	26.10.-30.11.2009	Epyeshona
09-WU-16	22.11.2009	Ondiri Nawa
09-WU-17	26.10.-28.11.2009	Oshakati
09-WU-18	06.11.2009	Epyeshona
09-WU-19	13.11.2009	Epyeshona
07a-WSU-01	03.09.2007	Oshakati

07a-WSU-02	06.09.2007	Oshakati
07b-WSU-01	21.08.2007	Windhoek
07a-EI-01	11.09.2007	Windhoek
07a-EI-02	14.09.2007	Windhoek
07b-EI-01	15.08.2007	Windhoek
07a-SC-02	13.09.2007	Windhoek
07a-SC-03	17.09.2007	Windhoek
07b-SC-01	16.08.2007	Windhoek
07b-SC-02	16.08.2007	Windhoek
07b-SC-03	21.8.2007, 20.9.2007	Windhoek
07b-SC-04	18.09.2007	Windhoek
07b-SC-05	18.09.2007	Windhoek
07b-SC-06	18.09.2007	Windhoek
09-SC-01	25.10.-6.11.2009	Oshakati
09-SC-02	29.10.2009, 3.+7.11.2009	Oshakati
09-SC-03	28.10.2009	Ondangwa
09-SC-04	3.11.-29.11.2009	Oshakati, Epyeshona
09-SC-05	8.11.2009, 15.11.2009	Olushandja

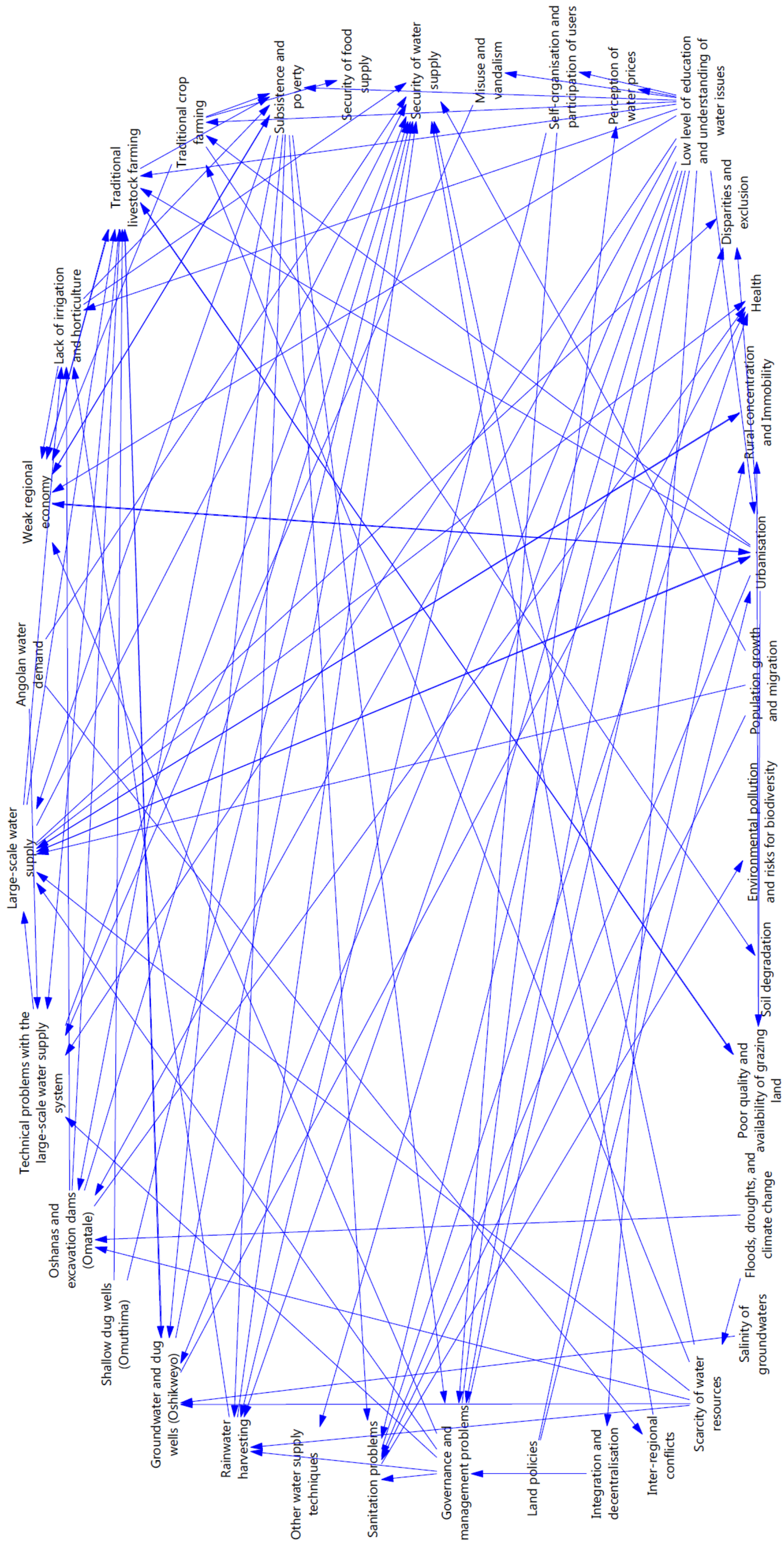

Figure A.1 Causal-loop diagram of the model including interdependencies with more than five propositions (created with Vensim)

Table A.2 Full normalised Cross-Impact Matrix (CIM)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Activity	Passivity	Q-value	P-value
1			1	1					1		1										1	1	1	1	1	1	1		1	1		1		1	1	1	1	18	9	2.00	162
2	1								1																					1								3	6	0.50	18
3				1							1								1			1		1	1					1		1		1	1			10	10	1.00	100
4																								1	1					1		1		1				5	7	0.71	35
5															1		1							1	1					1		1		1				7	7	1.00	49
6																						1		1	1					1		1		1	1			7	6	1.17	42
7									1	1					1					1				1						1						1		7	6	1.17	42
8																									1					1		1		1			1	5	4	1.25	20
9	1	1			1	1	1	1		1		1													1	1	1	1	1	1					1	1		16	13	1.23	208
10			1				1		1		1	1																1								1		7	5	1.40	35
11			1						1	1												1	1							1			1		1			8	8	1.00	64
12									1	1	1																											3	5	0.60	15
13																														1								1	3	0.33	3
14	1		1	1	1	1							1			1			1											1			1	1				11	2	5.50	22
15			1	1	1																																	3	2	1.50	6
16			1			1								1			1			1										1								6	2	3.00	12
17											1		1										1											1				4	5	0.80	20
18																			1														1					2	2	1.00	4
19																1																						1	5	0.20	5
20																								1								1						2	2	1.00	4
21	1						1		1													1								1								5	3	1.67	15
22	1		1				1		1		1						1				1				1	1						1	1	1		1		13	8	1.63	104
23	1										1																							1				3	3	1.00	9
24																										1												1	7	0.14	7
25	1																											1	1	1								4	9	0.44	36
26		1	1	1	1	1	1	1	1	1	1	1										1					1	1	1			1	1	1	1	1		20	4	5.00	80
27									1																				1	1					1			4	5	0.80	20
28	1		1	1	1	1		1	1			1																	1	1								10	6	1.67	60
29		1							1			1													1		1	1										6	7	0.86	42
30				1																																		1	20	0.05	20
31																																1						1	4	0.25	4
32	1		1		1	1	1	1	1													1					1	1	1						1	1		13	14	0.93	182
33																		1	1												1	1			1	1		6	5	1.20	30
34		1			1												1	1	1											1		1				1		8	13	0.62	104
35		1												1			1													1	1	1		1		1		8	10	0.80	80
36																					1	1									1	1		1	1			6	10	0.60	60
37		1											1																	1	1							4	2	2.00	8
Passivity	9	6	10	7	7	6	6	4	13	5	8	5	3	2	2	2	5	2	5	2	3	8	3	7	9	4	5	6	7	20	4	14	5	13	10	10	2				

Table A.3 Ranking of system variables by Q-value based on the normalised matrix

No.	Name	Dimension	Activity	Passivity	Q-value	P-value
14	Scarcity of water resources	EL	11	2	**5.50**	22
26	Low level of education and understanding of water issues	SC	20	4	**5.00**	80
16	Floods, droughts, and climate change	EL	6	2	**3.00**	12
1	Large-scale water supply	TE	18	9	**2.00**	162
37	Angolan water demand	EN	4	2	**2.00**	8
21	Population growth and migration	SC	5	3	**1.67**	15
28	Self-organisation and participation of users	SC	10	6	**1.67**	60
22	Urbanisation	SC	13	8	**1.63**	104
15	Salinity of groundwater	EL	3	2	**1.50**	6
10	Water supply and sanitation policies	PI	7	5	**1.40**	35
8	Other water supply techniques	TE	5	4	**1.25**	20
9	Governance and management problems	PI	16	13	**1.23**	208
33	Traditional crop farming	EN	6	5	**1.20**	30
6	Rainwater harvesting	TE	7	6	**1.17**	42
7	Sanitation problems	TE	7	6	**1.17**	42
3	Oshanas and excavation dams (Omatale)	TE	10	10	**1.00**	100
5	Groundwater and dug wells (Oshikweyo)	TE	7	7	**1.00**	49
11	Land policies	PI	8	8	**1.00**	64
18	Soil degradation	EL	2	2	**1.00**	4
20	Environmental pollution and risks for biodiversity	EL	2	2	**1.00**	4
23	Rural concentration and immobility	SC	3	3	**1.00**	9
32	Subsistence and poverty	EN	13	14	**0.93**	182
29	Misuse and vandalism	SC	6	7	**0.86**	42
17	Poor quality and availability of grazing land	EL	4	5	**0.80**	20
27	Perception of water prices	SC	4	5	**0.80**	20
35	Lack of irrigation and horticulture	EN	8	10	**0.80**	80
4	Shallow dug wells (Omuthima)	TE	5	7	**0.71**	35
34	Traditional livestock farming	EN	8	13	**0.62**	104
12	Integration and decentralisation	PI	3	5	**0.60**	15
36	Weak regional economy	EN	6	10	**0.60**	60
2	Technical problems with the large-scale water supply system	TE	3	6	**0.50**	18
25	Disparities and exclusion	SC	4	9	**0.44**	36
13	Inter-regional conflicts	PI	1	3	**0.33**	3
31	Security of food supply	SC	1	4	**0.25**	4
19	Deforestation	EL	1	5	**0.20**	5
24	Health	SC	1	7	**0.14**	7
30	Security of water supply	SC	1	20	**0.05**	20

Table A.4 Ranking of system variables by P-value based on the normalised matrix

No.	Name	Dimension	Activity	Passivity	Q-value	P-value
9	Governance and management problems	PI	16	13	1.23	**208**
32	Subsistence and poverty	EN	13	14	0.93	**182**
1	Large-scale water supply	TE	18	9	2.00	**162**
22	Urbanisation	SC	13	8	1.63	**104**
34	Traditional livestock farming	EN	8	13	0.62	**104**
3	Oshanas and excavation dams (Omatale)	TE	10	10	1.00	**100**
26	Low level of education and understanding of water issues	SC	20	4	5.00	**80**
35	Lack of irrigation and horticulture	EN	8	10	0.80	**80**
11	Land policies	PI	8	8	1.00	**64**
28	Self-organisation and participation of users	SC	10	6	1.67	**60**
36	Weak regional economy	EN	6	10	0.60	**60**
5	Groundwater and dug wells (Oshikweyo)	TE	7	7	1.00	**49**
6	Rainwater harvesting	TE	7	6	1.17	**42**
7	Sanitation problems	TE	7	6	1.17	**42**
29	Misuse and vandalism	SC	6	7	0.86	**42**
25	Disparities and exclusion	SC	4	9	0.44	**36**
4	Shallow dug wells (Omuthima)	TE	5	7	0.71	**35**
10	Water supply and sanitation policies	PI	7	5	1.40	**35**
33	Traditional crop farming	EN	6	5	1.20	**30**
14	Scarcity of water resources	EL	11	2	5.50	**22**
8	Other water supply techniques	TE	5	4	1.25	**20**
17	Poor quality and availability of grazing land	EL	4	5	0.80	**20**
27	Perception of water prices	SC	4	5	0.80	**20**
30	Security of water supply	SC	1	20	0.05	**20**
2	Technical problems with the large-scale water supply system	TE	3	6	0.50	**18**
12	Integration and decentralisation	PI	3	5	0.60	**15**
21	Population growth and migration	SC	5	3	1.67	**15**
16	Floods, droughts, and climate change	EL	6	2	3.00	**12**
23	Rural concentration and immobility	SC	3	3	1.00	**9**
37	Angolan water demand	EN	4	2	2.00	**8**
24	Health	SC	1	7	0.14	**7**
15	Salinity of groundwater	EL	3	2	1.50	**6**
19	Deforestation	EL	1	5	0.20	**5**
18	Soil degradation	EL	2	2	1.00	**4**
20	Environmental pollution and risks for biodiversity	EL	2	2	1.00	**4**
31	Security of food supply	SC	1	4	0.25	**4**
13	Inter-regional conflicts	PI	1	3	0.33	**3**

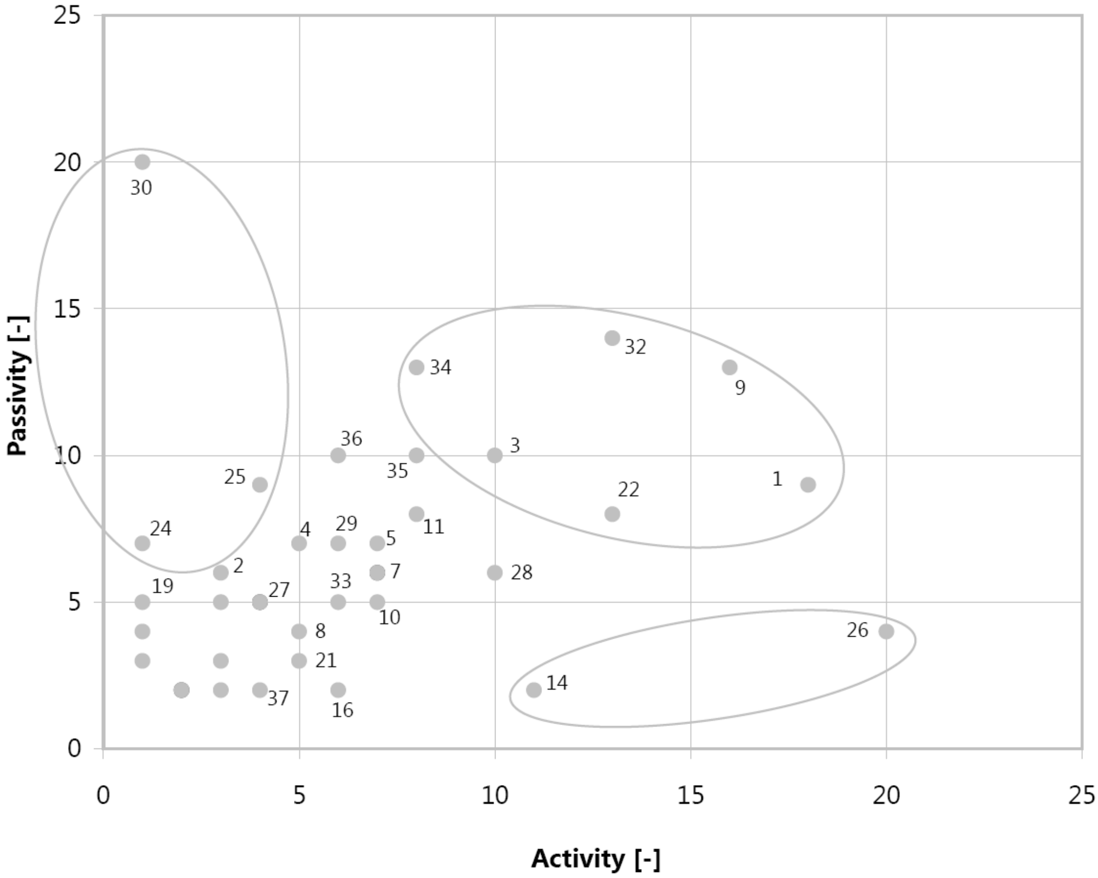

Figure A.2 Location of system variables in the activity and passivity diagram of the normalised matrix

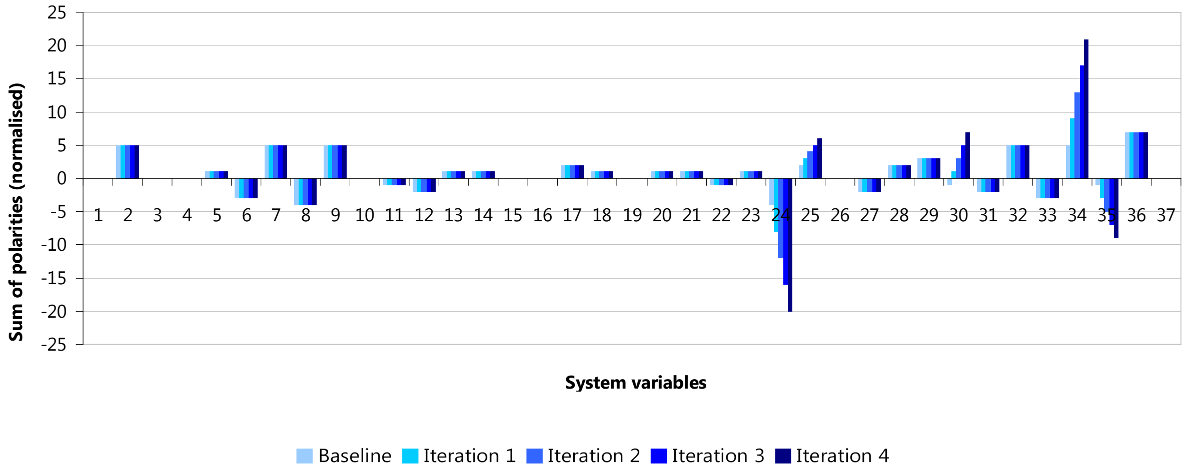

Figure A.3 Water supply scenario W2a using the sum of polarities based on the normalised model

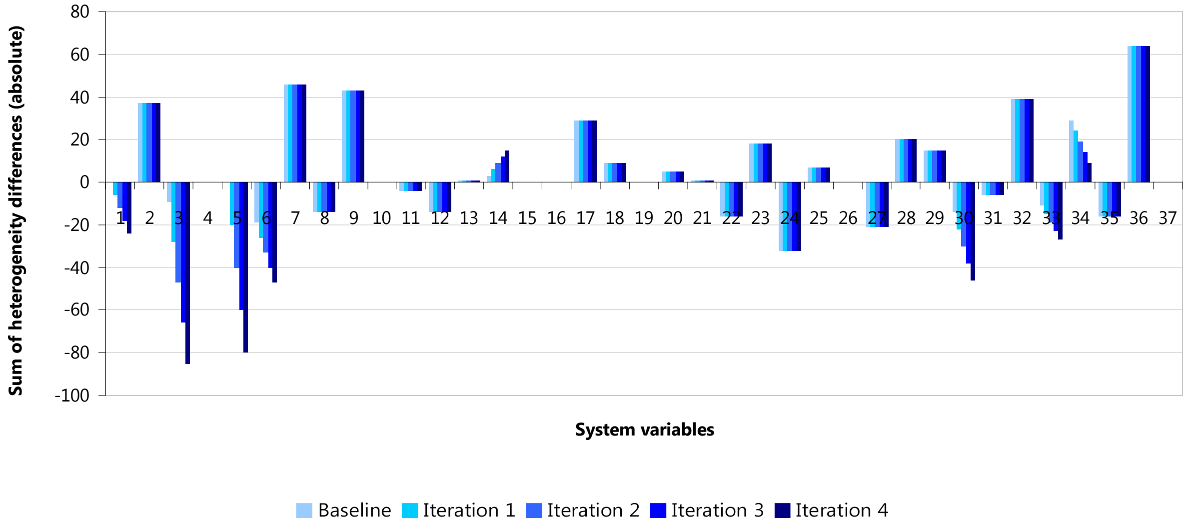

Figure A.4 Scenario K1 Ecology using the sum of heterogeneity differences based on the absolute model

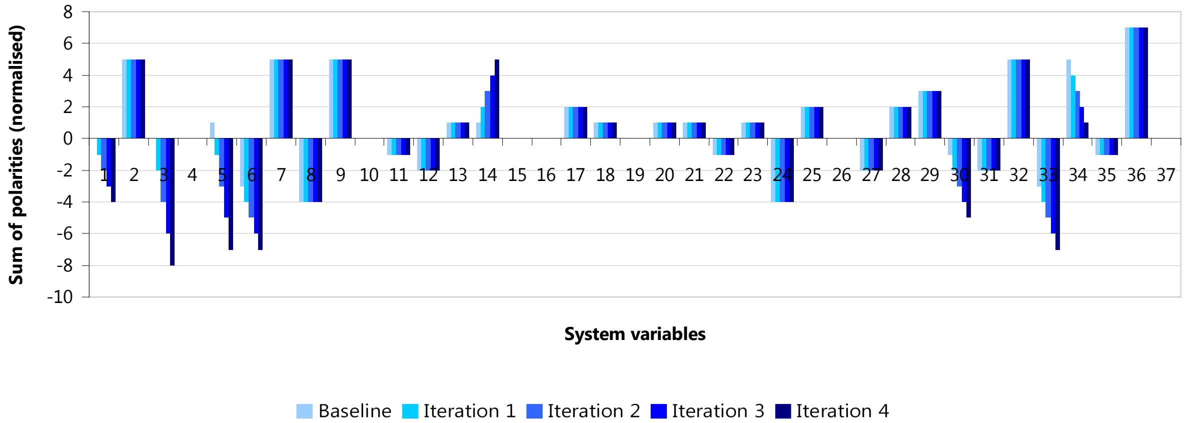

Figure A.5 Scenario K1 Ecology using the sum of polarities based on the normalised model

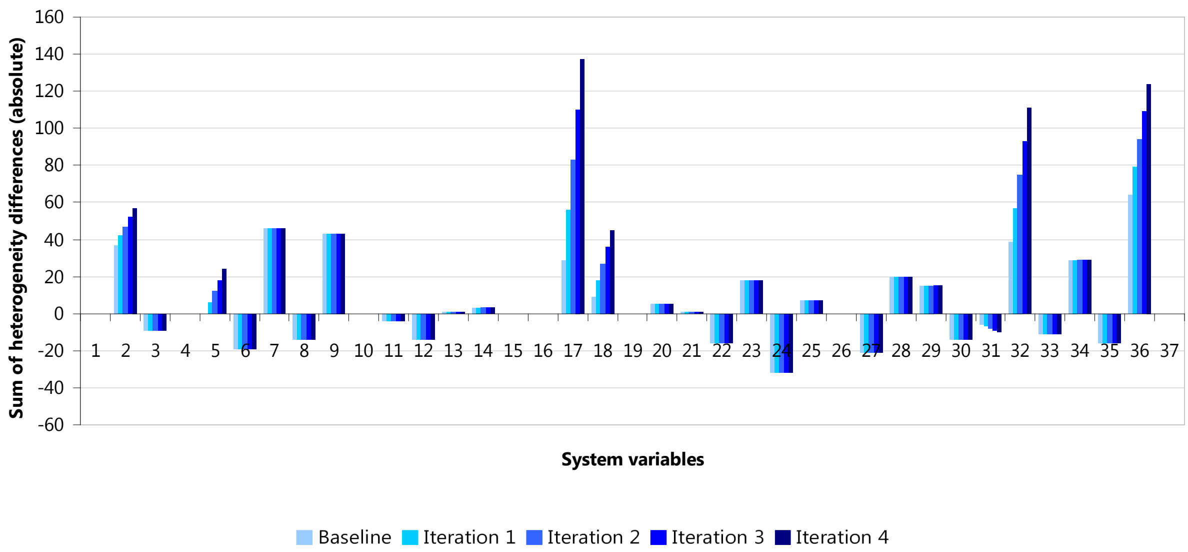

Figure A.6 Scenario K2 Traditional Farming using the sum of heterogeneity differences based on the absolute model

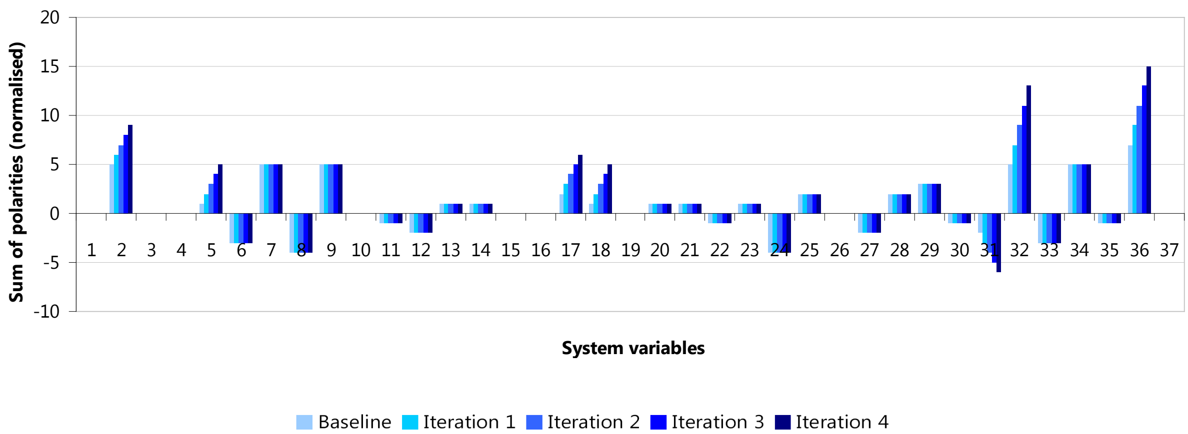

Figure A.7 Scenario K2 Traditional Farming using the sum of polarities based on the normalised model

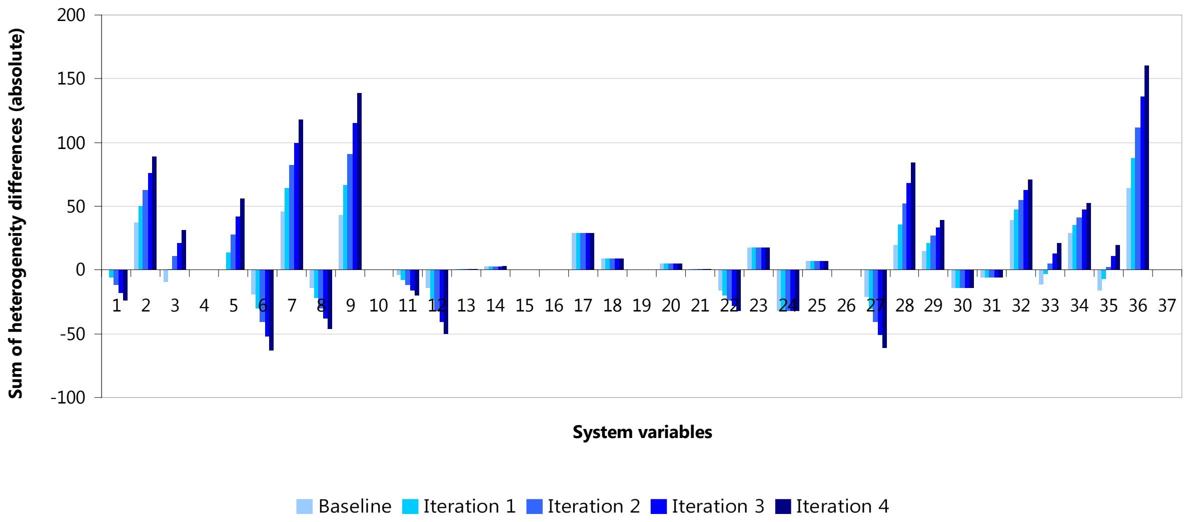

Figure A.8 Scenario K3 Education and Poverty using the sum of heterogeneity differences based on the absolute model

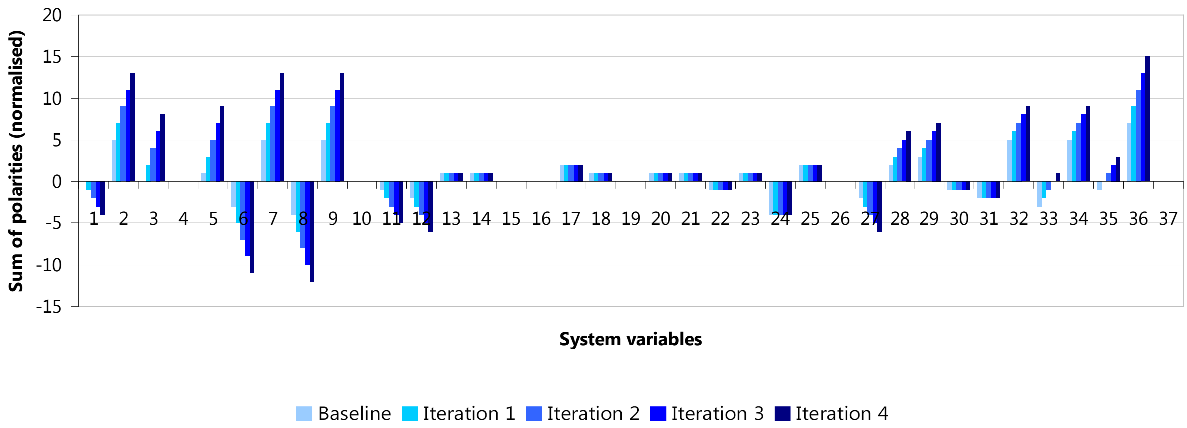

Figure A.9 Scenario K3 Education and Poverty using the sum of polarities based on the normalised model

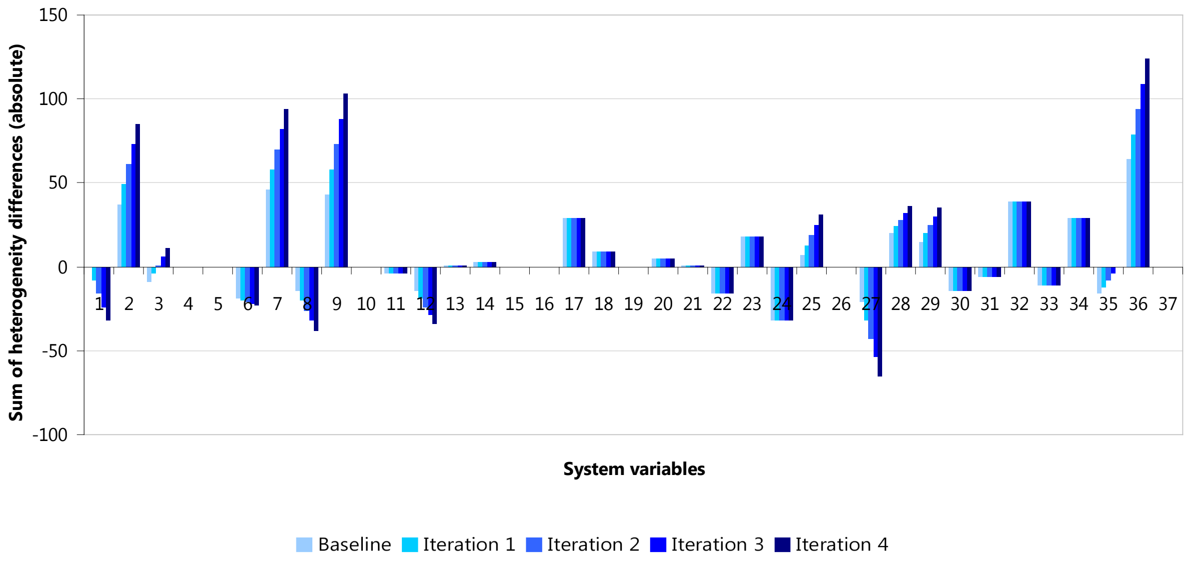

Figure A.10 Scenario K4 Organisation and Management using the sum of heterogeneity differences based on the absolute model

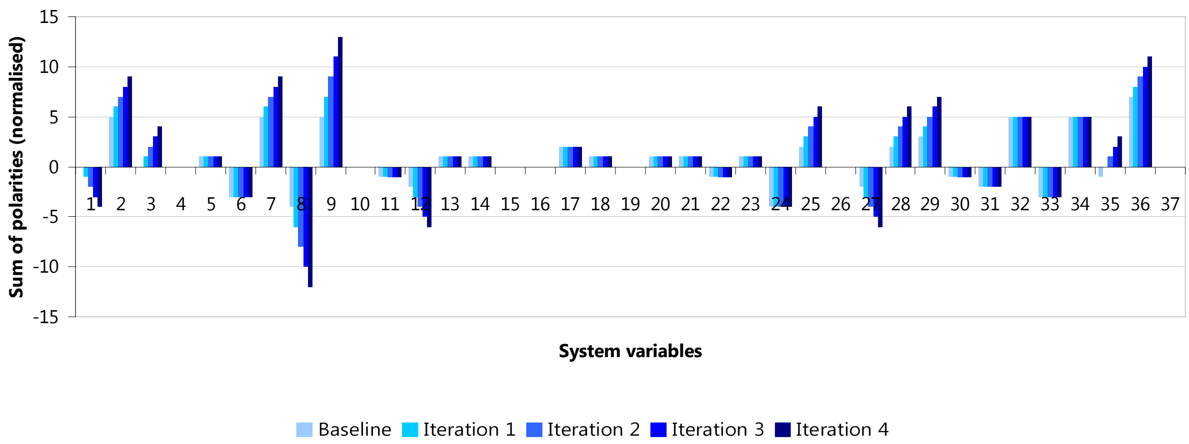

Figure A.11 Scenario K4 Organisation and Management using the sum of polarities based on the normalised model

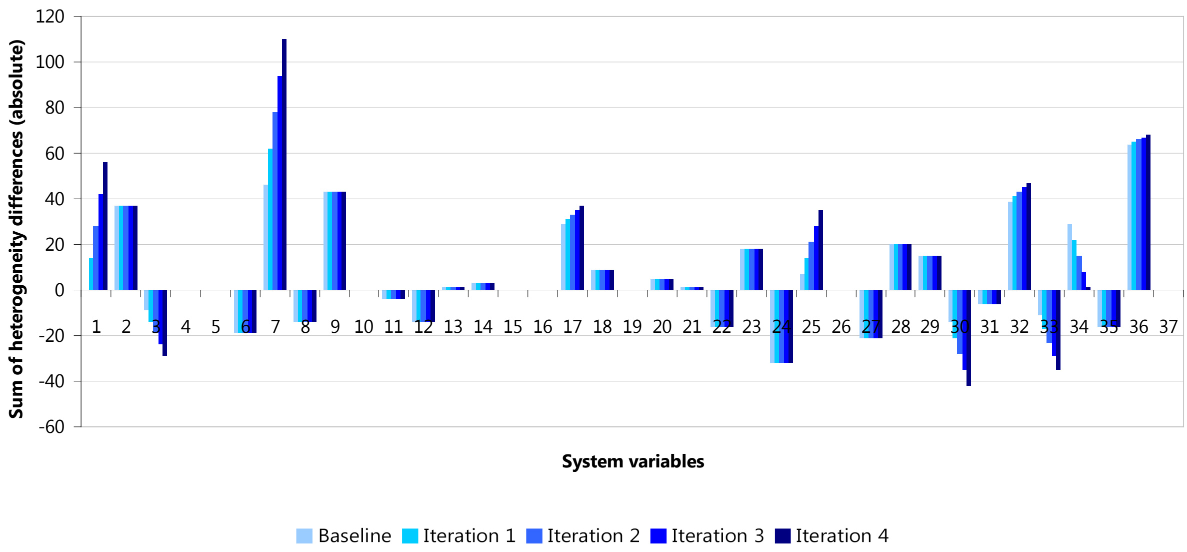

Figure A.12 Scenario K5 Population Growth using the sum of heterogeneity differences based on the absolute model

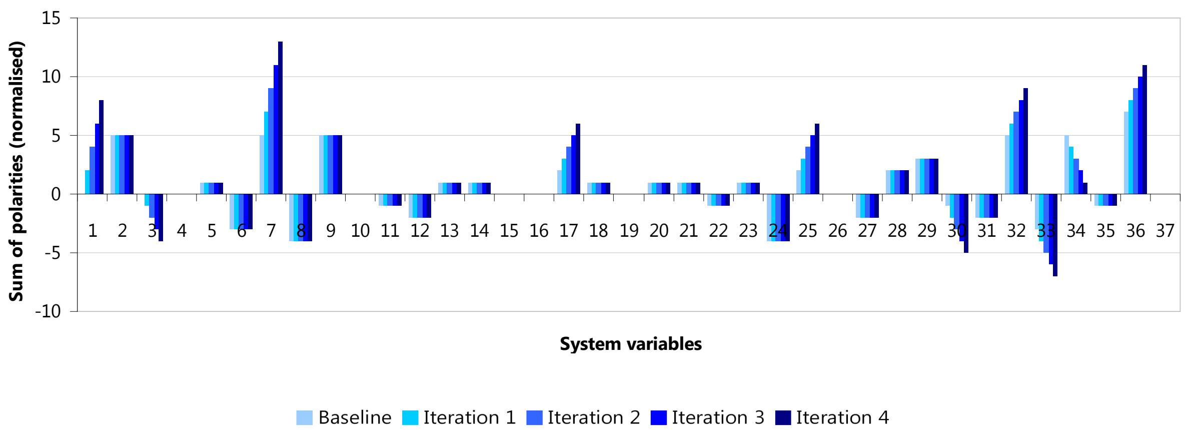

Figure A.13 Scenario K5 Population Growth using the sum of polarities based on the normalised model

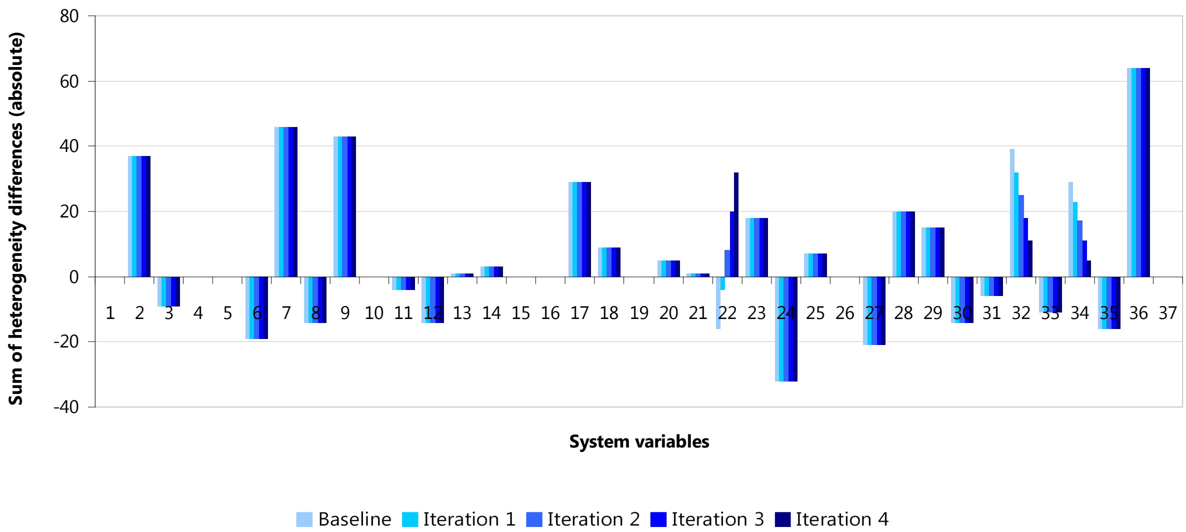

Figure A.14 Scenario K6 Regional Economy using the sum of heterogeneity differences based on the absolute model

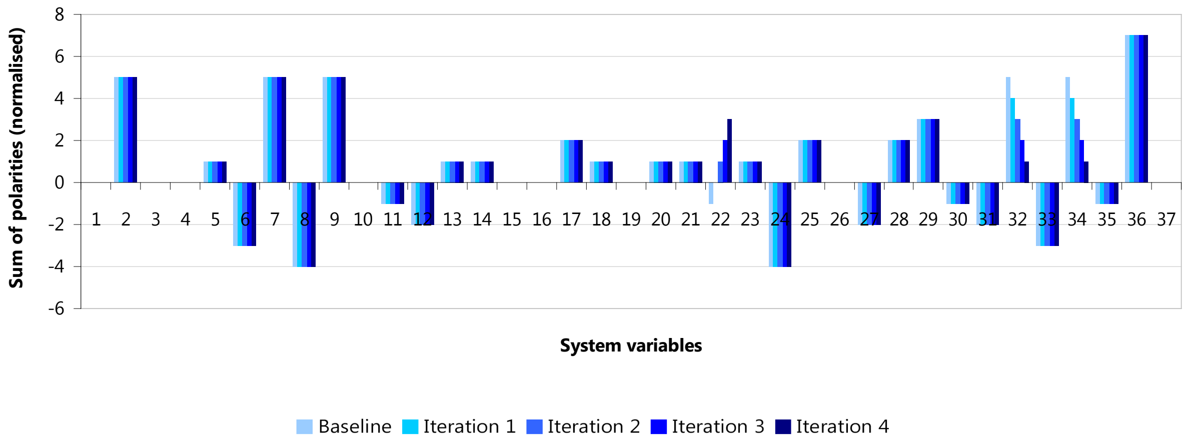

Figure A.15 Scenario K6 Regional Economy using the sum of polarities based on the normalised model

In der Schriftenreihe IWAR sind erschienen:

*WA*R 1	Brunnenalterung Wassertechnisches Seminar am 13.10.1978, TH Darmstadt, 1980	10,30 €
*WA*R 2	Festschrift zum 60. Geburtstag von Prof. Dr.-Ing. Günther Rincke. TH Darmstadt, 1979	vergriffen
*WA*R 3	Gniosdorsch, Lothar Georg: Ein Beitrag über den Einfluß der in Abhängigkeit von der verfahrens-mäßigen Durchführung der biologischen Abwasserreinigung bedingten Schlammeigenschaften auf die Schlammentwässerung und anschließende Verbrennung. Dissertation, FB 13, TH Darmstadt, 1979	vergriffen
*WA*R 4	Grundwassergewinnung mittels Filterbrunnen. 2. Wassertechnisches Seminar am 11.04.1980, TH Darmstadt, 1981	vergriffen
*WA*R 5	Rudolph, Karl-Ulrich: Die mehrdimensionale Bilanzrechnung als Entscheidungsmodell der Wassergütewirtschaft. Dissertation, FB 13, TH Darmstadt, 1980	vergriffen
*WA*R 6	Hantke, Hartmut: Vergleichende Bewertung von Anlagen zur Grundwasseranreicherung. Dissertation, FB 13, TH Darmstadt, 1981	vergriffen
*WA*R 7	Riegler, Günther: Eine Verfahrensgegenüberstellung von Varianten zur Klärschlamm-stabilisierung. Dissertation, FB 13, TH Darmstadt, 1981	vergriffen
*WA*R 8	Technisch-wissenschaftliche Grundlagen für Wasserrechtsverfahren in der öffentlichen Wasserversorgung. 3. Wassertechnisches Seminar am 05.und 06.03.1981, TH Darmstadt, 1982	25,60 €
*WA*R 9	Geruchsemissionen aus Abwasseranlagen. 4. Wassertechnisches Seminar am 15.10.1981, TH Darmstadt, 1982	vergriffen
*WA*R 10	Stadtplanung und Siedlungswasserwirtschaft in Entwicklungsländern.- Aspekte der Projektdurchführung. Vorträge in den Jahren 1980 - 1981. TH Darmstadt, 1982	vergriffen
*WA*R 11	Hierse, Wilfried: Untersuchungen über das Verhalten phosphathaltiger Schlämme unter anaeroben Bedingungen. Dissertation, FB 13, TH Darmstadt, 1982	vergriffen

*WA*R 12	Gossel, Hans: Untersuchungen zum Verhalten von Belebungsanlagen bei Stoßbelastungen. Dissertation, FB 13, TH Darmstadt, 1982	vergriffen
*WA*R 13	Hanel, Robert: Der Sauerstoffeintrag und seine Messung beim Belebungsverfahren unter besonderer Beachtung der Viskosität und Oberflächenspannung. Dissertation, FB 13, TH Darmstadt, 1982	vergriffen
*WA*R 14	Cichorowski, Georg: Regionale Differenzierung in der Gewässergütewirtschaft. Dissertation, FB 13, TH Darmstadt, 1982	23,-- €
*WA*R 15	Schreiner Horst: Stofftausch zwischen Sediment und Wasserkörper in gestauten Fließgewässern. Dissertation, FB 13, TH Darmstadt, 1982	25,60 €
*WA*R 16	Grundwasserbewirtschaftung - Grundwassermodelle, Grundwasser-anreicherung. 5. Wassertechnisches Seminar am 08.10.1982, TH Darmstadt, 1982	vergriffen
*WA*R 17	Rüthrich, Wulf: Abhängigkeit des Verhaltens der Wohnbevölkerung von Verkehrsimmissionen. Dissertation, FB 13, TH Darmstadt, 1982	vergriffen
*WA*R 18	Hill, Stefan: Untersuchungen über die Wechselwirkungen zwischen Porenverstopfung und Filterwiderstand mittels Tracermessungen. Dissertation, FB 13, TH Darmstadt, 1983	25,60 €
*WA*R 19	Kaltenbrunner, Helmut: Wasserwirtschaftliche Auswirkungen der Kühlverfahren von Kraftwerken und von Abwärmeeinleitungen in Fließgewässern. Dissertation, FB 13, TH Darmstadt, 1983	25,60 €
*WA*R 20	Roeles, Gerd: Auswirkungen von Müllverbrennungsanlagen auf die Standort-umgebung - Analyse der Wahrnehmungen von Störungen und Belästigungen. Dissertation, FB 13, TH Darmstadt, 1982	vergriffen
*WA*R 21	Niehoff, Hans-Hermann: Untersuchungen zur weitergehenden Abwasserreinigung mit vorwiegend biologischen Verfahrensschritten unter besonderer Berücksichtigung der Grundwasseranreicherung. Dissertation, FB 13, TH Darmstadt, 1983	vergriffen

*WA*R 22	Biologische Verfahren in der Wasseraufbereitung. 6. Wassertechnisches Seminar am 06.04.1984, TH Darmstadt, 1985	vergriffen
*WA*R 23	Optimierung der Belüftung und Energieeinsparung in der Abwassertechnik durch Einsatz neuer Belüftungssysteme. 7. Wassertechnisches Seminar am 16.11.1984, TH Darmstadt, 1985	vergriffen
*WA*R 24	Wasserverteilung und Wasserverluste. 8. Wassertechnisches Seminar am 30.05.1985, TH Darmstadt, 1985	vergriffen
*WA*R 25	Professor Dr. rer. nat. Wolters zum Gedächtnis - 1. Januar 1929 bis 26. Februar 1985. Beiträge von Kollegen, Schülern und Freunden. TH Darmstadt, 1986	vergriffen
*WA*R 26	Naturnahe Abwasserbehandlungsverfahren im Leistungsvergleich - Pflanzenkläranlagen und Abwasserteiche. 9. Wassertechnisches Seminar am 07.11.1985, TH Darmstadt, 1986	vergriffen
*WA*R 27	Heuser, Ernst-Erich: Gefährdungspotentiale und Schutzstrategien für die Grundwasservorkommen in der Bundesrepublik Deutschland. Dissertation, FB 13, TH Darmstadt, 1986	vergriffen
*WA*R 28	Rohrleitungen und Armaturen in der Wasserversorgung. 10. Wassertechnisches Seminar am 24.04.1986, TH Darmstadt, 1986	vergriffen
*WA*R 29	Bau, Kurt: Rationeller Einsatz der aerob-thermophilen Stabilisierung durch Rohschlamm-Vorentwässerung. Dissertation, FB 13, TH Darmstadt, 1986	vergriffen
*WA*R 30	Wehenpohl, Günther: Selbsthilfe und Partizipation bei siedlungswasserwirtschaftlichen Maßnahmen in Entwicklungsländern - Grenzen und Möglichkeiten in städtischen Gebieten unterer Einkommensschichten. Dissertation, FB 13, TH Darmstadt, 1987	vergriffen
*WA*R 31	Stickstoffentfernung bei der Abwasserreinigung - Nitrifikation und Denitrifikation. 11. Wassertechnisches Seminar am 13.11.1986, TH Darmstadt, 1987	vergriffen

*WA*R 32	Neuere Erkenntnisse beim Bau und Betrieb von Vertikalfilterbrunnen. 12. Wassertechnisches Seminar am 14.05.1987, TH Darmstadt, 1987	vergriffen
*WA*R 33	Ist die landwirtschaftliche Klärschlammverwertung nutzbringende Düngung oder preiswerte Abfallbeseitigung? Standpunkte und Argumente. 13. Wassertechnisches Seminar am 12.11.1987, TH Darmstadt, 1988	vergriffen
*WA*R 34	Automatisierung in der Wasserversorgung - auch für kleinere Unternehmen 14. Wassertechnisches Seminar am 09.06.1988, TH Darmstadt, 1988	33,20 €
*WA*R 35	Erkundung und Bewertung von Altlasten-Kriterien und Untersuchungsprogrammen. 15. Wassertechnisches Seminar am 12.10.1988, TH Darmstadt, 1989	vergriffen
*WA*R 36	Bestimmung des Sauerstoffzufuhrvermögens von Belüftungssystemen in Reinwasser und unter Betriebsbedingungen. Workshop am 15. u. 16.03.1988, TH Darmstadt, 1989	vergriffen
*WA*R 37	Belüftungssysteme in der Abwassertechnik - Fortschritte und Perspektiven. 16. Wassertechnisches Seminar am 10.11.1988, TH Darmstadt, 1989	vergriffen
*WA*R 38	Farinha, Joao António Muralha Ribeiro: Die stufenweise Versorgung mit Anlagen der Technischen Infrastruktur in Abhängigkeit von der Entwicklung der sozioökonomischen Verhältnisse der Bevölkerung - dargestellt am Beispiel der Bairros Clandestinos der Region Lissabon. Dissertation, FB 13, TH Darmstadt, 1989	vergriffen
*WA*R 39	Sicherstellung der Trinkwasserversorgung Maßnahmen und Strategien für einen wirksamen Grundwasserschutz zur langfristigen Erhaltung der Grundwassergewinnung. 17. Wassertechnisches Seminar am 01.06.1989, TH Darmstadt, 1989	33,20 €
*WA*R 40	Regenwassernutzung in privaten und öffentlichen Gebäuden - Qualitative und quantitative Aspekte, technische Anlagen. Studie für den Hessischen Minister für Umwelt und Reaktorsicherheit. TH Darmstadt, 1981	vergriffen

*WA*R 41	Folgenutzen kontaminierter Betriebsflächen unter besonderer Berücksichtigung der Sanierungsgrenzen. 18. Wassertechnisches Seminar am 11.10.1989, TH Darmstadt, 1989	vergriffen
*WA*R 42	Privatisierung öffentlicher Abwasseranlagen - Ein Gebot der Stunde? 19. Wassertechnisches Seminar am 09.11.1989, TH Darmstadt, 1989	30,70 €
*WA*R 43	Pöpel, H. Johannes; Joachim Glasenapp; Holger Scheer: Planung und Betrieb von Abwasserreinigungsanlagen zur Stickstoff-elimination. Gutachten für das Hess. Ministerium für Umwelt und Reaktorsicherheit. TH Darmstadt, 1990	35,80 €
*WA*R 44	Abfallentsorgung Hessen. Standpunkte - Gegensätze – Perspektiven. Abfallwirtschaftliches Symposium am 31.10.1989, TH Darmstadt, 1990	30,70 €
*WA*R 45	Brettschneider, Uwe: Die Bedeutung von Sulfaten in der Siedlungswasserwirtschaft und ihre Entfernung durch Desulfurikation. Dissertation, FB 13, TH Darmstadt, 1990	vergriffen
*WA*R 46	Grabenlose Verlegung und Erneuerung von nicht begehbaren Leitungen - Verfahren, Anwendungsgrenzen, Erfahrungen und Perspektiven. 20. Wassertechnisches Seminar am 29.03.1990, TH Darmstadt, 1990	35,80 €
*WA*R 47	Härtel, Lutz: Modellansätze zur dynamischen Simulation des Belebtschlamm-verfahrens. Dissertation, FB 13, TH Darmstadt, 1990	vergriffen
*WA*R 48	Pflanzenkläranlagen - besser als ihr Ruf? 21. Wassertechnisches Seminar am 18.09.1990, TH Darmstadt, 1990	vergriffen
*WA*R 49	Umweltverträglichkeitsprüfung (UVP) in der Wasserwirtschaft - administrativer Wildwuchs oder ökologische Keule? Dokumentation der Beiträge zum Interdisziplinären Kolloquium am 23.02.1990 und zum Sachverständigengespräch am 23.02.1990, TH Darmstadt, 1991	vergriffen
*WA*R 50	UVP in der abfallwirtschaftlichen Planung. 22. Wassertechnisches Seminar am 18.10.1990, TH Darmstadt, 1991	vergriffen

*WA*R 51	Biologische und chemische Phosphatelimination - Technische Möglichkeiten und Grenzen. 23. Wassertechnisches Seminar am 15.11.1990, TH Darmstadt, 1991	35,80 €
*WA*R 52	Pöpel, H. Johannes; Tankred Börner: Wurzelraum-Modellanlage Hofgeismar-Beberbeck - Pilotprojekt des Landes Hessen. Gutachten für das Hess. Ministerium für Umwelt und Reaktorsicherheit. TH Darmstadt, 1991	30,70 €
*WA*R 53	Wagner, Martin: Einfluß oberflächenaktiver Substanzen auf Stoffaustauschmechanismen und Sauerstoffeintrag. Dissertation, FB 13, TH Darmstadt, 1991	35,80 €
*WA*R 54	Belüftungssysteme in der Abwassertechnik 1991 - Fortschritte und Perspektiven. 1. gemeinsames Abwassertechnisches Seminar mit der Hochschule für Architektur und Bauwesen Weimar am 11. und 12.04. 1991 in Weimar, TH Darmstadt, 1991	30,70 €
*WA*R 55	Neuere gesetzliche Anforderungen und moderne technische Lösungen zur Sicherung der Wasserversorgung - Erkennen, Vermeiden und Beseitigen von Schadstoffen. 24. Wassertechnisches Seminar am 16.05.1991 TH Darmstadt, 1991	vergriffen
*WA*R 56	Zhang, Jiansan: Energiebilanzierung anaerob-mesophiler Stabilisierungsanlagen mit vorgeschalteter aerob-thermophiler Stufe. Dissertation, FB 13, TH Darmstadt, 1991	vergriffen
*WA*R 57	Glasenapp, Joachim: Leistungsfähigkeit und Wirtschaftlichkeit von Verfahrensvarianten zur Sickstoffelimination beim Belebtschlammverfahren. Dissertation, FB 13, TH Darmstadt, 1992	vergriffen
*WA*R 58	Börner, Tankred: Einflußfaktoren für die Leistungsfähigkeit von Pflanzenkläranlagen. Dissertation, FB 13, TH Darmstadt, 1992	vergriffen
*WA*R 59	Erzmann, Michael: Untersuchungen zur biologischen Elimination von chlorierten Lösemitteln aus Abwasser. Dissertation, FB 13, TH Darmstadt, 1992	35,80 €
*WA*R 60	Erfassung und Sanierung schadhafter Abwasserkanäle. 26. Wassertechnisches Seminar am 28.11.1991, TH Darmstadt, 1992	35,80 €

*WA*R 61	Realisierung von Entsorgungsanlagen Umsetzungsprobleme und Lösungsansätze aus planerischer, verwaltungsrechtlicher und politischer Sicht. 25. Wassertechnisches Seminar am 07.11.1991, TH Darmstadt, 1992	vergriffen
*WA*R 62	Koziol, Matthias: Umwelteffekte durch Förderung von Energieeinsparmaßnahmen in innerstädtischen Althausgebieten. Dissertation, FB 13, TH Darmstadt, 1992	25,60 €
*WA*R 63	Lautner, Gerd: Einführung in das Bauordnungsrecht. 7. erw. Auflage TH Darmstadt, 1992	vergriffen
*WA*R 64	Abwasserkanäle - Bemessung, Ausführung, Sanierung. 2. gemeinsames Seminar -Abwassertechnik- mit der Hochschule für Architektur und Bauwesen Weimar am 18. und 19.03.1992 in Weimar, TH Darmstadt, 1992	vergriffen
*WA*R 65	Optimierung der Grundwassergewinnung über Filterbrunnen Neue Bau- und Betriebserkenntnisse. 27. Wassertechnisches Seminar am 21.05.1992, TH Darmstadt, 1992	40,90 €
*WA*R 66	Kläschlammbehandlung und Klärschlammentsorgung -Stand und Entwicklungstendenzen. 31. Darmstädter Seminar -Abwassertechnik- am 12.11.1992, TH Darmstadt, 1992	35,80 €
*WA*R 67	Kreislaufwirtschaft Bau - Stand und Perspektiven beim Recycling von Baurestmassen. 32. Darmstädter Seminar -Abfalltechnik- am 09.03.1993, TH Darmstadt, 1993	30,70 €
*WA*R 68	Bewertung von Geruchsemissionen und –immissionen. 29. Darmstädter Seminar -Immissionsschutz- am 08.10.1992, TH Darmstadt, 1993	25,60 €
*WA*R 69	Möglichkeiten und Grenzen der Klärschlammentsorgung. 3. gemeinsames Seminar -Abwassertechnik- mit der Hochschule für Architektur und Bauwesen Weimar am 31.03. und 01.04.1993, TH Darmstadt, 1993	46,-- €
*WA*R 70	Sichere Wasserversorgung durch moderne Rohrleitungstechnik. 33. Darmstädter Seminar -Wasserversorgungstechnik- am 11.03.1993, TH Darmstadt, 1993	30,70 €

*WA*R 71	Aktuelle Aufgaben der Abwasserreinigung und Schlammbehandlung. 35. Darmstädter Seminar -Abwassertechnik- am 05. + 06.05.1993, TH Darmstadt, 1993	46,-- €
*WA*R 72	Raumordnungsverfahren mit Umweltverträglichkeitsprüfung und Umweltleitbilder für die Landes- und Regionalplanung. 28. und 30. Darmstädter Seminar -Raumplanung- am 17.09. und 05.11.1992, TH Darmstadt, 1993	40,90 €
*WA*R 73	Grohmann, Walter: Vergleichende Untersuchungen von Belüftungs- und Durchmischungssystemen zur bioverfahrenstechnischen Optimierung der aerob-thermophilen Stabilisation (ATS). Dissertation, FB 13, TH Darmstadt, 1993	35,80 €
*WA*R 74	Dioxinimmissionen und Quellen . 34. Darmstädter Seminar -Immissionsschutz- am 15.04.1993, TH Darmstadt, 1994	30,70 €
*WA*R 75	Betrieb von Abwasserbehandlungsanlagen Optimierung, Prozeßstabilität, Kosteneinsparung. 36. Darmstädter Seminar -Abwassertechnik- am 04.11.1993 in Darmstadt und 5. gemeinsames Seminar -Abwassertechnik- mit der Fakultät Bauingenieurwesen der Hochschule für Architektur und Bauwesen Weimar am 23. und 24.03.1994 in Weimar, TH Darmstadt, 1994	46,-- €
*WA*R 76	Umweltgerechte Ausweisung und Erschließung von Gewerbegebieten. 4. gemeinsames Seminar -Umwelt- und Raumplanung- mit der Fakultät Architektur, Stadt- und Regionalplanung der Hochschule für Architektur und Bauwesen Weimar am 08. und 09.09.1993 in Weimar, TH Darmstadt, 1994	vergriffen
*WA*R 77	Von der Umweltverträglichkeitsprüfung zum kooperativen Planungsmanagement. Das Scoping-Verfahren als erste Stufe!? 37. Darmstädter Seminar -Umwelt- und Raumplanung- am 11.11.1993, TH Darmstadt, 1994	vergriffen
*WA*R 78	Modellbildung und intelligente Steuerungssysteme in der Umwelttechnik. 38. Darmstädter Seminar -Abfalltechnik- am 24.02.1994, TH Darmstadt, 1994	25,60 €
*WA*R 79	Brauchwassernutzung in Haushalten und Gewerbebetrieben - Ein Gebot der Stunde? 39. Darmstädter Seminar -Wasserversorgungstechnik- am 17.03.1994, TH Darmstadt, 1994	25,60 €

*WA*R 80	Restabfallbehandlung in Hessen. 41. Darmstädter Seminar -Abfalltechnik- mit dem Hessischen Ministerium für Umwelt, Energie und Bundesangelegenheiten -HMUEB- am 16.06.1994, TH Darmstadt, 1994	vergriffen
*WA*R 81	Umweltbeeinflussung durch biologische Abfallbehandlungsverfahren. 42. Darmstädter Seminar -Abfalltechnik- mit dem Institut für Hygiene der FU Berlin und dem Institut für Meteorologie der TH Darmstadt am 08. und 09.09.1994 in Berlin, TH Darmstadt, 1994	46,-- €
*WA*R 82	Zeitgemäße Planung von Anlagen der Ortsentwässerung - Kanäle, Bauwerke, Sonderbauwerke. 6. gemeinsames Seminar -Abwassertechnik- mit der Fakultät Bauingenieurwesen der Hochschule für Architektur und Bauwesen Weimar am 15. und 16.03.1995 in Weimar, TH Darmstadt, 1995	vergriffen
*WA*R 83	Grundwasseranreicherung - Stand der Technik und neuere Entwicklungen. 44. Darmstädter Seminar -Wasserversorgungstechnik- mit dem Verein des Gas- und Wasserfaches e.V. -DVGW- am 26.04.1994, TH Darmstadt, 1995	30,70 €
*WA*R 84	Auswirkungen der Phosphorelimination auf die Schlammbehandlung. Theoretische Erkenntnisse und praktische Erfahrungen. Workshop vom 24. bis 25. November 1994, TH Darmstadt, 1995	30,70 €
*WA*R 85	Stickstoffelimination mit oder ohne externe Substrate ? - Erfahrungen und Überlegungen. 43. Darmstädter Seminar -Abwassertechnik- in Abstimmung mit der Abwassertechnischen Vereinigung e.V. (ATV) am 09.11.1994, TH Darmstadt, 1995	35,80 €
*WA*R 85	Stickstoffelimination mit oder ohne externe Substrate ? - Erfahrungen und Überlegungen. 2. Auflage. Wiederholung des 43. Darmstädter Seminars -Abwassertechnik- in Abstimmung mit der Abwassertechnischen Vereinigung e.V. (ATV) am 01.02.1996 in Düsseldorf, TH Darmstadt, 1996	35,80 €
*WA*R 86	Möglichkeiten und Grenzen der Einsparung von Investitions- und Betriebskosten bei der Abwasserbehandlung. 47. Darmstädter Seminar -Abwassertechnik- am 15.11.1995, TH Darmstadt, 1995	40,90 €

*WA*R 87	Jardin, Norbert: Untersuchungen zum Einfluß der erhöhten biologischen Phosphor-elimination auf die Phosphordynamik bei der Schlammbehandlung. Dissertation, FB 13, TH Darmstadt, 1996	35,80 €
*WA*R 88	Thermische Restabfallbehandlung für kleine Planungsräume. 45. Darmstädter Seminar -Abfalltechnik- am 22.06.1995 in Hanau, TH Darmstadt, 1996	35,80 €
*WA*R 89	Ferber, Uwe: Aufbereitung und Revitalisierung industrieller Brachflächen in den traditionellen Industrieregionen Europas. Sonderprogramme im Vergleich. Dissertation, FB 13, TH Darmstadt 1996	25,60 €
*WA*R 90	Mechanisch-biologische Restabfallbehandlung unter Einbindung thermischer Verfahren für Teilfraktionen. 48. Darmstädter Seminar -Abfalltechnik- am 29.02.1996, TH Darmstadt, 1996	vergriffen
*WA*R 91	Neuere Erkenntnisse bei Planung, Bau, Ausrüstung und Betrieb von Abwasserbehandlungsanlagen. 7. gemeinsames Seminar -Abwassertechnik- mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar am 11. und 12.09.1996 in Weimar, TH Darmstadt, 1996	40,90 €
*WA*R 92	Hygiene in der Abfallwirtschaft. 50. Darmstädter Seminar -Abfalltechnik- am 17.10.1996, TH Darmstadt, 1996	30,70 €
*WA*R 93	Europäische Richtlinien und Normen zur Abwassertechnik - Konsequenzen und Folgerungen für die Praxis in Deutschland. 51. Darmstädter Seminar -Abwassertechnik- am 14.11.1996, TH Darmstadt, 1996	25,60 €
*WA*R 94	Dickhaut, Wolfgang: Möglichkeiten und Grenzen der Erarbeitung von Umwelt-qualitätszielkonzepten in kooperativen Planungsprozessen. Durchführung und Evaluierung von Projekten. Dissertation, FB 13, TH Darmstadt 1996	30,70 €
*WA*R 95	Lautner, Gerd: Einführung in das Bauordnungsrecht. 8. erw. und aktual. Auflage, TH Darmstadt, 1997	15,40 €
*WA*R 96	Reichert, Joachim: Bilanzierung des Sauerstoffeintrags und des Sauerstoffverbrauchs mit Hilfe der Abluftmethode. Dissertation, FB 13, TH Darmstadt 1997	46,-- €

*WA*R 97	Kuchta, Kerstin: Produktion von Qalitätsgütern in der Abfallbehandlung. Dargestellt am Beispiel der Produktion in der thermischen Abfallbehandlung. Dissertation, FB 13, TH Darmstadt 1997	30,70 €
*WA*R 98	Görg, Horst: Entwicklung eines Prognosemodells für Bauabfälle als Baustein von Stoffstrombetrachtungen zur Kreislaufwirtschaft im Bauwesen. Dissertation, FB 13, TH Darmstadt, 1997	46,-- €
*WA*R 99	Tiebel-Pahlke, Christoph: Abfallentsorgungsplanung – Beeinflussung der Umweltauswirkungen von Deponien. Dissertation, FB 13, TH Darmstadt, 1997	30,70 €
*WA*R 100	Wagner, Martin: Sauerstoffeintrag und Sauerstoffertrag von Belüftungssystemen und deren Bestimmung mit modernen Meßmethoden. Habilitation, FB 13, TH Darmstadt, 1997	vergriffen
*WA*R 101	Neue Trends bei der Behandlung und Entsorgung kommunaler und industrieller Klärschlämme. 8. gemeinsames Seminar -Abwassertechnik- mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar am 10. und 11.09.1997 in Weimar, TH Darmstadt, 1997	35,80 €
*WA*R 102	Senkung der Betriebskosten von Abwasserbehandlungsanlagen. 52. Darmstädter Seminar -Abwassertechnik- am 06.11.1997 in Darmstadt, TU Darmstadt, 1997	35,80 €
*WA*R 103	Sanierung und Rückbau von Bohrungen, Brunnen und Grundwasser-messstellen. 53. Darmstädter Seminar -Wasserversorgung- am 13.11.1997 in Darmstadt mit dem Deutschen Verein des Gas- und Wasserfaches e.V. (DVGW), TU Darmstadt, 1997	vergriffen
*WA*R 104	Wünschmann, Gabriele: Untersuchungen zur Kompostierbarkeit von Reststoffen der Papier-industrie und Altpapier unter besonderer Berücksichtigung von Schad-stoffbilanzierungen. Dissertation, FB 13, TU Darmstadt, 1997	25,60 €

*WA*R 105	Mechanisch-biologische Restabfallbehandlung unter Einbindung thermischer Verfahren für Teilfraktionen. 54. Darmstädter Seminar -Abfalltechnik- am 06.02.1998 in Darmstadt mit dem Hessischen Ministerium für Umwelt, Energie, Jugend, Familie und Gesundheit und der Südhessischen Arbeitsgemeinschaft Abfall-wirtschaft (SAGA), TU Darmstadt, 1998	40,90 €
*WA*R 106	Zentrale oder dezentrale Enthärtung von Trinkwasser – Konkurrenz oder sinnvolle Ergänzung ? 55. Darmstädter Seminar -Wasserversorgung- am 14.05.1998 in Darmstadt mit dem Deutschen Verein des Gas- und Wasserfaches e.V. (DVGW), TU Darmstadt, 1998	35,80 €
*WA*R 107	Dach, Joachim: Zur Deponiegas- und Temperaturentwicklung in Deponien mit Siedlungsabfällen nach mechanisch-biologischer Abfallbehandlung. Dissertation, FB 13, TU Darmstadt, 1998	35,80 €
*WA*R 108	Einsparung von Kosten für Betriebsmittel, Energie und Personal auf Abwasserbehandlungsanlagen. 9. gemeinsames Seminar -Abwassertechnik- am 16. und 17.09.1998 in Weimar mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar, TU Darmstadt, 1998	40,90 €
*WA*R 109	Fortschritte in der Abwassertechnik – 15 Jahre Forschungs- und Entwicklungstätigkeit von Prof. Dr.-Ing. H. Johannes Pöpel. 56. Darmstädter Seminar -Abwassertechnik- am 05.11.1998 in Darmstadt, TU Darmstadt, 1998	40,90 €
*WA*R 110	Qualitativer und Quantitativer Grundwasserschutz - Stand und Perspektiven. 57. Darmstädter Seminar -Wasserversorgung- am 10.06.1999 in Darmstadt mit dem Deutschen Verein des Gas- und Wasserfaches e.V. (DVGW), TU Darmstadt, 1999	35,80 €
*WA*R 111	Schwing, Elke: Bewertung der Emissionen der Kombination mechanisch-biologischer und thermischer Abfallbehandlungsverfahren in Südhessen. Dissertation, FB 13, TU Darmstadt, 1999	30,70 €
*WA*R 112	Schade, Bernd: Kostenplanung zur Analyse der Wirtschaftlichkeit von biologischen Restabfallbehandlungsanlagen. Dissertation, FB 13, TU Darmstadt, 1999	30,70 €

*WA*R 113	Lohf, Astrid: Modellierung der chemisch-physikalischen Vorgänge im Müllbett von Rostfeuerungsanlagen. Dissertation, FB 13, TU Darmstadt, 1999	25,60 €
*WA*R 114	Stackelberg, Daniel von: Biologische Festbettdenitrifikation von Grundwasser mit abbaubarem Trägermaterial. Dissertation, FB 13, TU Darmstadt, 1999	30,70 €
*WA*R 115	Folgerungen aus 10 Jahren Abwasserbeseitigung in den neuen Bundesländern - Erfahrungen und Perspektiven. 10. gemeinsames Seminar –Abwassertechnik- am 01. und 02.09.1999 in Weimar mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar, TU Darmstadt, 1999	40,90 €
*WA*R 116	Abwasserwiederverwendung in wasserarmen Regionen - Einsatzgebiete, Anforderungen, Lösungsmöglichkeiten. 58. Darmstädter Seminar –Abwassertechnik- am 11.11.1999 in Darmstadt, TU Darmstadt, 1999	vergriffen
*WA*R 117	Reinhardt, Tim: Untersuchungen zur Dynamik biologischer Prozesse in drei-Phasen-Systemen am Beispiel der Restabfallrotte unter besonderer Berück-sichtigung anaerober Teilprozesse. Dissertation, FB 13, TU Darmstadt, 1999	30,70 €
*WA*R 118	Umweltfachpläne und Umweltgesetzbuch - Ein Beitrag zur Fortentwicklung des Umweltfachplanungssystems und „Von der Landschaftsplanung zur Umweltleitplanung?“ 46. Darmstädter Seminar -Umwelt- und Raumplanung- am 28.09.1995 in Darmstadt, TU Darmstadt, 1999	30,70 €
*WA*R 119	Herr, Christian: Innovative Analyse und primärseitige Prozeßführungsoptimierung thermischer Abfallbehandlungsprozesse - am Beispiel der Mülleingangs-klassifizierung bei der Rostfeuerung. Dissertation, FB 13, TU Darmstadt, 2000	33,20 €
*WA*R 120	Neumüller, Jürgen: Wirksamkeit von Grundwasserabgaben für den Grundwasserschutz - am Beispiel des Bundeslandes Hessen. Dissertation, FB 13, TU Darmstadt, 2000	35,80 €
*WA*R 121	Hunklinger, Ralph: Abfalltechnische Kennzahlen zur umweltgerechten Produktentwicklung. Dissertation, FB 13, TU Darmstadt, 2000	30,70 €

*WA*R 122	Wie zukunftsfähig sind kleinere Wasserversorgungsunternehmen? 60. Darmstädter Seminar -Wasserversorgung- am 29. Juni 2000 in Darmstadt, TU Darmstadt, 2000	35,80 €
*WA*R 123	Maßnahmen zur Betriebsoptimierung von Pumpwerken, Kanalisationssystemen und Abwasserbehandlungsanlagen. 11. gemeinsames Seminar -Abwassertechnik- in Weimar am 20. und 21. September 2000 mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar, TU Darmstadt, FB 13, 2000	40,90 €
*WA*R 124	Mohr, Karin: Entwicklung einer on-line Emissionsmeßtechnik zur quasi-kontinuierlichen Bestimmung von Organohalogen-Verbindungen in Abgasen thermischer Prozesse. Dissertation, FB 13, TU Darmstadt, 2000	30,70 €
*WA*R 125	El-Labani, Mamoun: Optimierte Nutzung bestehender Abfallverbrennungsanlagen durch Errichtung vorgeschalteter Reaktoren zur Behandlung heizwertreicher Abfälle. Dissertation, FB 13, TU Darmstadt, 2000	25,60 €
*WA*R 126	Durth, Anke: Einfluß von Temperatur, Anlagenkonfiguration und Auslastung auf die Ablaufkonzentration bei der biologischen Abwasserreinigung. Dissertation, FB 13, TU Darmstadt, 2000	vergriffen
*WA*R 127	Meyer, Ulrich: Untersuchungen zum Einsatz von Fuzzy-Control zur Optimierung der Stickstoffelimination in Abwasserbehandlungsanlagen mit vorgeschalteter Denitrifikation. Dissertation, FB 13, TU Darmstadt, 2000	33,20 €
*WA*R 128	Kommunale Klärschlammbehandlung vor dem Hintergrund der neuen europäischen Klärschlammrichtlinie. 61. Darmstädter Seminar -Abwassertechnik- am 09.11.2000 in Darmstadt, TU Darmstadt, FB 13, 2000	35,80 €
*WA*R 129	Mengel, Andreas: Stringenz und Nachvollziehbarkeit in der fachbezogenen Umweltplanung. Dissertation, FB 13, TU Darmstadt, 2001	46,-- €

*WA*R 130	Kosteneinsparungen durch neuartige Automatisierungstechniken in der Wasserversorgung. 62. Darmstädter Seminar -Wasserversorgung- am 07.06.2001 in Darmstadt, TU Darmstadt, FB 13, 2001	30,70 €
*WA*R 131	Aktive Zukunftsgestaltung durch Umwelt- und Raumplanung. Festschrift zum 60. Geburtstag von Prof. Dr.-Ing. Hans Reiner Böhm. TU Darmstadt, FB 13, 2001	25,60 €
*WA*R 132	Aktuelle Ansätze bei der Klärschlammbehandlung und -entsorgung. 12. gemeinsames Seminar -Abwassertechnik- in Weimar am 05. und 06. September 2001 mit der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar, TU Darmstadt, FB 13, 2001	40,90 €
*WA*R 133	Zum Bodenwasser- und Stoffhaushalt auf unterschiedlich bewirtschafteten Flächen unter Einbeziehung ökonomischer Aspekte Interdisziplinäre Projektstudie der Technischen Universität Darmstadt (TUD) mit Partner. TU Darmstadt, FB 13, 2001	30,70 €
*WA*R 134	Neues zur Belüftungstechnik - Probleme, Lösungsmöglichkeiten, Entwicklungen. 64. Darmstädter Seminar -Abwassertechnik- am 15.11.2001 in Darmstadt, TU Darmstadt, FB 13, 2001	35,-- €
*WA*R 135	Auswirkungen der Verordnung über die umweltverträgliche Ablagerung von Siedlungsabfällen und über biologische Abfallbehandlungsanlagen. 63. Darmstädter Seminar -Abfalltechnik- am 12. und 13.11.2001 in Darmstadt, TU Darmstadt, FB 13, 2001	35,-- €
*WA*R 136	Bockreis, Anke: Infrarot-Thermographie zur Überwachung von Flächenbiofiltern. Dissertation, FB 13, TU Darmstadt, 2001	35,-- €
*WA*R 137	Luft, Cornelia: Luftgetragene mikrobielle Emissionen und Immissionen an aeroben mechanisch-biologischen Abfallbehandlungsanlagen. Dissertation, FB 13, TU Darmstadt, 2002	30,-- €
*WA*R 138	Danhamer, Harald: Emissionsprognosemodell für Deponien mit mechanisch-biologisch vorbehandelten Abfällen - Schwerpunkt: Modellierung des Gashaushaltes. Dissertation, FB 13, TU Darmstadt, 2002	25,-- €

*WA*R 139	Lieth, Sabine: Stickstoffelimination aus kommunalem Abwasser mit getauchten Festbetten nach Vorbehandlung mit HCR-Reaktoren. Dissertation, FB 13, TU Darmstadt, 2002	35,-- €
*WA*R 140	Streit, Hans-Ulrich: Optimierung des Kombinationsbetriebs eines Advanced Oxidation Process mit einer Stripp-Anlage zur Grundwassersanierung. Dissertation, FB 13, TU Darmstadt, 2002	vergriffen
*WA*R 141	Spura, Patrik: Ein Vergleich des anlagebezogenen tschechischen Luftreinehalterechts mit jenem der Europäischen Union vor dem Hintergrund des anstehenden Beitritts. Dissertation, Univ. Frankfurt a.M., 2002	40,-- €
*WA*R 142	Hilligardt, Jan: Nachhaltige Regionalentwicklung durch freiwillige regionale Kooperation - Faktoren einer erfolgreichen Initiierung untersucht an der Region Starkenburg. Dissertation, FB 13, TU Darmstadt, 2002	30,-- €
*WA*R 143	Heiland, Peter: Vorsorgender Hochwasserschutz durch Raumordnung, interregionale Kooperation und ökonomischen Lastenausgleich. Dissertation, FB 13, TU Darmstadt, 2002	vergriffen
*WA*R 144	Dapp, Klaus: Informationsmanagement in der Planung am Beispiel des vorsorgenden Hochwasserschutzes. Dissertation, FB 13, TU Darmstadt, 2002	vergriffen
*WA*R 145	Schüler, Doris: Untersuchungen an der Technikumsanlage VERONA zur Bildung und zum Abbau von polyhalogenierten Dioxinen und Furanen und anderen Organohalogenverbindungen in Verbrennungsprozessen. Dissertation, FB 13, TU Darmstadt, 2002	25,-- €
*WA*R 146	Grundwasserproblematik im Hessischen Ried : Eine unlösbare Aufgabe? 65. Darmstädter Seminar -Wasserversorgung- am 23.10.2002 in Darmstadt, TU Darmstadt, FB 13, 2002	30,-- €
*WA*R 147	Rückgewinnung von Phosphor aus Klärschlamm und Klärschlammasche. 66. Darmstädter Seminar -Abwassertechnik- am 07.11.2002 in Darmstadt, TU Darmstadt, FB 13, 2002	35,-- €

*WA*R 148	Schneider, Andreas: Role of LCA concepts at the Research and Development phase of a new process for waste treatment - The Trefoil Kiln process subject to IPPC and BAT requirements. Dissertation, FB 13, TU Darmstadt, 2002	25,-- €
*WA*R 149	Sonnenburg, Alexander: Untersuchungen zur Denitrifikation von Grundwasser in Schüttungen mit abbaubarem Trägermaterial. Dissertation, FB 13, TU Darmstadt, 2002	vergriffen
*WA*R 150	Emissionen aus der Abfallbehandlung. Energie - Emissionen – Messtechnik. 67. Darmstädter Seminar -Abfalltechnik- am 13. Februar 2003 in Darmstadt, TU Darmstadt, FB 13, 2003	35,-- €
*WA*R 151	Rationalisierungsmaßnahmen in der Wasserversorgung. Umsetzungsstatus und künftige Entwicklungen. 68. Darmstädter Seminar -Wasserversorgung- am 15. Oktober 2003 in Darmstadt, TU Darmstadt, FB 13, 2003	vergriffen
*WA*R 152	Verantwortungspartnerschaft beim vorsorgenden Hochwasserschutz. 69. Darmstädter Seminar - Umwelt- und Raumplanung - am 16. Oktober 2003 in Darmstadt, TU Darmstadt, FB 13, 2003	vergriffen
*WA*R 153	Biofiltration. Renaissance eines Verfahrens durch erhöhte Anforderungen im In- und Ausland ? 70. Darmstädter Seminar -Abwassertechnik- am 06. November 2003 in Darmstadt, TU Darmstadt, FB 13, 2003	35,-- €
*WA*R 154	Seiler, Kainan: Planung der Abwasserentsorgung im ländlichen Raum anhand von räumlichen Einflussfaktoren. Dissertation, FB 13, TU Darmstadt, 2004	30,-- €
*WA*R 155	Ludwig, Thomas: Entwicklung der Emissionsmessanlage DioxinCop. Dissertation, FB 13, TU Darmstadt, 2004	25,-- €
*WA*R 156	Haffner, Yvonne: Sozialwissenschaftliche Modellierung zur Privatisierung der Wasserversorgung. Dissertation, FB 2, TU Darmstadt, 2004	vergriffen

*WA*R 157	Geruch : Messung – Wirkung – Minderung. 71. Darmstädter Seminar -Abfalltechnik- am 24. Juni 2004 in Darmstadt, TU Darmstadt, FB 13, 2004	35,-- €
*WA*R 158	Qualitätssicherung bei Wassergewinnungsanlagen - Umsetzung und aktuelle Entwicklung im Regelwerk. 72. Darmstädter Seminar –Wasserversorgung– am 06.10.2004 in Darmstadt, TU Darmstadt, 2004	vergriffen
*WA*R 159	Wasserwiederverwendung - eine ökologische und ökonomische Notwendigkeit wasserwirtschaftlicher Planung weltweit ? 73. Darmstädter Seminar –Abwassertechnik– am 04.11.2004 in Darmstadt, TU Darmstadt, 2004	vergriffen
*WA*R 160	Weil, Marcel: Ressourcenschonung und Umweltentlastung bei der Betonherstellung durch Nutzung von Bau- und Abbruchabfällen. Dissertation, FB 13, TU Darmstadt, 2004	35,-- €
*WA*R 161	Unendlicher Wachstum auf unendlicher Fläche ? 74. Darmstädter Seminar –Umwelt- und Raumplanung– am 27.01.2005 in Darmstadt, TU Darmstadt, 2005	vergriffen
*WA*R 162	Gernuks, Marko: Entwicklung einer Methode zur Bewertung von Umweltaspekten mit der Ableitung von Umweltzielen im Rahmen von EMAS. Dissertation, FB 13, TU Darmstadt, 2004	vergriffen
*WA*R 163	Rother, Elmar: Optimising Design and Operation of the Biofiltration Process for Municipal Wastewater Treatment. Dissertation, FB 13, TU Darmstadt, 2005	35,-- €
*WA*R 164	Hilligardt, Jan: Regionale Kooperation der Landkreise, Städte und Gemeinden. Stand - Potenziale - Perspektiven. Habilitation, FB 13, TU Darmstadt, 2005	vergriffen
*WA*R 165	Gramel, Stefan: Privatisierung von Wasserversorgungsunternehmen - Auswirkungen auf den Umwelt- und Ressourcenschutz? Dissertation, FB 13, TU Darmstadt, 2004	35,-- €
*WA*R 166	Krause, Stefan: Untersuchungen zum Energiebedarf von Membranbelebungsanlagen. Dissertation, FB 13, TU Darmstadt, 2005	35,-- €

*WA*R 167	Rückgewinnung von Phosphor aus Abwasser und Klärschlamm. Konzepte - Verfahren - Entwicklungen. 75. Darmstädter Seminar –Abwassertechnik- am 12./13.12.2005 in Darmstadt, TU Darmstadt, 2005	vergriffen
*WA*R 168	Hora, Maike: Abfallverursacher Elektrogeräte. Ansätze zur prospektiven Bilanzierung von Abfallströmen in der umweltgerechten Produktentwicklung. Dissertation, FB 13, TU Darmstadt, 2005	30,-- €
*WA*R 169	Zhang, Wensheng: Ökologische siedlungswasserwirtschaftliche Konzepte für urbane Räume Chinas unter Berücksichtigung deutscher Techniken und Erfahrungen. Dissertation, FB 13, TU Darmstadt, 2005	30,-- €
*WA*R 170	Steinberg, Iris: Untersuchungen zur Effizienzsteigerung von biologischen und nicht-thermischen Abluftreinigungsverfahren bei der biologischen Abfall-behandlung. Dissertation, FB 13, TU Darmstadt, 2005	30,-- €
*WA*R 171	Haupter, Birgit: Transnationale Förderprogramme zur Raumentwicklung. Untersuchungen zur Wirkung für die räumliche Planung zum Hochwasserschutz. Dissertation, FB 13, TU Darmstadt, 2006	35,-- €
*WA*R 172	Ott, Carsten: Straßenkehrichtentsorgung: Anlagenkonzept und Nachhaltig-keitsanalyse. Dissertation, FB 13, TU Darmstadt, 2006	30,-- €
*WA*R 173	1 Jahr Abfallablagerungsverordnung - Wo bleibt der Müll? 76. Darmstädter Seminar –Abfalltechnik– am 1.06.2006 in Darmstadt, TU Darmstadt, 2006	35,-- €
*WA*R 174	Wachstumsregion - Handlungsansätze für mehr Nachhaltigkeit. 77. Darmstädter Seminar –Umwelt- und Raumplanung– am 11.09.2006 in Darmstadt, TU Darmstadt, 2006	30,-- €
*WA*R 175	Interdisziplinarität in der Umwelt- und Raumplanung - Theorie und Praxis. *Festschrift für Professor Böhm* TU Darmstadt, 2006	40,-- €

*WA*R 176	Neue maschinen- und verfahrenstechnische Möglichkeiten zur Einsparung von Betriebskosten bei der Abwasserbehandlung. 78. Darmstädter Seminar -Abwassertechnik- am 02.11.2006 in Darmstadt, TU Darmstadt, 2006	35,-- €
*WA*R 177	Einsparpotenziale in der Trinkwasserversorgung durch Optimierung von Wasserverteilungsnetzen. 79. Darmstädter Seminar –Wasserversorgung- am 05.10.2006 in Darmstadt, TU Darmstadt, 2006	30,-- €
*WA*R 178	Meyer, Lutz: Exergiebasierte Untersuchung der Entstehung von Umweltbelastungen in Energieumwandlungsprozessen auf Komponentenebene: Exergoökologische Analyse. Dissertation, FB 13, TU Darmstadt, 2006	35,--
*WA*R 179	Gasafi, Edgar: Entwicklung einer lebenswegbasierten Screening-Methode zur Entscheidungsunterstützung in frühen Phasen der Verfahrens-entwicklung. Dissertation, FB 13, TU Darmstadt, 2006	35,-- €
*WA*R 180	Treskatis, Christoph: Bewirtschaftung von Grundwasserressourcen - Planung, Bau und Betrieb von Grundwasserfassungen. Habilitation, FB 13, TU Darmstadt, 2006	45,-- €
*WA*R 181	Uihlein, Andreas: Modellierung der Kohlenstoffströme zur Untersuchung der Nutzung von Kohlenstoffträgern in Deutschland. Dissertation, FB 13, TU Darmstadt, 2006	vergriffen
*WA*R 182	den Boer, Emilia: A Novel Approach for Integrating Heavy Metals Emissions from Landfills into Life Cycle Assessment - Consideration of Waste Pretreatment, Landfill Processes and Long-Term Effects Dissertation, FB 13, TU Darmstadt, 2006	30,-- €
*WA*R 183	Klimawandel - Anpassungsstrategien in Deutschland und Europa. 80. Darmstädter Seminar -Umwelt- und Raumplanung- am 29.03.2007 in Darmstadt, TU Darmstadt, 2007	25,-- €
*WA*R 184	Stephan, Henrik: Bewertungsmethodik für Fertigungsverfahren im Karosseriebau aus Sicht des betrieblichen Umweltschutzes. Dissertation, FB 13, TU Darmstadt, 2007	vergriffen

*WA*R 185	Schaum, Christian A.: Verfahren für eine zukünftige Klärschlammbehandlung –Klärschlamm-konditionierung und Rückgewinnung von Phosphor aus Klärschlamm-asche. Dissertation, FB 13, TU Darmstadt, 2007	35,-- €
*WA*R 186	Rohde, Clemens: Milchsäurefermentation von biogenen Abfällen. Dissertation, FB 13, TU Darmstadt, 2007	35,-- €
*WA*R 187	Risikoanalyse von Trinkwassereinzugsgebieten und Fassungen. 81. Darmstädter Seminar -Wasserversorgung- am 11.10.2007 in Darmstadt, TU Darmstadt, 2007	30,-- €
*WA*R 188	Cangahuala Janampa, Ana: Wasserverlustmanagement in Wasserverteilungsanlagen in Entwicklungs- ländern am Beispiel von Peru. Anwendung verschiedener Methoden zur multikriteriellen Entscheidungsunterstützung. Dissertation, FB 13, TU Darmstadt, 2007	vergriffen
*WA*R 189	Pollmann, Olaf: Optimierung anthropogener Stoffströme am Beispiel des Papier-recyclings. Dissertation, FB 13, TU Darmstadt, 2007	vergriffen
*WA*R 190	Wie sieht die Abwasserbehandlung der Zukunft aus? -Vierte, fünfte, sechste Reinigungsstufe? 82. Darmstädter Seminar -Abwassertechnik- am 15.11.2007 in Darmstadt, TU Darmstadt, 2007	35,-- €
*WA*R 191	Koffler, Christoph: Automobile Produkt-Ökobilanzierung. Dissertation, FB 13, TU Darmstadt, 2007	35,-- €
*WA*R 192	Koch, Michael: Untersuchungen zum Einfluss der Energiedissipationsdichte auf Reaktionsabläufe im "Highloaded Compact Reactor" (HCR®). Dissertation, FB 13, TU Darmstadt, 2007	35,-- €
*WA*R 193	den Boer, Jan: Sustainability Assessment for Waste Management Planning - Development and Alternative Use of the LCA-IWM Waste Management System Assessment Tool. Dissertation, FB 13, TU Darmstadt, 2007	30,-- €

*WA*R 194	Biogas - Klimaretter oder Ressourcenverschwender. 83. Darmstädter Seminar -Abfalltechnik- am 11.12.2007 in Darmstadt, TU Darmstadt, 2007	vergriffen
*WA*R 195	Scheck, Natalie: Die Strategische Umweltprüfung als Instrument zur Förderung einer nachhaltigen Entwicklung - Untersuchung am Beispiel der Regionalplanung Südhessen. Dissertation, FB 13, TU Darmstadt, 2007	30,-- €
*WA*R 196	Klimawandel – Markt für Strategien und Technologien?! 84. Darmstädter Seminar -Abfalltechnik und Umwelt- und Raumplanung- am 26.06.2008 in Darmstadt, TU Darmstadt, 2008	vergriffen
*WA*R 197	Hähnlein, Christian: Numerische Modellierung zur Betriebsoptimierung von Wasserverteilnetzen. Dissertation, FB 13, TU Darmstadt, 2008	30,-- €
*WA*R 198	Berger, Jan: Biologische Methanoxidation in Deponieabdeckschichten. Dissertation, FB 13, TU Darmstadt, 2008	35,-- €
*WA*R 199	Wellge, Steffen: Evaluation von betrieblichen Umweltmanagementsystemen. Dissertation, FB 13, TU Darmstadt, 2009	35,-- €
*WA*R 200	Bieker, Susanne: Semizentrale Ver- und Entsorgungssysteme: neue Lösungen für schnell wachsende urbane Räume. Untersuchung empfehlenswerter Größenordnungen. Dissertation, FB 13, TU Darmstadt, 2009	35,-- €
*WA*R 201	Hoffmann, Karl Peter: Reduzierung von CO_2-Emissionen durch den Einsatz von Erdgas aus Biogas in dezentralen Stirling-KWK-Anlagen. Dissertation, FB 13, TU Darmstadt, 2009	35,-- €
*WA*R 202	Loock, Peter: Veränderung der Leistungsfähigkeit feinblasiger Membranbelüftungselemente unter abwassertechnischen Betriebsbedingungen. Dissertation, FB 13, TU Darmstadt, 2009	35,-- €
*WA*R 203	Warsen, Jens: Validierung von Stoffflussdaten in der Ökobilanz durch Daten aus dem öffentlichen Berichtswesen. Dissertation, FB 13, TU Darmstadt, 2009	35,-- €

*WA*R 204	Klärschlammfaulung und –verbrennung: das Behandlungskonzept der Zukunft? 85. Darmstädter Seminar -Abwassertechnik- am 13.04.2010 in Darmstadt, TU Darmstadt, 2010	35,-- €
*WA*R 205	Neue Herausforderungen und Chancen in der Wasserversorgung. Darmstädter Seminar -Wasserversorgung und Grundwasserschutz- im Rahmen des 1. Darmstädter Ingenieurkongresses Bau und Umwelt am 14. und 15.09.2009 in Darmstadt, TU Darmstadt, 2010	35,-- €
*WA*R 206	Pennekamp, Sandra: Raumentwicklung im Spannungsfeld zwischen Wachstum und Schrumpfung - was können überregionale Partnerschaften leisten? Dissertation, FB 13, TU Darmstadt, 2010	35,-- €
*WA*R 207	Frommer, Birte: Regionale Anpassungsstrategien an den Klimawandel – Akteure und Prozess. Dissertation, FB 13, TU Darmstadt, 2010	35,-- €
IWAR 208	Chang, Yue: Greywater treatment within semi-centralised supply and treatment systems by the example of the People’s Republic of China. Dissertation, FB 13, TU Darmstadt, 2010	35,-- €
IWAR 209	Sakaguchi-Söder, Kaori: A new method for compound-specific stable chlorine isotope analysis. Dissertation, FB 13, TU Darmstadt, 2010	35,-- €
IWAR 210	Henkel, Jochen: Oxygen transfer phenomena in activated sludge. Dissertation, FB 13, TU Darmstadt, 2010	35,-- €
IWAR 211	Doktorandenschule Abfall 2010 Manigod / Frankreich, 5. - 8. September 2010, TU Darmstadt, 2011	40,-- €
IWAR 212	Preis und Leistung - Wasserversorgung bewerten und vergleichen. 86. Darmstädter Seminar -Wasserversorgung- am 22.02.2011 in Darmstadt, TU Darmstadt, 2011	30,-- €
IWAR 213	Siembida-Lösch, Barbara: Reduction of Membrane Fouling in Membrane Bioreactors - Development of Innovative and Sustainable Techniques. Dissertation, FB 13, TU Darmstadt, 2011	35,-- €

IWAR 214	Müller, Bodo: Weiterentwicklung und Validierung der Methode der Input-Output basierten Sachbilanz für deutsche Gebäudeökobilanzen. Dissertation, FB 13, TU Darmstadt, 2011	35,-- €
IWAR 215	Eren, Onat: Automatisierung von numerischen Kurzzeit-Wasserbedarfsprognose-verfahren und ihre Anwendung in der Wasserversorgung. Dissertation, FB 13, TU Darmstadt, 2011	35,-- €
IWAR 216	Biobasierte Produkte und Energie aus Biomasse. 87. Darmstädter Seminar Abfalltechnik- am 08.12.2011 in Darmstadt, TU Darmstadt, 2011	vergriffen
IWAR 217	Meda, Alessandro: Einsatz von Biofiltern für die Wasser- und Nährstoffwiederverwendung und für die weitergehende Abwasserreinigung zur Spurenstoff-entfernung. Dissertation, FB 13, TU Darmstadt, 2012	35,-- €
IWAR 218	Hoffmann, Marc: Abfalltechnische Erweiterung von Bioabfallbehandlungsanlagen für die Herstellung biobasierter Produkte. Dissertation, FB 13, TU Darmstadt, 2012	35,-- €
IWAR 219	Maerz, Peter: Die Metalle der Schlacken aus Abfallverbrennungsanlagen. Dissertation, FB 13, TU Darmstadt, 2012	35,-- €
IWAR 220	Petzet, Sebastian: Phosphorrückgewinnung in der Abwassertechnik - Neue Verfahren für Klärschlamm und Klärschlammaschen. Dissertation, FB 13, TU Darmstadt, 2012	35,-- €
IWAR 221	Günkel-Lange, Tobias: Sauerstoffzufuhr und α-Werte feinblasiger Belüftungssysteme beim Belebungsverfahren - Abhängigkeiten und Bemessungsempfehlungen. Dissertation, FB 13, TU Darmstadt, 2013	35,-- €
IWAR 222	Zhang, Guomin: Abwasserreinigung und Wasserkreislaufführung in der Papierindustrie – Weiterentwicklung deutscher Techniken für den chinesischen Markt -. Dissertation, FB 13, TU Darmstadt, 2013	35,-- €
IWAR 223	Back, Sonja: Anwendungspotential der mikrobiellen Methanoxidation im Deponie-Schwachgasbereich – Feldstudie auf einer MBA-Deponie. Dissertation, FB 13, TU Darmstadt, 2013	35,-- €

IWAR 224 Zimmermann, Martin: 35,-- €
Sustainable Transformations of Water Supply Regimes. The Cuvelai-Etosha Basin in Central Northern Namibia.
Dissertation, FB 13, TU Darmstadt, 2013

<u>Bestellungen über:</u>

Technische Universität Darmstadt
Institut I*WA*R
Franziska-Braun-Straße 7
D-64287 Darmstadt
E-Mail: raumplanung@iwar.tu-darmstadt.de

Telefon: ++49 (0)6151 / 16 36 48
FAX: ++49 (0)6151 / 16 37 39