Tipping Points in Community-Based Management

A design-science research approach to study Community-based Management of domestic rural water points in Sub-Saharan Africa

by

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Graciela Nava
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Executive Summary

Globally, 663 million people are still without access to an improved source of drinking water[1] (Unicef, 2015, United Nations, 2015). While the proportion of the global population using this type of source increased from 76% to 91% over the last 25 years, severe problems of insufficient and unequal access remain.

On the one hand, problems of inequality between rural and urban areas. From the global population still without improved sources, eight out of ten people live in rural areas. In these settings, access is limited to 84% of the population, compared to 96% in their citified counterparts.

On the other hand, problems of inequality between world regions. In 2000, the United Nations' Millennium Development Goals set the target of halving the proportion of the global population without access to an improved source of drinking water by 2015. While the world met this target five years before its expiration date, regional statistics show that four developing regions did not[2].

Within these developing regions, Sub-Saharan Africa is home to nearly 50% of the global population that remains without access to safe water (Unicef, 2015). From the region's population, nearly 63% live in rural areas, where they rely on water points -shallow wells, boreholes, hand pumps and protected springs- for access (Rivett et al., 2013, Schnegg and Bollig, 2016), and by 2020, 57% of the global population is expected to depend on these local infrastructures (Van Den Broek and Brown, 2015, UNICEF, 2011).

Since the late 1980's, water points are managed under the Community-based Management (CBM) paradigm (Quin et al., 2011, Harvey and Reed, 2006, Moriarty et al., 2013, Mugumya, 2013). According to this paradigm, local users ought to participate in the construction, operation and maintenance of their water point, and pay user fees to co-finance these activities (Biteete et al., 2013, Moriarty et al., 2013). By engaging in these activities, they are expected to develop a sense of ownership over the water point, which would then keep participation ongoing, and knowledge and expertise to take part in the development of their own communities. Before the CBM era, these sites were managed by public actors and users were not required to be actively engaged or to make financial contributions.

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[1] Improved sources of drinking water, also known as sources of safe drinking water, include household connections, public standpipes, boreholes, protected dug wells, protected springs and rainwater collections (United Nations, 2016).

[2] While the Caucasus and Central Asia, Northern Africa, Oceania and Sub-Saharan Africa decreased the proportion of the population without access to an improved water source from 2000 to 2015, these regions did not achieve the Millennium Development Goal of halving this number (Unicef, 2015).

Since the adoption of the CBM paradigm, 427 million people have gained access to improved sources of drinking water in Sub-Saharan Africa. However, approximately one third of the region's water points remain non-functional at any point in time (Hanatani and Fuse, 2012, Van Den Broek and Brown, 2015, RWSN, 2009). This situation forces users to walk long distances to the nearest alternative, which is often a contaminated source that increases their risk of contracting diarrheal diseases (Prüss-Üstün et al., 2004). Furthermore, from the water points that are functional, a proportion delivers a service that is below the minimum requirements by the World Health Organization (WHO, 2016) in terms of quality, affordability and acceptability (Unicef, 2015).

While the need for Sub-Saharan Africa to tackle these problems is widely recognized (Unicef, 2015, UN General Assembly, 2015), there is a lack of insight regarding how this goal can be achieved. Accordingly, the aim of this research was to shed light on how the management of water points can be modified to improve the functionality rates of water points, and as a result, the services delivered to water users. Moreover, it aims at exploring whether potential changes would be affordable to the relevant stakeholders.

To achieve this goal, a complexity-informed modeling process was implemented to design, build, validate and apply a system dynamics model. This process was informed not only by insights from the literature, but also by findings from a set of structured, semi-structured and open interviews with experts on rural water delivery.

Overall, four products resulted from this research: a system dynamics model, recommendations for its future use and improvement, and insights from its application to the case of Kabarole district, in Uganda. These products are further specified below:

(1) **A system dynamics model was designed, built and validated based on three functional requirements.**

First, it represents the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts. Second, it is suitable to represent how changes in CBM systems influence service levels. Third, it enables the assessment of the financial costs of policy interventions.

(2) **Three sets of recommendations were drawn for future model use.**

The model should be used under a case study research design. Analyzing a particular situation instead of the generality allows users to gain context-specific insights. It can be used both, quantitatively to simulate different scenarios, or qualitatively, as a boundary object in discussions with relevant stakeholders. Next, model assumptions should be verified for a given case and results should be interpreted in this light. Finally, when parameterizing the model, particular attention should be paid to the initial number of water points, *annual net population growth rate, accessibility target, allocation policy* and *OpEx effect on lifespan.* Conducting sensitivity analysis to these variables is recommended.

(3) **Two recommendations were drawn for model improvement.**

The quantitative effect that operation and minor maintenance have on water points' lifespan and reliability should be clarified, possibly by means of statistical analysis. Second, the current model should be simplified into a more aggregated version: further analysis and validation of the model along with its application to multiple case studies can reveal which structures govern its behavior and help define a different level of granularity.

(4) Insights on the problem situation were made explicit at three levels: the case study of Kabarole district, reflections on CBM systems and on the CBM paradigm.
Regarding the case study of Kabarole, it was found that the proportion of the annual budget that the district allocates to the construction of water points (70%) surpasses the actual need for these infrastructures. In contrast, the funding allocated for capital maintenance is insufficient to repair the majority of non-functioning water points. Thus, in order to prevent a crisis of low functionality rates and overinvestment, a change in its allocation policy is needed: a greater proportion of its budget should be re-allocated from its current investment on new water points to repairs and maintenance of existing water points. Moreover, findings suggest that changing this policy might be sufficient to achieve standard service levels in Kabarole, instead of increasing the district's annual budget.

Regarding CBM systems, two stages were found in their development: before sufficient water points have been constructed to reach the target proportion of the population using safe water (Phase 1), and after this number has been reached (Phase 2). For a system in Phase 2, insufficient capital maintenance will produce a state of crisis in which the system will have low functionality rates and require overinvestment in new infrastructure to prevent the collapse of its service levels. Thus, decision makers must be aware of the tipping-point between Phase 1 and Phase 2, and implement policies that can be rapidly adapted according to the needs of the system.

Regarding CBM, this paradigm was not found to be suitable for achieving sustainable water services for all. For CBM systems in Phase 2, ongoing operation and maintenance become crucial for maintaining standard service levels. As long as rural water delivery adheres to the principles of the CBM paradigm, the success of policy interventions will depend largely on factors outside the control of decision makers, such as context-specific management and participation. While components of the CBM paradigm continue to be operational and relevant, the future of rural water delivery lies beyond the paradigm's boundaries. Thus, a more resilient approach that produces the expected outcomes in a reliable manner needs to be designed. Overall, these findings are relevant for good and services that are managed under the CBM paradigm, other than water.

Finally, recommendations for future research were drawn at four levels: (1) model improvement (as previously described); (2) validation of findings; (3) rural water delivery; and (4) the CBM paradigm.

Future validation of findings should include interviews with diverse stakeholders, diversification of the portfolio of modeling and simulation methods, and application of the system dynamics model to study multiple cases. Research in rural water delivery should support the identification of tipping points in CBM systems, and the design of adaptive policies. In addition, it should study the conditions under which new management models, local markets and sustainable supply chains for water points' spare parts, can emerge. Finally, further research on the CBM paradigm should study CBM systems of goods and services other than rural water. Through this sub-sequent research, findings from this study could be transferred and applied to policy analysis in similar problem situations.

Contents

List of Figures

List of Tables

Part I

Defining research purpose and approach

1 Introduction

Globally, 663 million people are still without access to an improved source of drinking water[3] (Unicef, 2015, United Nations, 2015). While the proportion of the global population using this type of source increased from 76% to 91% over the last 25 years, severe problems of insufficient and unequal access remain.

On the one hand, problems of inequality between rural and urban areas. From the global population still without improved sources, eight out of ten people live in rural areas. In these settings, access is limited to 84% of the population, compared to 96% in their citified counterparts.

On the other hand, problems of inequality between world regions. In 2000, the United Nations' Millennium Development Goals set the target of halving the proportion of the global population without access to an improved source of drinking water by 2015. While the world met this target five years before its expiration date, regional statistics show that four developing regions did not[4].

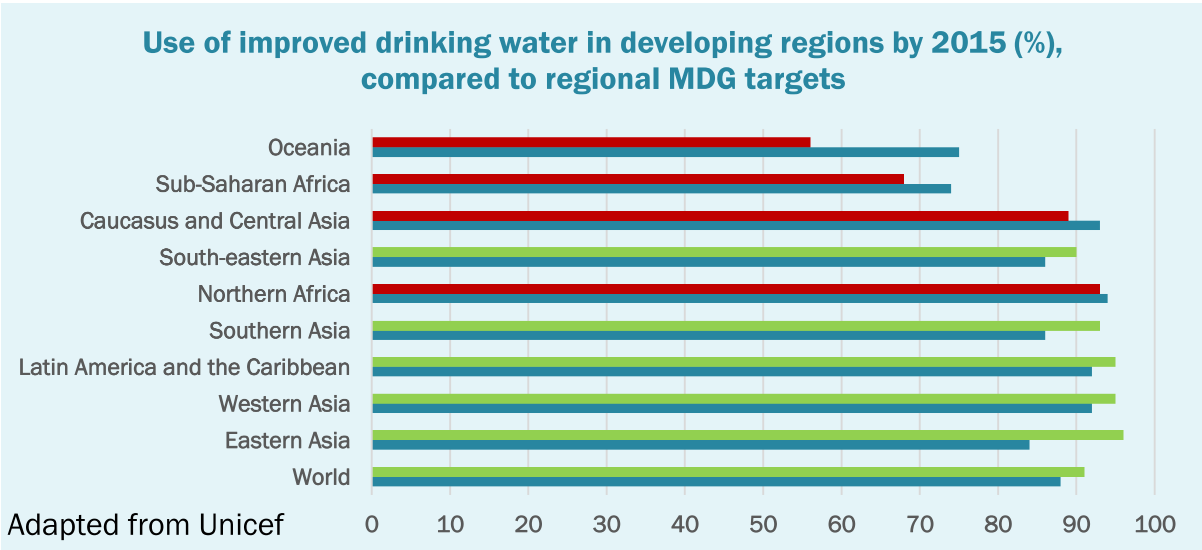

Figure 1 Use of improved drinking water in developing regions by 2015 (%), compared to regional MDG targets.

Therefore, in spite of the significant increase in the proportion of the global population with access to improved sources of drinking water and international efforts to ensure the Human Right to Water and Sanitation (see Textbox 1), the world is yet to bridge the gap between rural and urban areas, and between developed and developing regions. Bridging this gap is a necessary condition to achieve the sixth United Nations' Sustainable Development Goal: to ensure access to water and sanitation for all by 2030 (UN General Assembly, 2015).

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[3] Improved sources of drinking water, also known as sources of safe drinking water, include household connections, public standpipes, boreholes, protected dug wells, protected springs and rainwater collections (United Nations, 2016).

[4] While the Caucasus and Central Asia, Northern Africa, Oceania and Sub-Saharan Africa decreased the proportion of the population without access to an improved water source from 2000 to 2015, these regions did not achieve the Millennium Development Goal of halving this number (Unicef, 2015).

Textbox 1 Human Right to Water and Sanitation

Human Right to Water and Sanitation: Selected Milestones

1992 The Dublin Principles (ICWE, 1992). At the International Conference of Water and Environment, held in Dublin, a group of experts recognized water scarcity as a global problem, and proposed guidelines for its management.

1992 Conference on Environment and Development. Rio Summit (United Nations, 1992). Water was recognized as a right of individuals in the document *Agenda 21.*

2000 United Nations' (UN) Millennium Development Goals (MDG) (UN General Assembly, 2000). The UN member states set the goal of halving, by 2015, the proportion of people without access to improved water sources.

2010 Recognition of the Human Right to Water and Sanitation (UN General Assembly, 2010). Water should be sufficient, safe, accessible, acceptable, affordable and reliable.

2015 United Nations' Sustainable Development Goals (SDG) (UN General Assembly, 2015). The UN member states set the goal of ensuring, by 2030, water and sanitation for all.

1.1 Improved sources of drinking water in Sub-Saharan Africa

Within the developing regions that did not meet the Millennium Development target in 2015, Sub-Saharan Africa is home to nearly 50% of the global population that remains without access to improved sources of drinking water (Unicef, 2015). From the region's population, nearly 63% live in rural areas. In these settings, the majority of the population relies on water points for safe drinking water, i.e. shallow wells, boreholes, hand pumps and protected springs (Rivett et al., 2013, Schnegg and Bollig, 2016), and by 2020, 57% of the global population is expected to depend on these local infrastructures (Van Den Broek and Brown, 2015, UNICEF, 2011).

Figure 2 Map of the African continent, with Sub-Saharan Africa depicted in deep-blue.

Water points in Sub-Saharan Africa have been managed under the Community-based Management (CBM) paradigm since the late 1980's (Quin et al., 2011, Harvey and Reed, 2006, Moriarty et al., 2013, Mugumya, 2013). According to this paradigm, local users ought to participate in the construction, operation and maintenance of their water point, and pay user fees to co-finance these activities (Biteete et al., 2013, Moriarty et al., 2013). By engaging in the water point's management, users are expected, first, to develop a sense of ownership over the water point, which would then keep participation ongoing. Second, to develop knowledge and expertise to take part in the development of their own communities. Before the CBM era, these sites were managed by public actors and users were not required to be actively engaged or to make financial contributions.

Figure 3 Children playing in a shallow well, in Ethiopia.

Since the adoption of the CBM paradigm, 427 million people have gained access to improved sources of drinking water in Sub-Saharan Africa. However, approximately one third of the region's water points remain non-functional at any point in time (Hanatani and Fuse, 2012, Van Den Broek and Brown, 2015, RWSN, 2009). This situation forces users to walk long distances to the nearest alternative, which is often a contaminated source that increases their risk of contracting diarrheal diseases (Prüss-Üstün et al., 2004). Furthermore, from the water points that are functional, a proportion delivers a service that is below the minimum requirements by the World Health Organization (WHO, 2016), in terms of quality, affordability and acceptability (Unicef, 2015).

While the need for Sub-Saharan Africa to tackle these problems is widely recognized (Unicef, 2015, UN General Assembly, 2015), there is a lack of insight regarding how this goal can be achieved. On the one hand, some authors have suggested incremental changes to the CBM paradigm and gradual introduction of context-specific policies, without departing from its underlying principles. For instance, Lockwood and Le Gouais (2011) and Mugumya (2013) make a case for professionalizing the management of water points instead of relying on volunteer-based participation. On the other hand, other authors argue that the CBM paradigm *"[…] has turned out to be a blueprint for breakdown"* (Van Den Broek and Brown, 2015, p. 61) and *"[…] is arguably at the end of what it can do."* (Moriarty et al., 2013). Moreover, they make a call, first, for a resolution to the problem of low water points' functionality rates (Van Den Broek and Brown, 2015). Second, for the exploration of alternatives beyond this paradigm (Van Den Broek and Brown, 2015, Moriarty et al., 2013), such as cross-subsidization (Swyngedouw, 2006), private management of water points (Harvey and Reed, 2006) and a water services delivery approach (Moriarty et al., 2013).

Accordingly, the aim of this research is to shed light on how the management of water points, currently undertaken through the CBM paradigm, can be modified to improve the functionality rates of water points, and as a result, the services delivered to water users. Moreover, it aims at exploring whether potential changes would be affordable to the relevant stakeholders.

1.2 Reading ahead: structure of the thesis

This study is divided into four parts (Figure 4): (I) Defining research purpose and approach, (II) Exploring the problem statement, (III) Qualitative and quantitative system dynamics modeling, and (IV) making insights and recommendations explicit.

Part	Part Description	Chapter	Chapter Description
I	Defining research purpose and approach	1	Introduction
		2	Research Definition
II	Learn and Plan: exploring the problem statement	3	CBM for domestic rural water points
		4	System demarcation and Functional requirements
III	Design and Build: qualitative and quantitative system dynamics modeling	5	Conceptualization of the systems model
		6	Specification of the systems model
IV	Apply and Re-learn: making insights and recommendations explicit	7	Applying the model to the study of a CBM system
		8	Reflections on CBM systems for rural water delivery Reflections on the CBM paradigm Recommendations for future research

Figure 4 Structure of the thesis

In Part I, research purpose and approach are presented, both in conceptual and methodological terms. In the current chapter, the problem domain and need for this research were contextualized. In Chapter 2, key concepts are introduced, the problem statement and problem owner are made explicit, and the research objective is presented. Moreover, the research approach and methodology are detailed.

In Part II, the problem statement is explored from a systems and a multi-actor perspective. First, in Chapter 3, the CBM paradigm and its implementation are further detailed. Then, in Chapter 4, the system under study is delineated and functional requirements are provided for a system dynamics model.

In Part III, a system dynamics model of the problem is discussed. In Chapter 5, the model sub-systems along with dynamic hypotheses, core assumptions and key conceptualization choices are presented. Then, in Chapter 6, the translation of the model from concept to equations is explained, along with the main sources of uncertainty in it.

In Part IV, the application of the model to study the problem statement is discussed, and conclusions and recommendations are drawn. In Chapter 7, the use of the model to study a particular case within Sub-Saharan Africa is reported. Then, in Chapter 8, before providing recommendations for future research, implications of the case study for CBM systems and the CBM paradigm are discussed, and conclusions are presented.

For the reader's convenience, each chapter begins with a brief introductory text and with a reader's key: a set of four boxes that detail the chapter's background, objective, sections and highlights. Then, they conclude with a brief summary emphasizing its main concepts or contributions.

2 Research Definition

The primary driver for this research is the need for Sub-Saharan Africa to ensure water and sanitation for all by 2030. More specifically, the need for this region to increase access to improved sources of drinking water.

At first glance, the nature of this need seems to be technical and one might be tempted to provide engineering solutions alone such as increasing the number of water points. At second glance, however, other components are identified, i.e., low functionality rates of existing water points, involvement of multiple actors who have the desire and ability to influence the problem situation, and different perceptions of the problem itself and its potential solutions.

Accordingly, three policy analysis perspectives were adopted to define this research: a systems, a multi-actor and a pragmatic perspective. Instead of looking at engineering systems in isolation, adopting these perspectives enabled the researcher to make the problem explicit and to integrate both, engineering and non-engineering components.

The first section of this chapter presents the delineation of the problem and research scope, including the problem statement and the research objective. Then, in the second section, research approach, methodology and methods are presented. For the reader's convenience, boxes containing key concepts are included along the chapter.

Chapter 2: a reader's key

Background

The primary driver for this research is the need for Sub-Saharan Africa to ensure water and sanitation for all by 2030.

Objective

To define the research by making the problem and research scope, methodological approach and research methods explicit.

Sections

Problem definition and Research objective

Research approach and Methodology

Highlights

In section 2.2.2, the overarching methodology designed for this research is presented: complexity-informed modeling.

2.1 Problem definition and Research objective

To translate the need for this research into a problem definition, and then, into a research objective, three policy analysis perspectives were integrated: a systems, a multi-actor and a pragmatic perspective.

2.1.1 Systems and multi-actor perspective

The systems perspective, also known as systems thinking, calls for the interpretation of the world in terms of feedbacks and interrelations (Richmond, 1997). It aims at tackling the limitations of linear analyses by identifying the underlying causes of a certain effect.

Systems Perspective	From a systems perspective, or systems thinking, the world is interpreted in terms of feedback and interrelations, instead of in terms of linear relations. This perspective enables the design of policy interventions that aim at improving a systems performance over long periods of time, under different and even uncertain conditions.

From this perspective, problems such as low functionality rates of water points are pieces in a larger puzzle: the socio-technical system of water delivery[5]. Geels (2004) defines socio-technical systems *"[...] in an abstract, functional sense as the linkages between elements necessary to fulfill societal functions (e.g. transport, communication, nutrition)."* (p.900). These elements include not only large-scale engineering components (i.e. water points), but also human actors (i.e. water users, public officers, development partners) and a socio-technical regime –set of rules and institutions that regulates the linkages between elements in the system (i.e. the CBM paradigm, idiosyncrasies, country-specific regulations, commercial models for the production and distribution of water points and spare parts).

Socio-technical system	Interactions between elements that are needed to fulfill societal functions, such as transport or communication. These elements include large-scale engineering components, human actors and a socio-technical regime –set of rules and institutions, that regulates interactions within the system.

In the socio-technical system of water delivery, low functionality rates of water points are a symptom of the system's undesired behavior. Other symptoms, perhaps more difficult to identify and measure, can include problems of insufficient water quantity, quality, accessibility, acceptability, and affordability. In the world of rural water services delivery, these symptoms are measured through the *water service levels,* as specified in Table 1.

[5] In this document, the terms *system of water delivery* or *socio-technical system of water delivery* is reserved for CBM systems: those that deliver safe water to inhabitants of rural Sub-Saharan Africa through water points that are managed under the Community-based Management paradigm.

Table 1 Water service levels and indicators

	Quantity (liters per person per day)	**Quality**	**Accessibility** (minutes walking to a water source per person per day)	**Reliability**	**Status**
High	>60	Good	<10	Very reliable	Improved
Intermediate	>40	Acceptable	10 - 30	Reliable/secure	
Basic (normative)	>20		30 - 60		
Sub-standard	>5	Problematic	>= 60	Problematic	Unimproved
No service	<5	Unacceptable		Unreliable/ insecure	

Source: Moriarty et al. (2013).

By adopting this perspective and studying the feedbacks and interrelations between engineering components, actors, and institutions and regulations, insights are gained on the complex causes that result in low service levels. Based on these insights, policy interventions can be designed to improve the system's performance over large periods of time and under different conditions.

The second perspective adopted in this analysis is the multi-actor perspective. According to it, socio-technical systems, such as the system of water delivery, are characterized by constellations of actors (Kickert et al., 1997, Crozier and Friedberg, 1980). From the main characteristics that these constellations typically exhibit (De Bruijn and Herder, 2009), two of them are specified below the key concept box.

Multi-actor Perspective	From a multi-actor perspective, socio-technical systems are characterized by constellations of actors who have different perceptions of problems and perhaps conflicting interests; nevertheless, these actors depend on each other as none of them can solve the problem on their own.

First, actors who are part of the system have different perceptions of the problem and perhaps conflicting interests; nevertheless, they depend on each other as none of them can solve the problem on their own (De Bruijn and Herder, 2009). The socio-technical system of water delivery is located at the interface between public and private domains, and includes actors such as public authorities responsible for ensuring access to improved sources of drinking water; users who are required to play a central role in the construction, operation and management of the water points; companies involved in the production, distribution and procurement of water points and spare parts, and development partners regularly involved in the implementation of CBM. The role of these actors is specified further in Chapter 3.

Second, increasing access to improved water sources in rural Sub-Saharan exhibits characteristics of wicked problems: problems that cannot be definitively described or solved, for attempts to create a solution change the problem definition (Rittel and Webber, 1973). When dealing with this kind of problems, potential solutions usually require large financial and political investments that condition future decisions. For instance, financing new water points would limit the resources that are available for other investments, such as maintenance or capacity building. Moreover, these solutions are not true-or-false: it is difficult to assess whether a solution has been successful, as actors have different perceptions of how the problem should be solved. Nevertheless, decision makers are expected to decide wisely and unequivocally upon potential solutions, in spite of the uncertain nature of the problem, i.e., while delivering water services in rural areas of Sub-Saharan Africa is challenging, the region is still expected to ensure water and sanitation for all by 2030.

Wicked Problems	Problems that cannot be definitively described or solved, for attempts to create a solution change the problem definition (Rittel and Webber, 1973).

Adopting a multi-actor perspective had a double effect on the research definition. On the one hand, it influenced the delineation of an appropriate research scope. Instead of trying to find a solution to a wicked or unsolvable problem, the research was designed to explore the boundaries of what is known in order to reveal knowledge gaps and learn about the uncertainties associated to the problem situation. Thus, the scope of this study was defined as exploratory, and problem statement and research objective were defined accordingly.

On the other hand, adopting a multi-actor perspective influenced the research approach, methodology and methods. When studying socio-technical systems, including perceptions from multiple actors in the research process can deepen the insights gained and can help build confidence on the research outcomes (Thissen and Walker, 2013, Enserink et al., 2010). Therefore, obtaining and analyzing inputs from actors was included in the design of the research process.

2.1.2 Problem statement and Problem owner

Based on both, a systems and a multi-actor perspective, the problem was made explicit through the following **problem statement**.

Problem Statement	There is a lack of insight regarding how changes in the Community-Based Management paradigm for domestic rural water points can increase the water service levels experienced by participating communities in Sub-Saharan Africa, at costs affordable to the relevant stakeholders.

Although multiple actors have an interest in the problem statement and can exert influence over its evolution, development partners are identified as **problem owners** for this research. These actors are regularly involved in the implementation of the CBM paradigm by providing funding and services to public actors, or by undertaking projects directly with groups of users. Furthermore, they play a strategic role in achieving long-lasting policy changes in the water sector.

Problem Owner	Development partners that are regularly involved in the implementation of CBM projects by providing funding and services to national, regional and local governments, or by undertaking projects directly with groups of users.

2.1.3 Research objective and question

Finally, a pragmatic perspective (Creswell, 2013) was adopted to specify the research objective.

Pragmatic Perspective	From a pragmatic perspective, the problem statement is placed at the center of the research (Creswell, 2013): gaining insights to address the problem statement is its objective.

From this viewpoint, the research objective reflects the problem statement, and the research question was formulated accordingly.

Research Objective	To deepen insights regarding how changes in the Community-based Management paradigm for domestic rural water points can influence the water service levels experienced by participating communities in Sub-Saharan Africa, as well as the financial costs of these changes.

Research Question	How changes in the Community-based Management paradigm for domestic rural water points influence the water service levels experienced by participating communities in Sub-Saharan Africa, and what are their associated costs?

The overarching research approach and methodology, as well as methods used to achieve this objective are presented in the next section (2.2).

2.2 Research approach and Methodology

When conducting a research study, policy analysts can adopt different research approaches and types of activities. According to Mayer et al. (2013), policy analysis activities can be grouped in six clusters: research and analyze, design and recommend, clarify values and arguments, advise strategically, democratize, and mediate. The combination of activities between clusters determines the policy analysis style of the study, which can be rational, argumentative, client advice, participatory, process or interactive. By making the policy analysis style of a certain study explicit, practitioners can clarify the perspective that they have adopted and can select appropriate research methods. Figure 5 presents a diagrammatic representation of the policy analysis styles (in the hexagon's edges) and activities (in the hexagon's vertices).

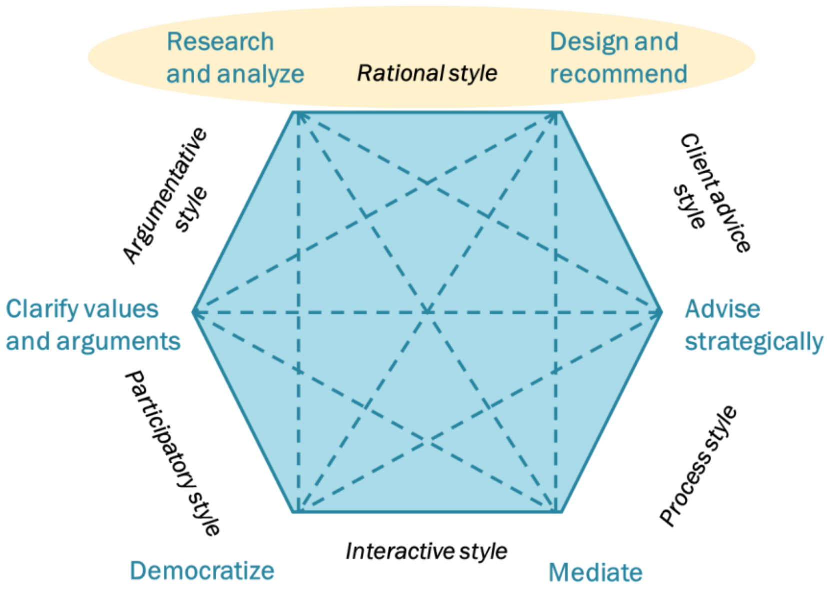


Figure 5 Positioning of this research in Mayer et al.'s (2013) policy analysis styles and activities

In this study, a rational policy analysis style was adopted. In this style, policy analysts assume that the problem situation is, at a large extent, empirically knowable and measurable. Thus, they make use of scientific tools, such as those from system analysis, to gain insights on the problem situation, draw recommendations, and inform the design of interventions. In Figure 5, the yellow area represents the positioning of this research in Mayer et al.'s (2013) hexagon.

In the remaining parts of this section, the rational policy style and overarching research approach adopted for this study are detailed. Then, the overarching methodology and adopted methods are explained.

2.2.1 Overarching research approach

In particular, this study was shaped around the design, use and improvement of a systems model: one of the main tools of systems analysis. A systems model is a representation of the problem situation from a systems perspective, in this case, the problem of low functionality rates of water points within the broader context of the socio-technical system of water delivery. Its design, construction and use enables the study of the problem statement from a Systems and multi-actor perspective (Mayer et al., 2013, Quade and Carter, 1989, Miser, 1985).

While systems models are not necessarily computer models, the one in this study is computational and is built using the system dynamics method, as detailed in sub-section 2.2.3. Therefore, to design, use and improve this model, a **design-science** research approach was adopted (Hevner et al., 2004, Bots, 2007). The aim of this approach is *"to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts"* (Hevner et al., 2004; p1).

Design-science research approach	Research approach adopted in this study, which aim is "to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts" (Hevner et al., 2004; p1).

From this approach, the research process is conceptualized as a series of transformations between five modular deliverables: problem statement (PS), design problem formulation (DPF), design or conceptualization of the systems model (DSM), realization of the systems model (RSM), and recommendations for its use and improvement (RUI). A diagrammatic representation of this process is depicted in Figure 6.

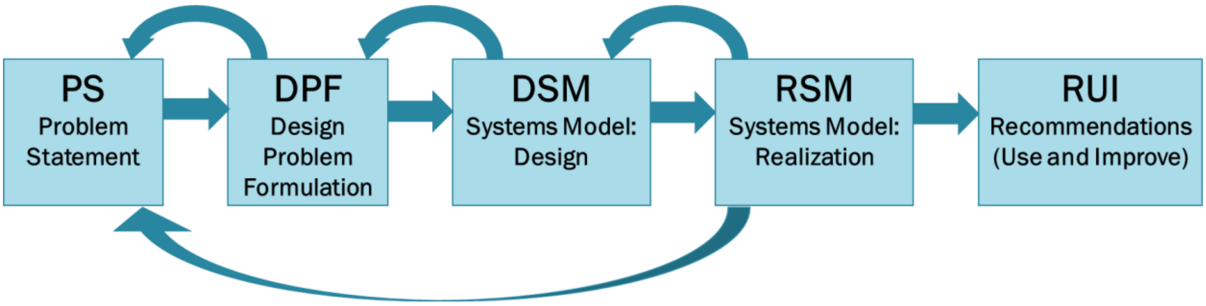


Figure 6 Design-process as a series of transformations. Adapted from Bots' (2007)

The process begins with the problem analysis loop (PS ↔ DPF), when the problem statement, as well as goals, constraints, available means and an instrument to measure the success of potential interventions are made explicit. Furthermore, a set of functional requirements are defined to answer the following question: *what should the systems model be able to represent and measure?* Next, in the solution-finding loop (DPF ↔ DSM), a systems model is conceptualized, according to the functional requirements (DPF) that were defined in the previous loop. Then, in the implementation loop (DSM ↔ RSM), the systems model that was conceptualized in the previous loop is specified into a computer model, and in the evaluation loop (RSM ↔ PS), it is used to gain insights on the problem statement and re-assess its formulation. Finally, in the recommendations loop (RSM ↔ RUI), recommendations are drawn for future use and refinement of the tool.

The overarching methodology of this study, presented in the next section, was designed with this research approach as a basis.

2.2.2 Overarching methodology and outcomes

System dynamics models can be used to explore the ambiguous space between policy design, implementation and adaptation in the field of water management (Clifford-Holmes et al., 2016, van Waas et al., 2015). The design, building and use of this type of models is guided by the traditional methodology of system dynamics, consisting of four main phases: conceptualization, specification, model testing and model use (van Daalen and Thissen, 2001, Pruyt, 2013).

For this research, the traditional methodology of system dynamics was combined with semi-structured, structured and open interviews to inform the systems model. Then, the model was applied to study a single case with the aim of testing the model's validity. The systematic combination of these methods is the overarching methodology of this study, and is hereinafter referred to as the a complexity-informed modeling process.

On the one hand, this process was designed to satisfy requirements of a rational style of policy analysis: to produce valid and reliable results by making use of state-of-the-art knowledge, gathering sound data, and presenting formal argumentation and validation (Mayer et al., 2013). Hence, the use of a traditional methodology of system dynamics. On the other hand, it was designed to integrate not only the researcher's perspective and insights, but also those of stakeholders in the socio-technical system of water delivery. Hence, the inclusion of interviews and the case study.

Complexity-informed modeling process	**Overarching methodology tailored to design, build, validate and use a systems model by making use of state-of-the-art knowledge, gathering sound data and input from stakeholders, and presenting formal argumentation and validation of conclusions.**

The complexity-informed modeling process consists of six steps, described in Table 2: (I) learn, (II) plan, (III) design, (IV) build, (V) apply, and (VI) re-learn. As a whole, these activities are conducted to clarify the boundaries of the system, define its structure, and make explicit the external effects that stakeholders in the system cannot control. They also allow the researcher to identify knowledge gaps, draw of recommendations, and inform the design of interventions.

Table 2 Six steps in the complexity-informed modeling process

Research Step	Objective and Description
Step 1: Learn	To enhance the researcher's understanding of the problem situation by learning from the literature and stakeholders.
Step 2: Plan	To distill functional requirements for the systems model, in order to answer the question: *what should the systems model be able to represent and measure?*
Step 3: Design	To design, validate and re-design the conceptualization of the systems model, using knowledge from literature and stakeholders.
Step 4: Build	To transform the conceptual model into a computer model accurately.
Step 5: Apply	To use the computer model to explore possible developments and interventions, and to validate the results with knowledge from literature and stakeholders.
Step 6: Re-learn	To use the findings from the previous steps to inform the design of interventions, and to draw recommendations for future use and improvement of the systems model.

Four expected outcomes should emerge from the implementation of these six steps: a systems model, recommendations for its future improvement, insights regarding the problem situation, and recommendations for future model use.

Systems model	A systems model that can be used to deepen insights regarding how changes in enabling and restricting conditions of Community-based Management systems for domestic rural water points can influence the water service levels experienced by communities in Sub-Saharan Africa, as well as the financial costs of these changes.
Recommendations for model improvement	Recommendations for future improvement of the model.
Recommendations for model use	Recommendations for using the model to enhance policy and decision-making processes regarding the management of domestic rural water points in Sub-Saharan Africa.
Insights regarding the problem situation	Insights gained from the use of the model regarding possible developments and interventions in the system of rural water delivery.

2.2.3 Research methods

A relation of the research steps and selected methods is presented in Table 3, after which a brief description of each method is provided.

Table 3 Synthesis of selected research methods

Research methods	Step 1: Learn	Step 2: Plan	Step 3: Design	Step 4: Build	Step 5: Apply	Step 6: Re-learn
Literature Review	X		X			
Interviews	X		X	X	X	
Text analysis	X					
Causal mapping		X				
List extension method			X			
Qualitative system dynamics			X			
Quantitative system dynamics				X	X	
Argumentation						X

Literature review. Two systematic literature reviews were conducted in this study. First, in Step 1, to enhance the researcher's understanding of the problem situation; findings are presented in Chapter 3. Then, in Step 3, to enable the selection of the method to build the systems model, as described in Chapter 5 and Appendix 2. Both sets of literature were retrieved by means of systematic searches of keywords in the engine Scopus.

Interviews. The types of interviews were used in this research: structured, semi-structured and open. In Step 1, semi-structured interviews were conducted to gain insights into the problem situation. Audio from each interview was processed into a transcript, and the product was analyzed through text analysis and color coding. The main findings are integrated into Chapter 3, and a report of the interviews is available in Appendix 1.

In Step 3 and Step 4, structured interviews were conducted. First, to validate a qualitative system dynamics model. Second, to gain insights for the quantitative system dynamics model. Findings from these interviews are integrated in Chapter 5, 6 and 7, and summaries from these interviews are presented in Appendix 3..

Finally, open interviews were conducted in Step 4 and Step 5. In the former, to verify the construction of a quantitative system dynamics model (Appendix 4). In the latter, to validate findings that emerged from using the quantitative model. Findings of this interview are discussed in section 7.2.4.

Text analysis. Transcripts from the semi-structured interviews in Step 1 were coded thematically according to the method proposed by Saldaña (2009). Then, fragments were grouped by color, analyzed, and used to enhance the researcher's understanding of the problem situation. In Chapter 3, quotations are used to confirm or emphasize the findings.

Causal mapping. In Step 2, causal mapping was used to demarcate the system by building a systems diagram (Enserink et al., 2010), or preliminary causal model. Using this method, the main components of the problem were classified in four types: system, internal or endogenous variables; means or policy actions; external factors; and objectives or criteria. The systems diagram and a detailed description of these elements are provided in the first section of Chapter 4.

List extension method. In Step 3, to build a qualitative system dynamics model, the systems diagram from Step 2 served as a basis to conceptualize the causal relations between variables of the system. It was developed further with the List Extension method (Coyle, 1996), which begins with a *model list* that contains the most important variables, according to what the model aims to represent. The list is expanded by adding a new column to the left of the model list, called *first extension.* This addition contains variables that directly influence the model list. Then, the procedure is repeated until variables external to the system are found. The model is presented in Chapter 5.

Qualitative system dynamics. Also in Step 3, the qualitative model was used to gain knowledge on the system structure. More specifically, to make the dynamic hypothesis or expected behavior, core assumptions and key conceptualization choices explicit.

Quantitative system dynamics. In Step 4, the qualitative system dynamics model was translated into a quantitative one. This model, which consists of sets of differential equations, was built in Vensim DSS®, a software that solves these sets deterministically, by applying numerical integration methods and discrete sufficiently small time steps to ensure numerical reliability. An overview of the model is presented in Chapter 6.

Then, in Step 5, the model was applied to study a particular case of CBM systems within Sub-Saharan Africa: the district of Kabarole, in Uganda. By parameterizing the model with values that represent the situation in this region, insights were obtained regarding Kabarole’s current situation, and the design of interventions to improve the delivery of rural water services. Then, findings were used to reflect on the possible developments of CBM systems in Sub-Saharan Africa. This process and results are reported in Chapter 7.

Argumentation. In Step 6, insights from the previous five steps were used to draw conclusions, recommendations for model use and improvement, and recommendations for the problem situation.

Chapter 2 in a nutshell

Problem definition and Research objective

- Primary driver for this research: the need for Sub-Saharan Africa to ensure water and sanitation for all by 2030, and more specifically, the need for this region to increase access to improved sources of drinking water.
- Problem statement: defined as the lack of insight regarding how changes in the CBM paradigm for domestic rural water points can increase the water service levels experienced by participating communities in Sub-Saharan Africa, at costs affordable to the relevant stakeholders.
- Problem owners: development partners that are regularly involved in CBM projects.
- Research objective: to deepen insights regarding how changes in the Community-based Management paradigm for domestic rural water points can influence the water service levels experienced by participating communities in Sub-Saharan Africa, as well as the financial costs of these changes.
- Research question: how do changes in the Community-based Management paradigm for domestic rural water points influence the water service levels experienced by participating communities in Sub-Saharan Africa, and what their associated costs?

Research approach and Methodology

- Design-science research approach: Research approach adopted in this study, which aim is “to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts” (Hevner et al., 2004; p1).
- Complexity-informed modeling process: overarching methodology tailored to design, build and use a systems model by making use of state-of-the-art knowledge, gathering high quality data and input from stakeholders, and presenting formal argumentation and validation of conclusions. This process consists of six steps: learn, plan, design, build, apply and re-learn.
- Expected outcomes: a systems model, insights regarding the problem situation, recommendations for future model use and improvement.

Part II

Learn and Plan: exploring the problem statement

3 Learn: CBM of domestic rural water points in Sub-Saharan Africa

As a starting point in the complexity-informed modeling process, three blocks of thematic sub-questions were answered, both, theoretically and empirically:

Block 1 CBM Paradigm	• What are concepts and theories central to the CBM paradigm? • How is CBM implemented, and what expenditures does it require?
Block 2 CBM Systems	• What are enabling conditions of CBM systems? • What are restricting conditions of CBM systems?
Block 3 Potential alternatives	• What innovations exists beyond CBM for rural water delivery? • What are foreseeable developments in rural water delivery?

On the one hand, theoretical insights were gained by means of a literature review. On the other hand, empirical insights were obtained by means of four semi-structured interviews with experienced problem owners. Transcripts from these interviews were analyzed using color coding and text analysis.

In this chapter, answers are provided for the sub-questions in the three thematic blocks and quotes from the interviewees are included to confirm and support these answers.

Chapter 3: a reader's key

Background

CBM is the paradigm under which improved sources of water are managed in rural areas of Sub-Saharan Africa.

Objective

To enhance the reader's understanding on three thematic blocks: CBM Paradigm, CBM systems and Potential alternatives.

Sections

Block 1: CBM Paradigm

Block 2: CBM Systems

Block 3: Potential alternatives

Highlights

Sections in this chapter are accompanied by quotes from interviews with problem owners.

3.1 Block 1: CBM Paradigm

"[...] the idea [of the CBM paradigm] is that the communities are in charge of the management, the operation and maintenance, of the facility. Does not always mean full ownership even though you try to promote this sense of ownership."

Fourth interviewee, expert on CBM systems.
Appendix 1, page 131

"[...] the intention [of the CBM paradigm] was good, the notion of having services delivered, managed and delivered at the level closest to the end user came from a desire to democratize the ways that we provide public services to our citizens, and support them to attain their highest attainable level of developments. It was a good one. There are many good intentions in there, more involvement and empowerment of women. And inclusiveness for the poor, or other marginalized groups. [...] it sounds good. Right?"

Second interviewee, expert on CBM systems.
Appendix 1, page 130

3.1.1 Concepts and theories central to CBM

Economic theories identify four main types of economic goods: private, public, club and common-pool resources. This classification depends on whether the good is rival or non-rival, and excludable or non-excludable. A rival good is one whose consumption by a user prevents or reduces the consumption of other potential users. A good is excludable when it is possible to prevent users from having access to it.

Table 4 Four types of economic goods

	Excludable	Non-Excludable
Rival	Private goods Such as food or clothing.	Common-pool resources Such as the timber, coal or water systems.
Non-Rival	Club goods Such as cable television or non-congested toll roads*.	Public goods Such as public infrastructure, language or knowledge.

*Congestion occurs when an excess demand causes negative externalities, such as traffic or pollution.

Water systems are considered common-pool resources. These resources, also known as commons, are those that generate finite quantities of resource units so that one person's use subtracts from the quantity of resource units available to others (Ostrom, 2002; p1318). In other words, overusing a common-pool resource jeopardizes its long-term availability by causing the resource's depletion. Moreover, their management is challenging as it encompasses two famous incentive problems: the Tragedy of the commons and the problem of free-riding (Dietz et al., 2002, Ostrom et al., 1994).

First, users of a common-pool resource face a dilemma between their individual and collective behavior. On the one hand, if all users restrain their consumption of the resource, the system can thrive and all users can enjoy its benefits in the long-term. On the other hand, if a given user restrains their consumption but other users do not, the resource will be depleted and the given user will miss the opportunity to enjoy its short-term benefits. This dilemma is known as the *Tragedy of the commons*, after an influential homonymous article published in Science (Hardin, 1968).

The second incentive problem is free-riding. The costs of excluding users from enjoying the benefits of a common-pool resource tend to be high. Therefore, some users do not necessarily pay their fair share of the cost of producing the common-pool resource, and instead they free-ride, turning the resource into an *open-access* common. Thus, the Tragedy of the commons and the problem of free-riding occur in systems of open-access, common-pool resources, with no operating institutions –or governance regime (Ostrom, 2002, Hardin, 1968).

The question on how to manage common-pool resources has been extensively addressed in the literature (Dietz et al., 2002), where many governance regimes have been proposed and studied. Generic categories of governance regimes include: government ownership, private ownership, collective ownership and open-access. Institutional arrangements for each of these regimes typically reach multiple layers of government and users. Ostrom (2002) [6] explains that these regimes regulate one or more of the following aspects:

- Users who are entitled to benefit from the resource.
- Time, quantity, location and technology to use the resource.
- Users who are obligated to contribute to the provision or maintenance of the resource.
- Design of monitoring and enforcement systems.
- Conflict resolution regarding use and users' obligations.
- Changes in the governance regime.

According to early theories on the management of common-pool resources (Gordon, 1954, Scott, 1955), users do not undertake efforts to design their own institutions. Nonetheless, Ostrom's work provides evidence that users collectively design and adapt the regime, particularly in areas that are located far from governmental authorities (Ostrom et al., 1994, Ostrom, 1990, Ostrom, 2002). Through the years, she (2002) studied cases of self-governed common-pool resources systems. Based on this research, she derived a series of principles that characterize the design of successful

[6] Elinor Ostrom: Nobel Prize winner for her analysis of economic governance, especially the commons (Nobelprize.org, 2009).

institutions, defined as institutions that overcome the Tragedy of the commons and the problem of free riding (Table 5). Authors other than Ostrom have developed similar design principles, including the works by Murphree (1997), Shackleton and Campbell (2001), Baland and Platteau (1996) and Stern et al. (2002).

Typically, long-term, successful institutions exhibit most of Ostrom's (2002) design principles, while fragile institutions exhibit only some of them. In contrast, failed institutions are usually characterized by only a few of these design principles. Overall, they enhance the shared understanding that local users have of the resources and of the costs and benefits of their cooperative management (Ostrom, 2002).

Over the last three decades, Ostrom's (1990) design principles for common-pool resource institutions have been influential in the management of natural resources (Saunders, 2010). After global events such as the Bruntland Report (WCED, 1987), the Dublin Statement on Water and Sustainable Development known as the Dublin Principles (ICWE, 1992) (see Textbox 2), Agenda 21 (United Nations, 1992) and the World Water Vision (World Water Commission, 2000), consensus in the world of international development suggests that sustainability goals can only be achieved through local solutions emerging from community action (Leach et al., 1999, Ghai and Vivian, 2014, Ghai, 1994). This consensus has led to the acceptance of Community-based Natural Resources Management (CBNRM), inspired by theorists of the *commons* (Ostrom, 2002, Stern et al., 2002, Baland and Platteau, 1996), as the predominant paradigm for the management of common-pool resources (Armitage, 2005).

Table 5 Ostrom's (1990) design principles for the management of common-pool resources

Principle	Description
Clearly defined boundaries	Individuals or households with rights to withdraw resource units from the common-pool resource are clearly defined. The boundaries of the common-pool resource itself are clearly defined.
Congruence	The distribution of benefits from the use of the common-pool resource is roughly proportionate to the costs imposed by provision rules. Restrictions to use the resource, such as time, place, technology, and/or quantity of resource units, are related to local conditions.
Collective-choice arrangements	Most individuals affected by operational rules can participate in modifying operational rules.
Monitoring	Monitors, who actively audit common-pool resource conditions and the behavior of local users, are accountable to the local users and/or are the local users themselves.
Graduated sanctions	Local users who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other local users, from officials accountable to these local users, or from both.
Conflict-resolution mechanisms	Local users and their officials have rapid access to low-cost, local arenas to resolve conflict among local users or between local users and officials.
Minimal recognitions of rights to organize	The rights of local users to devise their own institutions are not challenged by external governmental authorities.
Nested enterprises	Resource use, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Source: adapted from Ostrom (2002; p1331)

The CBNRM paradigm seeks to improve the management of common-pool resources by fully engaging users in the design and implementation of institutions, decisions, knowledge systems, customary practices, and regulations and sanctions (Armitage, 2005, Leach et al., 1999, Baland and Platteau, 1996). This paradigm is currently applied to the management of domestic rural water points (Luijten, 1999, Day, 2009, Manzungu, 2004), and is commonly referred to as the Community-based Management (CBM) paradigm or model.

Textbox 2 Synthesis of the Dublin Statement on Water and Sustainable Development

Synthesis of the Dublin Statement on Water and Sustainable Development

The Dublin Statement on Water and Sustainable Development is a declaration made by a group of experts on water problems who met as part of the 1992 International Conference on Water and the Environment, held on the 31st of January in Dublin, Ireland.

In their declaration, the experts recognized the increasing water scarcity resulting from conflicting use and overuse of the resource. Moreover, it sets out four recommendations for action at international, national and local level to reduce water scarcity.

The Dublin Principles

Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.

Principle 3: Women play a central part in providing, managing and safeguarding of water.

Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good.

3.1.2 CBM's implementation

The CBM paradigm, applied to domestic rural water points, is operationalized through CBM systems: groups of local users who procure and manage a water point throughout its complete life cycle (Quin et al., 2011, Harvey and Reed, 2006, Hanatani and Fuse, 2012). While CBM systems are also in place for the management of other water-related systems and ecosystems, the provision of drinking water services is exclusively addressed here.

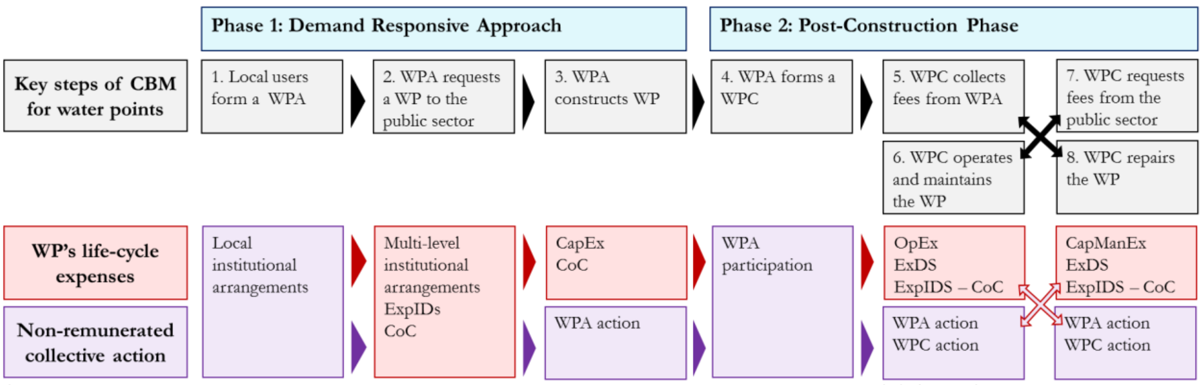
Ideally, the design and implementation of a CBM system occurs in two major phases: the Demand Responsive Approach and the Post-Construction Phase (Van Den Broek and Brown, 2015, Nicol, 2000, Isham and Kähkönen, 1999, Whittington et al., 1998, Quin et al., 2011). The Demand Responsive Approach requires all adults in a certain area wishing to access water to organize in a group, known as Water Users Association or Water Point Association (Schnegg and Bollig, 2016, Biteete et al., 2013, Whittington et al., 1998, Van Den Broek and Brown, 2015). Once formed, the Water Users Association is responsible for submitting a request for a water point to the corresponding public authorities, who will then evaluate the request and potentially provide funding and expertise for the installation expenses. After receiving the funds, the Water Users Association engages in the construction of the water point.

The second phase, the Post-Construction Phase, begins after the construction of the water point and is ongoing (Van Den Broek and Brown, 2015, Schnegg and Bollig, 2016, Breslin, 2003, Hanatani and Fuse, 2012, Quin et al., 2011). Elected volunteers from the Water Users Association form a local institution known as Water Point Committee. These volunteers, who provide their services free of charge, become the caretakers of the water point and are therefore responsible for its ongoing operation and maintenance. Moreover, they are in charge of collecting fees from the Water Users Association.

The Water Users Association is expected to fund the ongoing operation of the water point. However, stakeholders external to the community, such as the public sector and development partners, fund other expenses associated with this local infrastructure (Van Den Broek and Brown, 2015, Schnegg and Bollig, 2016, Breslin, 2003, Biteete et al., 2013).

The expenses of a CBM system are not limited to the construction and installation of a water point. Instead, they occur during its entire life-cycle, as identified by Fonseca et al. (2011). According to these authors, the Demand Responsive Approach requires Capital Expenditures (CapEx), which are funds to procure and install the water point and to finance initial institutional arrangements. Then, the Post-Construction Phase requires Operation and Minor Maintenance Expenditures (OpEx), which are the day-to-day operation costs and small repairs that should be funded by the Water Users Association. Also in the Post-Construction Phase, expenses are needed to renew, repair or rehabilitate the water point (CapManEx). Moreover, expenditures in Direct Support are potentially needed to assist the Water Point Committee in its tasks (ExpDS), while expenditures in Indirect Support are needed for government planning, policy making or regulation (ExpIDS). Finally, the Cost of Capital (CoC) is the cost of servicing capital, including the repayment of loans.

Figure 7 depicts the two-phased implementation process of the CBM paradigm, explicating the key steps in the process (grey), and identifying the key steps that are part of the water point's life-cycle expenses (red), and the key steps that require non-remunerated action (purple).



Source: prepared by the author, based on Van Den Broek and Brown (2015), Schnegg and Bollig (2016), Biteete et al. (2013).

Figure 7 CBM Implementation

Initially, the success of CBM systems was measured in terms of percentage of rural population with access to improved water sources, also known as water coverage. Based on this indicator, the implementation of the CBM paradigm produced many successes over the last decades. Moriarty et al. (2013), for instance, emphasize that the target for global access to safe water was met five years before its due date, and that globally, water coverage increased from 62% to 81%. Thus, from the macro-system level perspective, the implementation of CBM systems has been successful.

Nevertheless, macro-level and aggregated statistics do not accurately reflect the complex realities on the ground, which are more challenging. First, CBM systems face a functionality challenge. Estimates suggest that 30 to 40% of domestic rural water points in Sub-Saharan Africa are not working at any point in time (RWSN, 2009, Van Den Broek and Brown, 2015, Hanatani and Fuse, 2012). These interruptions in the service provided are not necessarily captured by simple statistics such as water coverage (Moriarty et al., 2013). As a result to this criticism, additional statistics have been proposed, such as the water service levels discussed in sub-section 2.1.1 and presented in Table 1.

The second challenge concerns the inconsistencies in the methodologies to collect and interpret data on water coverage and water service levels (Moriarty et al., 2013). Different methods are used by different stakeholders, resulting in figures that are not always comparable and do not always reflect the actual service received by users.

The third challenge is posed by international trends in rural populations (Moriarty et al., 2013). The global drop in poverty levels and the emergence of middle-classes are raising the expectations of water users, including users in rural environments (Clifford Holmes et al., 2014, Clifford-Holmes et al., 2016). Furthermore, the related phenomena of urbanization is increasing the feasibility of technologies such as piped schemes.

3.2 Block 2: CBM Systems

> *"[...] the term community is often very problematic though, because it makes it sound like in a single place, there is a single community. [...] I find a lot of community-based natural resource management to be very naïve from a social dynamics perspective."*
>
> First interviewee, expert on system dynamics for water management.
> Appendix 1, page 136

> *"Well, the thing [water point] is not working because half a day maintenance and caretaker training isn't helping to actually keep the thing working on the long term, and especially when you don't have the tools, or the tools walk away."*
>
> Second interviewee, expert on CBM systems.
> Appendix 1, page 137

"So basically, Direct Support has an impact to the communities, because Direct Support should be doing things like institutional models [...]to make sure that your water user group, whatever it is, is there."

Third interviewee, expert on CBM systems.
Appendix 1, page 133

"What I saw also is that in villages where the traditional leaderships, so there you have leader chiefs, where the chiefs were very strong, then also were able to motivate the people to take good care of the facilities. In areas where the chiefs were less strong, then it would be different."

Fourth interviewee, expert on CBM systems.
Appendix 1, page 134

3.2.1 Restricting conditions

High failure rates of water points and the lack of operation and maintenance are often identified as the physical manifestations of unsuccessful CBM systems (Schnegg and Bollig, 2016, Van Den Broek and Brown, 2015). While these manifestations owe to the lack of funds and community involvement in operation and maintenance of water points, the causes of the failure of CBM systems are complex and messy (Van Den Broek and Brown, 2015).

Causes that are reported in the literature as contributing to the lack of funds for the operation and maintenance of water points are summarized below. Then, other conditions that restrict the success of CBM systems are presented.

Causes of the lack of funding for operation and maintenance

In a literature review of community-based systems for domestic rural water points in Sub-Saharan Africa, Van Den Broek and Brown's (2015) argue that indirect causes of the lack of funding can be classified in five groups.

Political, such as political promises and lack of authority.

Historical, including resistance to pay fees; expectation of external funding; resistance to exclude debtors and to change traditional management; and lack of local support.

Geographical, such as low willingness to pay due to access to alternative water sources, unclear identification of the group of users, and lack of sanctions.

Social, covering lack of peer trust and trust in local managers; willingness to pay only when the water point breaks down; lack of volunteer managers, enforcement, participation, and interest in collective and long-term benefits.

Implementation, including low satisfaction; lack of awareness of the need for funding; non-representative Water Point Committees; the fact that excluding debtors threatens the Human Right to water; and users not developing a sense of ownership over the local infrastructure. When a sense of ownership is indeed developed, it does not necessarily increase the willingness to pay.

Additional details on each group of indirect causes are available in Annex 1.

Unsustainable supply chains for water points and spare parts

In a field note about sustainable rural water supplies, Harvey (2011) explains that one of the biggest challenges that CBM systems face is the unsustainability of supply chains for water points and spare parts. This situation is caused by inappropriate technology choice, leading to CBM systems that communities cannot afford, or do not accept; inappropriate institutions; insufficient support; inappropriate design or implementation of technology; and unavailability of spare parts to maintain or repair a water point.

The unavailability of spare parts occurs because most of the hand pumps, the most common technology choice for water points, are usually manufactured in India, and spare parts must also be imported (Sansom and Koestler, 2009). Measures to increase their availability are further complicated by low profits for the private sector and conflicting procurement schemes for the construction of the water point and its spare parts.

Mismatch between the services demanded and the services required

The role of the first phase in the implementation of CBM systems, the Demand Responsive Approach, is to guarantee that users receive the service that they require and that they believe they can finance (Moriarty et al., 2013). In practice, however, some users request lesser services than advised by international standards (WHO, 2016), while other request more than that, and more than they can afford. This has fostered a dependence upon funding from external stakeholders, instead of communities' self-sufficiency.

Lack of direct support to CBM systems during the Post-Construction Phase

Most communities are unable to manage CBM systems without some level of external or direct support, such as technical expertise, advice, funding or simply motivation (Van Den Broek and Brown, 2015, Moriarty et al., 2013). While direct support is usually part of the design of CBM systems, local institutions receive most of that support during the Demand Responsive Approach Phase, and not during the Post-Construction Phase, when water points fail. One of the reasons for this unbalanced investment is that, over the last three decades, the focus of public policy was to satisfy the pressing need of providing hardware for first-time access to water (Moriarty et al., 2013).

Idealization of groups of users as communities

The CBM paradigm is based on several assumptions, implicit and explicit, that do not always hold (Moriarty et al., 2013, Schnegg and Bollig, 2016, Van Den Broek and Brown, 2015, Harvey and Reed, 2007). These assumptions include community participation in the development of a CBM system, community ownership of the CBM system and willingness to volunteer in the maintenance and operation of the infrastructure. These assumptions are derived from the idealization of rural communities (Moriarty et al., 2013, Harvey and Reed, 2007): while CBM systems rely on participation of a community of water users, in reality, groups of users are not necessarily communities.

3.2.2 Enabling conditions

Solutions to address the indirect causes of water point failure are recurrent and can be classified in three types (Van Den Broek and Brown, 2015): promoting collective action and enhancing local capacity, providing external support to local institutions in the Post-Construction Phase, and technical solutions for early information.

Promoting collective action and enhancing local capacity

Participatory processes are often facilitated in order to promote the establishment of a Water Point Association and a later Water Point Committee (Van Den Broek and Brown, 2015, Marks and Davis, 2012, Kähkönen, 1999). These processes aim at increasing the sense of ownership that individuals have over the local infrastructure. Moreover, capacity building is also promoted with the aim of improving local knowledge and expertise to operate and maintain the water point (Van Den Broek and Brown, 2015, Mandara et al., 2013). The expectation is that communities and managers of CBM systems will be increasingly engaged in the management of the system and will be better qualified to perform their duties, and that willingness to pay for the water service will increase.

Providing direct support to local institutions in the Post-Construction Phase

Direct support for communities and local institutions managing CBM systems is crucial for improving the provision of water services (Moriarty et al., 2013). After the 1990s, it became clear that local services providers are not always able to perform their duties without external, formal and periodic support (Lockwood, 2002, Lockwood et al., 2003, Schouten and Moriarty, 2003, Harvey and Reed, 2007). According to Moriarty et al. (2013) this type of support is sometimes provided by local governments, private companies, national government agencies, local services providers, or combinations of the above.

Technical solutions for early information

In order to enable fast responses to water point failure, the design and implementation of early information systems on the functionality of water points has been promoted (Jonoski et al., 2013, Jürrens et al., 2009, Hellström, 2008, Hutchings et al., 2012, Van Den Broek and Brown, 2015, Rivett et al., 2013, Harvey and Reed, 2007). These solutions aim at enabling members of the community, including local water managers, to gather and report information on the state of a water point in real time. By providing an early notice of a water point's failure, the Water Point Committee or other actors can procure the necessary resources to renovate, repair or rehabilitate the water point. This early notice and procurement system aims at avoiding long-lasting water point failure. Examples include the use of mobile telephone systems to report issues.

3.3 Block 3: Potential alternatives

"So, it had potential, it's not there yet, and I think we need to actually fundamentally reconsider community-based management as the mode of delivering the services. I don't think it's doing what it needs to do."

Second interviewee, expert on CBM systems.
Appendix 1, page 148

"Well, I think and hope indeed that we should now be going in the direction of having more is called I think the CBM+. Still CBM, community-based management but with support from the service authority. I think for, yeah, many areas you cannot move away from community-based management..."

Fourth interviewee, expert on CBM systems.
Appendix 1, page 149

3.3.1 Innovations beyond the CBM paradigm

Efforts to tackle the global challenge of available and sustainable management of water and sanitation for all (UN-Water, 2015) have rarely reached beyond the CBM paradigm (Van Den Broek and Brown, 2015). Nonetheless, actors in the domestic rural water supply sector have identified alternatives to CBM. Harvey (2011), for instance, proposes to address the problem of unsustainable supply chains for water points by procuring infrastructure as close to the users as possible. Other alternatives include the return to publicly managed infrastructures and cross-subsidization (Swyngedouw, 2006), self-supply through rainwater harvesting (MWE, 2011b), and privately managed infrastructures (Harvey, 2008).

3.3.2 Foreseeable developments

In a recent article, Moriarty et al. (2013) argue that the focus of present and future efforts to improve global rural water supply should transition from first-time access to an improved water source, to the provision of sustainable water services. The new focus must be the delivery of services to users by service providers that are clearly identified, who are aided by support agents, under accepted and enforceable regulations. This transition requires explicit recognition of the need for financing for the CBM system throughout its entire life cycle, and the acceptance that this funding will require ongoing subsidy.

Further, they identify ten building blocks needed to achieve this transition: professionalization of community management; recognition and promotion of alternative service provider options; monitoring service delivery and sustainability; harmonization and coordination; support to service providers; capacity support to local government; learning and adaptive management; asset management; regulation of rural services and service providers; and financing for life-cycle costs.

Nonetheless, questions remain on both, potential evolution of CBM systems and opportunities for the paradigm's redesign. First, there is a lack of insight regarding how changes in enabling and restricting conditions of the CBM paradigm can increase the water service levels experienced by communities in rural Sub-Saharan Africa, at costs affordable to the relevant stakeholders. The second lack of insight refers to whether modifying CBM systems through changes in the supply chains, public or private management, cross-subsidization or self-supply would indeed improve the water service levels provided.

Chapter 3 in a nutshell

Block 1: CBM Paradigm

Concepts central to the CBM paradigm

- Common-pool resources: goods whose consumption reduces the availability for future consumption, and whose access is difficult to limit to specific users.
- Tragedy of the commons: dilemma in which users must choose between individual, short-term yet certain benefits of a common-pool resource, and collective, long-term yet uncertain ones.
- The problem of free-riding: it is difficult to exclude users from enjoying the benefits of a common-pool resource, even for users who do not pay a fair share of the production costs.
- Community-based management: a paradigm for the management of common-pool resources that aims at overcoming the Tragedy of the commons and the problem of free-riding.

Concepts central to CBM of domestic rural water points

- In CBM's first phase, the Demand Responsive Approach, potential users form a group (often known as Water Users Association), request a water point to authorities, and oversee its construction.
- In CBM's second phase, the Post-Construction Phase, the Water Users Association elects a group of representatives (often known as Water Point Committee) to operate and maintain the water point.
- The expenses associated to CBM systems can be grouped in Capital Expenditures, Capital Maintenance Expenditures, Operation and Minor Maintenance Expenditures, Expenditures in Direct Support, Expenditures in Indirect Support, and Costs of Capital.

Block 2: CBM Systems

- Enabling conditions: promotion of collective action and enhancement of local capacity, provision of support during the Post-Construction Phase (PCP), and technical solutions for early information.
- Restricting conditions: lack of funding, mismatch between services demanded by potential users and services received, lack of support, and idealization of groups of users as communities.
- The lack of funding results, indirectly, in the lack of operation and maintenance and on high failure rates of water points, with political, historical, geographical, social and implementation causes.

Block 3: Potential alternatives

- Rural water delivery must achieve a transition in ten building blocks (Moriarty et al., 2013).
- While efforts to improve rural water delivery rarely reach beyond the CBM paradigm, suggested alternatives include changes in the supply chains for water points, returning to publicly managed infrastructures, cross-subsidization, self-supply through rainwater harvesting, and privately managed infrastructures.

4 Plan: System demarcation and Functional Requirements

Theoretical and empirical findings from Step 1 were used to demarcate the system by building a systems diagram, or preliminary causal model. This diagram aims at clarifying the elements that will be investigated further, and classifying them into four main components: system, internal or endogenous variables; means or policy actions; external factors; and objectives or criteria. Moreover, the main actors who participate in the system were identified. Based on the systems diagram, guidelines or functional requirements of a qualitative system dynamics model were distilled.

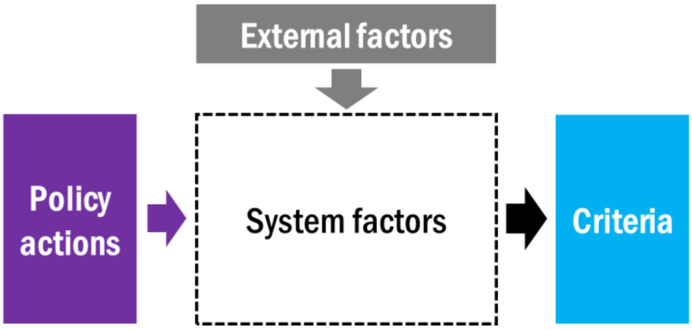


Figure 8 Four main components of a systems diagram

In the first section of this chapter, the systems diagram and its elements are presented and explained. Then, in the second section, functional requirements of the systems model are laid out.

Chapter 4: a reader's key

Background

Knowledge on the CBM paradigm, CBM systems and Potential alternatives was gained from literature and interviews with problem owners.

Objective

To demarcate the system under study and distill functional requirements for a system dynamics model.

Sections

Demarcating the system

Distilling functional requirements

Highlights

A color-coded systems diagram and a set of functional requirements for a system dynamics model are presented.

4.1 Demarcating the system

The systems diagram (Figure 9) summarizes the elements that are relevant for the problem analysis, and organizes them into four main components: system, internal or endogenous variables; means or policy actions; external factors; and criteria. In Figure 9, the question marks indicate that the causal relations between and within the components are not yet known. The qualitative determination of these relations is the aim of Chapter 5.

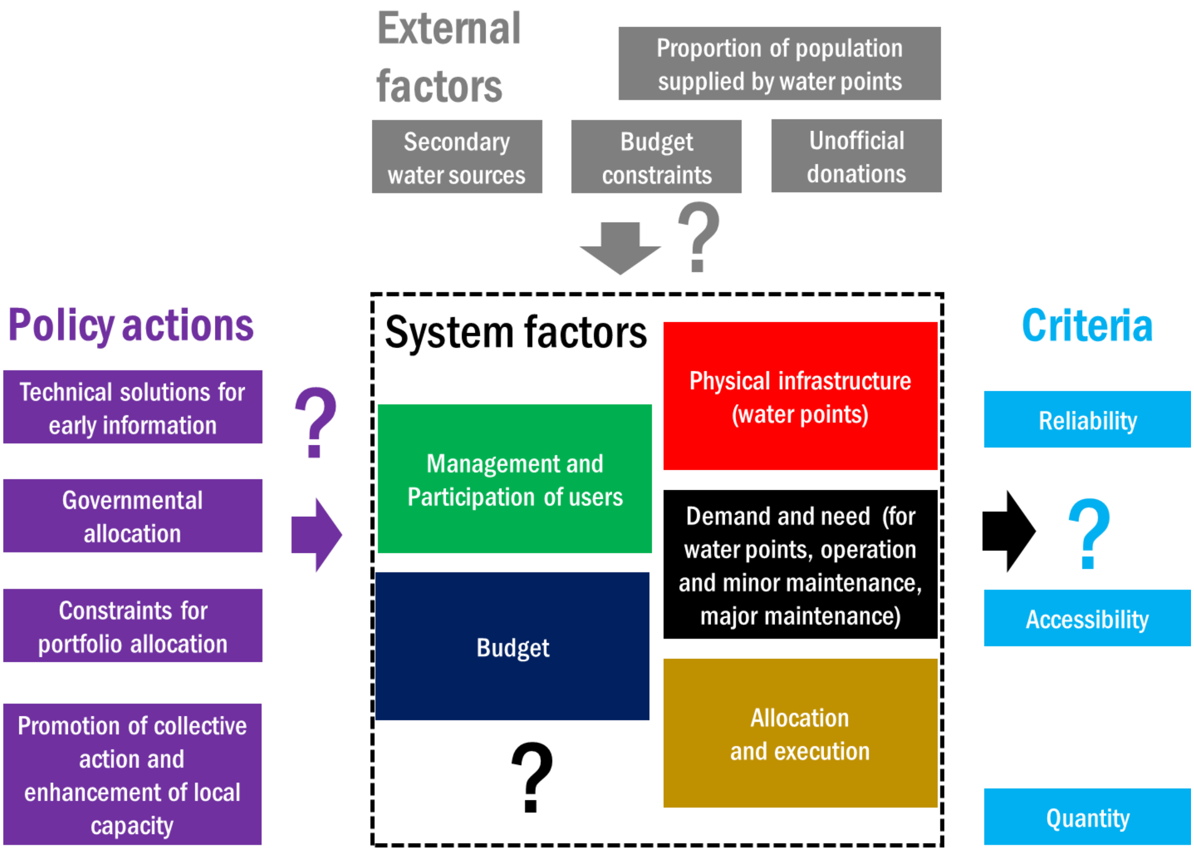


Figure 9 Systems diagram of CBM systems

4.1.1 Defining the criteria

The criteria, in light blue, represent the indicators of the state of the problem: they are a proxy to measure whether the problem has been addressed. In practice, water services are the delivery of water to people, and water service levels are the measurement of the quality of the water services provided (Moriarty et al., 2010). Water service levels are often quantified through four categories: accessibility, reliability, quantity, and quality. The exact indicators within each category vary depending on the institution performing the calculation, and the location under study. Nonetheless, some frequent definitions are provided below.

Accessibility measures the actual access that users have to a water points. It includes measurements such as the distance from the users to the closest water point, and the number of users per water point. **Reliability** is typically defined as the proportion of time that a water point functions, compared to its expected performance. **Quantity** is the measurement of liters that every user receives per day. **Quality** is the measurement of physical, chemical and biological parameters of water quality.

This research limits the system's criteria to those that are not geographically explicit, and can therefore be quantified through averages at highly aggregated levels. Water quality is therefore excluded from the analysis, as different modeling methods, which are geographically explicit, can represent more accurately physical, chemical and biological processes. Moreover, accessibility is only measured as the number of users per water point, as the distance from users to the closest water point is highly dependent on local conditions. Therefore, the system has three criteria:

Criteria 1: **Accessibility**. Number of users per water point.
Criteria 2: **Reliability**. Proportion of time that water points are functional.
Criteria 3: **Quantity**. Liters that every user receives per day.

4.1.2 Defining the system variables

The second component are the system variables, contained in the blue, dotted box. These variables play a role in the causal chain that affects the criteria. They are coded with five colors, representing five sub-systems of the problem, each of which is explained below.

Physical infrastructure, depicted in red. Physical infrastructure in the system, including shallow wells, boreholes, hand pumps, or protected springs, which are functional or non-functional. Other technologies are excluded, such as gravity flow and piped schemes.

Demand and need, depicted in black. On the one hand, this sub-system represents the new water points that are needed to reach the maximum number of persons per water point target set in the corresponding regulations (CapEx need); the water points that require capital maintenance due to ageing and failure (CapManEx need); and the water points that are functional and require operation and minor maintenance (OpEx need). While these variables are named according to the expenditure that is required to address the need: CapEx, CapManEx and OpEx, they represent a number of water points rather than the financial resources needed to complete the action.

On the other hand, this sub-system accounts for CapManEx demand: the number of demands from users to have a non-functional water point repaired.

Management and participation, depicted in green. A central component of CBM is the participation of users in the entire life cycle of the physical infrastructure. This sub-system represents the extent at which groups of users participate in collective activities (express the need for a water point, attend collective meetings and are informed about decisions, pay the corresponding fees), defined as community participation, and the extent at which local managers engage in the operation of the system (collect service fees, operate and maintain the infrastructure, express the need for external support), defined as community management.

Available budget, depicted in dark blue. Financial resources that are available as system variables: the budget granted by the public sector to construct new water points, maintain existing ones, and provide direct support to local users and managers. It also includes financial resources available and exercised for the operation of water points, which are collected from local users.

Allocation and execution, depicted in yellow. Allocation and execution of financial resources to install new water points, to repair, renew or rehabilitate existing ones, or to provide direct support to local managers.

4.1.3 Defining the external factors

The third component are the external factors, in grey. These factors cannot be influenced by the actors in the system, but influence the system variables or the criteria. Four external factors were selected, based on the findings presented in Chapter 3.

Percentage of population with access to a secondary water source. Users who have access to a secondary water source are less likely to pay the corresponding fees to access the services provided by the water point. Likewise, this access may also affect their willingness to engage in participation.

Budget constraints from users. Users' financial contribution to the operation and management of the water point are highly dependent on other needs that they have. Whether a monthly contribution will be made is highly unpredictable.

Unofficial donations of water points by charities. Foreign organizations, principally charities, may donate water points unofficially. This donation does not involve the public sector and occurs outside the official institutional arrangements. Therefore, these water points are often unofficial and are not registered in public records.

Population supplied by water points. Population projections in rural Sub-Saharan Africa are rarely accurate. Decision makers face the challenge of designing policies without knowing the population share that they should serve.

4.1.4 Defining policy actions

Finally, the fourth component are policy actions, in purple. They represent variables that actors can affect, that can indirectly influence the criteria, and that are typical solutions implemented within the CBM paradigm.

Technical solutions for early information. Actions that enable fast reporting of water point failure, usually through mobile telephone systems, to speed up their repair.

Governmental allocation for Capital Expenditures (CapEx), Capital Maintenance Expenditures (CapManEx) and Direct Support (DS). Financial resources periodically provided by public actors to construct water points, repair, renew or rehabilitate existing ones, and provide direct support to local users and managers.

Constraints for portfolio allocation. Public actors may set rules for the proportion of resources that should be spent in each activity (CapEx, CapManEx, DS).

Promotion of collective action and enhancement of local capacity. Programs and projects funded and undertaken by private actors, such as development partners.

4.1.5 Preliminary identification of actors

Insights from Chapter 3 were used to identify the relevant actors of CBM systems (Table 6). This identification is preliminary, as relevant actors vary considerably depending on the particular CBM system under study.

Table 6 Relevant actors in CBM systems

Actor	Relevance
WUA: Water Users Association	During the Demand-Responsive approach, it is the organization responsible for expressing the need for a new water point and participating in the selection of the technology and in its construction. During the Post-Construction phase, the WPA selects the management system, participate in users' meetings, and contribute financially to operation and maintenance costs.
WPC: Water Point Committee	After the installation of a water point, the WPC is in charge of its management during its entire life-cycle. The WPC is formed by officials elected from and by the WPA, who are required to provide their services on a volunteer basis. Their tasks include setting and collecting water tariffs, managing, and implementing operation and maintenance activities. Moreover, they may be recipients of training and capacity building.
Technicians and mechanics	Technical experts, internal or external to the WPA, whose capacity and availability makes the installation and maintenance of water points possible.
Actors from the public sector	Actors from the public sector legitimize CBM as the operating paradigm and set the sector guidelines for policies, i.e., technical solutions for early information, governmental allocations constraints for portfolio allocation; provision of funding for direct support.
Development partners	Private or foreign public organizations who take part in the design or implementation of water policies, or contribute with resources such as funding, expertise or workforce. Their financial contributions are typically very high.
Charities	Private organization who contribute, unofficially, with resources such as funding, expertise or workforce. Their contributions are typically not accounted for in official management systems of the receiving country.

4.2 Distilling functional requirements

Based on the demarcation of the system, three functional requirements for the system dynamics model were distilled:

First, the system dynamics model should represent the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts:

- **Demand Responsive Approach**, in which users form a group that requests the construction of a water point and participate in the selection of the technology and in its construction.
- **Post-Construction Phase**, in which the group of users selects a management system with representatives, participate in decisions regarding the system, and contribute financially to operation and maintenance costs, and in which their representatives operate and manage the water point.
- **Life-cycle expenses of CBM systems**: Capital Expenditures, Capital Maintenance Expenditures, Operation and Minor Maintenance Expenditures, Expenditures in Direct Support, Expenditures in Indirect Support, and Costs of Capital.

Second, the system dynamics model should be suitable to represent how changes in CBM systems influence service levels:

- **Enabling conditions:** promotion of collective action and enhancement of local capacity, provision of support during the Post-Construction Phase (PCP), and technical solutions for early information.
- **Restricting conditions**: lack of funding, mismatch between services demanded by potential users and services received, lack of support, and idealization of groups of users as communities.

Third, it should enable the assessment of the financial costs of policy interventions:

- **Policies within the CBM paradigm:** technical solutions for early information, governmental allocations, constraints for portfolio allocation and promotion of collective action and enhancement of local capacity.
- **Changes in the CBM paradigm:** for instance, changes in the supply chains for water points, returning to publicly managed infrastructures, cross-subsidization, self-supply through rainwater harvesting, and privately managed infrastructures.

These functional requirements guided the design, building, validation and use of the system dynamics model. Moreover, they were used to assess its performance, as described in Chapter 7.

Chapter 4 in a nutshell

Demarcating the system

- A color-coded systems diagram with four elements was presented: criteria, system factors, external factors and policy actions.
- A description of each element was provided, and the system demarcation was made explicit.
- A preliminary identification of actors in CBM systems was provided.

Distilling functional requirements

Three functional requirements were distilled for the system dynamics model:
- First, the system dynamics model should represent the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts.
- Second, the system dynamics model should be suitable to represent how changes in CBM systems influence service levels.
- Third, it should enable the assessment of the financial costs of policy interventions.

Part III

Design and Build: qualitative and quantitative system dynamics modeling

5 Design: qualitative system dynamics modeling

System dynamics was chosen as the modeling and simulation method for this research. This method allows the exploration of different structures and behaviors from a high-level perspective, while representing the complexity of the system. It also enables the identification of system components that can be studied in more detail with different methods. Further details on its selection are provided in Appendix 2.

In the first section of this chapter, a qualitative system dynamics model is presented by means of *aggregated causal-loop diagrams*: representations of the main causal relations between variables. A diagram is provided for each of the five sub-system identified in Chapter 4 (physical infrastructure, demand and need, management and participation, available budget and portfolio allocation) and for a set of key performance indicators: variables that measure the system's performance. Furthermore, findings from a qualitative analysis of each sub-system are presented in the form of dynamic hypothesis or expected behavior, core assumptions and key conceptualization choices.

In the second section of this chapter, the process to validate the model with experts in CBM systems and its key findings are explained. A more detailed description of this process, as well as assumptions, modeling choices, and detailed *causal-loop diagrams* are available in Appendix 3.

Chapter 5: a reader's key

Background

There is a lack of insight regarding the causal relations between and within components of the systems diagram presented in Chapter 4.

Objective

To conceptualize the causal relations within CBM systems, validate them with experts, and gain insights on their expected behavior.

Sections

Qualitative model and analysis

Expert validation process

Highlights

Main changes to the qualitative model, resulting from the expert validation process, are explained in Section 5.2.

5.1 Qualitative model and analysis

In qualitative system dynamics, *aggregated causal-loop diagrams* are representations of the main causal relations between variables. In these diagrams, arrows from one variable to another represent causal relations, and the arrow's polarity indicates whether the effect is positive or negative. In the following sub-sections, an *aggregated causal-loop diagram* is presented for each of the five sub-systems identified in Chapter 4 and for a set of key performance indicators. Furthermore, their dynamic hypothesis, core assumptions and key conceptualization choices are made explicit.

5.1.1 Sub-system 1: Physical infrastructure

The sub-system of physical infrastructure is described with an ageing chain of water points (Figure 10). New water points *(New WP)* are installed by the public sector through official procedures *(WP from public sector)* and by charities *(WP from charities)*, the latter do not necessarily report their donations to the public sector. After a certain time, new water points age into older ones *(Older WP)*. Older water points are functional, nonetheless, they provide services of less quality than new water points, such as reduced water flow. These water points only require minor maintenance. After a certain time, older water points fail, turning into failed water points *(Failed WP)*.

The model considers *Failed WP's* as those needing major maintenance in form of repairs, renew or rehabilitation. However, these water points may still be delivering a reduced water flow. If they receive capital maintenance from the public sector, they become *New WP*. If they receive it from local managers, they become *Older WP.* The idea is that renovating a water point to its original state requires resources and expertise that is usually unavailable to local managers. Therefore, local managers can only perform a type of capital maintenance that does not entirely rejuvenate this infrastructure. Finally, *Operation and minor maintenance* can extend the lifetime of water points, delaying the period before a water point fails.

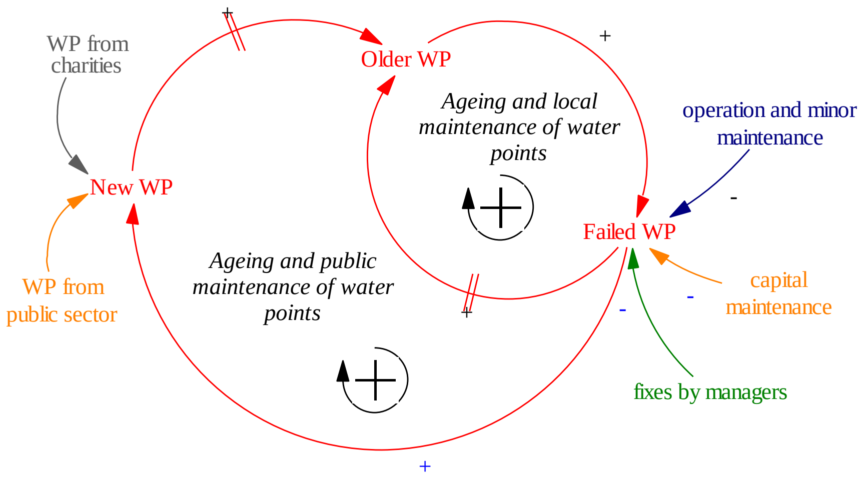


Figure 10 Aggregated causal loop diagram for Sub-system 1: physical infrastructure

Dynamic hypothesis: water points in the system are continuously ageing and require continuous capital maintenance. Nonetheless, operation and minor maintenance reduces the amount of capital maintenance that is required over time. When new water points are installed at a slower pace than the ageing process and capital maintenance is in place, most water points will be older.

Core assumptions: (1) in addition to the water points built by the public sector, charities can donate these infrastructures. (2) Operation and minor maintenance increases the lifespan of water points.

Key conceptualization choices: (1) the life-cycle of a water point has three stages: new, aged and failed. These phases are not clearly defined in the real-world, they are a proxy in the model to represent lifetime and quality state. (2) Only failed water points require capital maintenance, in the form of major repairs, renewals or rehabilitations. In reality, capital maintenance is required not only for water points that are no longer functional. (3) Only one type of water point is represented, while in reality these infrastructures are diverse.

5.1.2 Sub-system 2: Demand and Need

On the one hand, this sub-system measures the need for CapEx (new water points needed), CapManEx (water points needing repair, renewal or rehabilitation), and OpEx (water points needing operation or maintenance) (Figure 11). The model assumes that all water points require operation or maintenance, regardless of whether they are failed or functional. Moreover, it estimates the need for CapEx based on the accessibility criteria. In other words, it compares the actual Accessibility (persons per water point) to the Accessibility target, which represents the goal that is set as the maximum persons served by the same water point. The resulting number is the Accessibility gap, which is used to estimate the persons needing a water point, which divided by the Accessibility target, is the number of new water points needed. In turn, Accessibility depends on the number of water points and the persons served by water points, which is considered an external factor (Figure 12).

On the other hand, this sub-system accounts for the requests to repair, renew or rehabilitate failed water points. Water point failure ought to be detected and reported before it can be fixed, either to the managers of the CBM system or to the corresponding level of government. Therefore, the *requests being failed* depend on the *failed water points* and the *time to file a CapManEx request.* In turn, the *time to file a CapManEx request* can be reduced by *technical solutions for early information.* After requests have been filed, the *CapManEx demand* decreases through *CapManEx events being executed* with the intervention of the public sector, using public budget. It also decreases through *fixes by managers,* when *local capacity* is sufficient for managers to repair, renew or rehabilitate the failed water point without public intervention or budget.

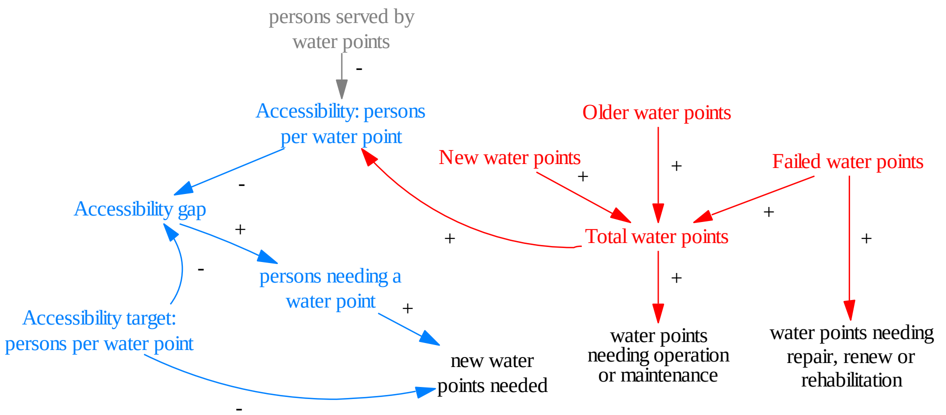


Figure 11 Aggregated causal loop diagram for Sub-system 2: CapEx, CapManEx, and OpEx need

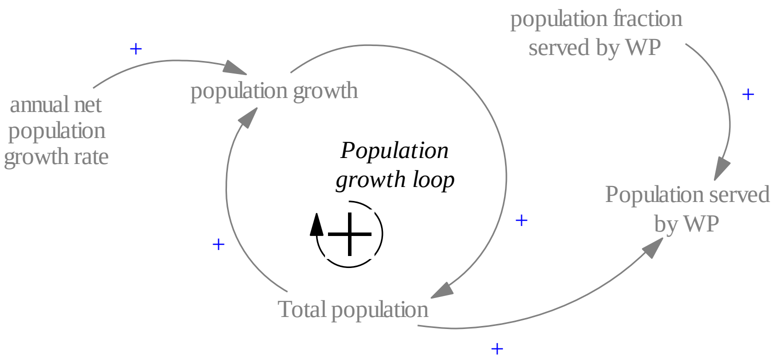


Figure 12 Extension of the aggregated causal loop diagram for Sub-system 2: total population served by water points

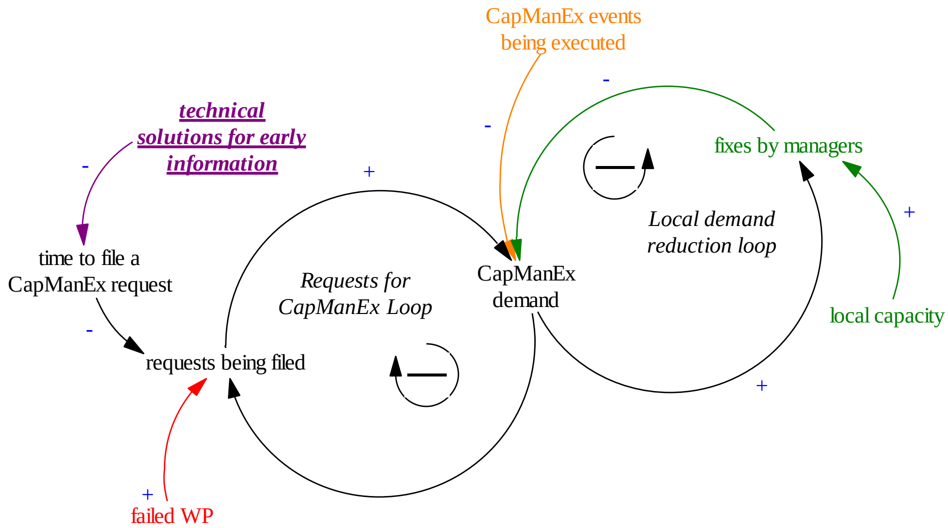


Figure 13 Aggregated causal loop diagram for Sub-system 2: CapManEx demand

Dynamic hypothesis: on the one hand, the number of water points needing operation and maintenance increases continuously, as the conceptualization of the system does not consider retirement of infrastructure. The water points needing repair, renew or rehabilitation depend on the number of failed water points, which in turn depends on operation and maintenance and on capital maintenance, as explained in sub-system 1. When water points are continuously built, the number of new water points needed is expected to decrease until the gap closes between the accessibility target and what the actual accessibility is. Changes in this gap will also depend on the persons served by water points, which in turn depend on the population growth.

On the other hand, CapManEx demand is expected to remain relatively constant: water points continuously fail and are continuously being repaired, as long as there is public budget available. Local capacity has a strong effect on CapManEx demand: if local managers have the skills and resources to repair, renew or rehabilitate their infrastructure, the demand for the public sector will be significantly lower.

Core assumptions: (1) all water points, functional and failed, require funding for operation or maintenance. (2) When local capacity is sufficient, local managers can undertake repairs, renewals and rehabilitation without assistance or resources from the public sector.

Key conceptualization choices: (1) the number of new water points needed is calculated based on accessibility. In other words, they are equal to the water points needed to reach the persons per water point target, based on the population at the moment of the calculation. (2) The annual net population growth rate is equal to the growth rate of the population served by water points. (3) Local capacity is determined by *management* and *participation.*

5.1.3 Sub-system 3: Management and Participation

This sub-system estimates the involvement of local communities in participation and management activities. On the one hand, *participation* of local users by expressing demand for water, selecting technology and location, providing labor and materials, contributing to capital, operation and maintenance costs, and selecting a management system is motivated by satisfaction and by their access to a secondary source. *Population with a secondary source* of water, other than the water point, tend to be less likely to participate in the CBM system. Moreover, participation also depends on the *satisfaction* of users on their water point, which is in turn a function of *accessibility, reliability* and *quantity.* On the other hand, *management,* involving water committee formation, training and capacity building, setting and collecting water tariffs, management and operation, is influenced by the *availability of OpEx funding* and by the *provision of Direct Support.*

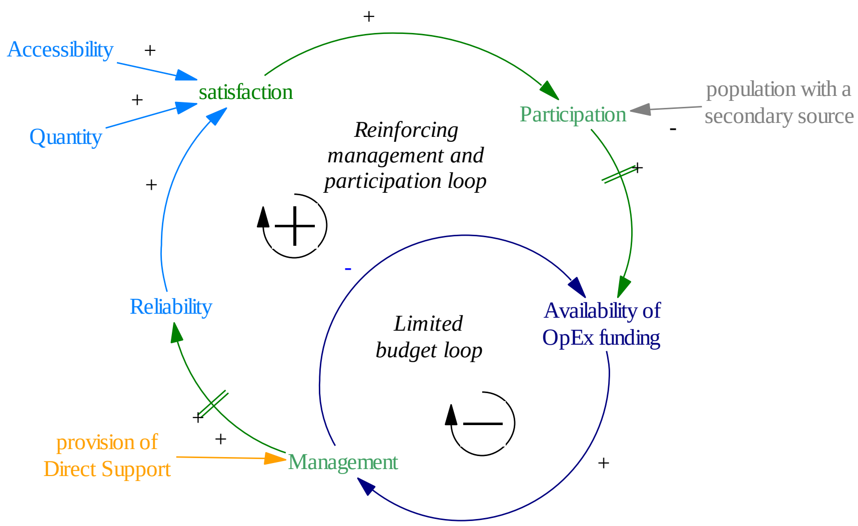


Figure 14 Aggregated causal loop diagram for Sub-system 3: participation and management

Dynamic hypothesis: participation and management follow similar patterns of behavior, as they influence each other. The structure of the causal loop diagram indicates that the patterns of behavior are reinforcing. Therefore, a decrease (or increase) in the water service levels will lead to less satisfaction, less participation and less management, which will in turn lead to even lower service levels (or higher). These increases and decreases are balanced by the Limited budget loop: the more financial resources are spent in management, the less financial resources are left. Thus, if an increase in management is not followed by an increase in the collection of funding, it will lead to a subsequent decrease in the water service levels, and then, participation. Changes in this patterns are nonetheless counteracted by Direct Support.

Core assumptions: (1) when participation is high, the collection of funding for operation and maintenance is also higher. (2) High engagement in management leads to higher expenditures in operation and maintenance. (3) Users who are satisfied with the water services obtained will participate more. (4) Users with access to a secondary water source will participate less.

Key conceptualization choices: (1) the variable *management* represents the engagement of a large and diverse group of activities: water committee formation, training and capacity building, setting and collecting water tariffs, management and operation. Moreover, it serves as a proxy for motivation of local managers to take part in the CBM system's activities. (2) Likewise, the variable *Participation* groups the expression of demand for water, selection of technology and location, provision of labor and materials, contribution to capital, operation and maintenance costs, and selection of a management system. (3) The variable *Satisfaction* integrates the experience of water services by users. This experience is equated with peer trust between the members of the community: if the services provided are good and operation and maintenance are conducted, users perceive that their peers are contributing to the thriving of the CBM system.

5.1.4 Sub-systems 4 and 5: Budget and Allocation and execution

Sub-system 4 accounts for the funding available to build new water points (CapEx), repair, renew or rehabilitate existing ones (CapManEx), provide Direct Support (DS) and undertake operation and maintenance (OpEx). System 5 considers the allocation rules to allocate this funding and the actual execution of these activities.

Funding for public sector is allocated to the first three categories of expenditures (CapEx, CapManEx and DS), which compete with each other for resources. This allocation occurs through the *allocation ratio CapEx, allocation ratio CapManEx,* and *allocation ratio DS.* These variables indicate the percentage of the *funding from public sector* that is allocated for each expenditure. Within each of these categories of expenditures, the number of events conducted depends on the cost of each event (*average cost of a CapEx event, average cost of a CapManEx event,* and *average cost of a DS event),* and on the capacity to undertake each activity *(CapEx capacity, CapManEx capacity, DS capacity).* The capacity variables represent the work force that the public sector makes available for each category. Therefore, a capacity of two represents twice the resources that are normally devoted to that particularly category of expenditures, in other words, twice the work force. In the case of capital maintenance, the number of CapManEx events conducted also depends on the *CapManEx demand,* or number of failed water points that have been reported and unattended.

In contrast, funding for operation and maintenance (*OpEx)* is collected by local managers from users. Thus, the *Availability of OpEx funding* increases with the *OpEx collection,* which in turn increases with *participation* and decreases due to users' budget constraints. *Availability of OpEx funding* decreases with *OpEx spending,* which increases with *Management.* In turn, *Management* is higher when *Availability of OpEx* funding is also higher.

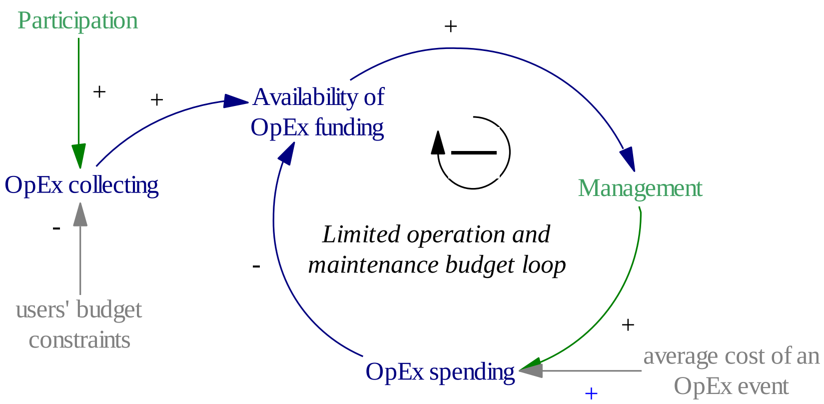


Figure 15 Aggregated causal loop diagram for Sub-system 4b: Available budget for OpEx

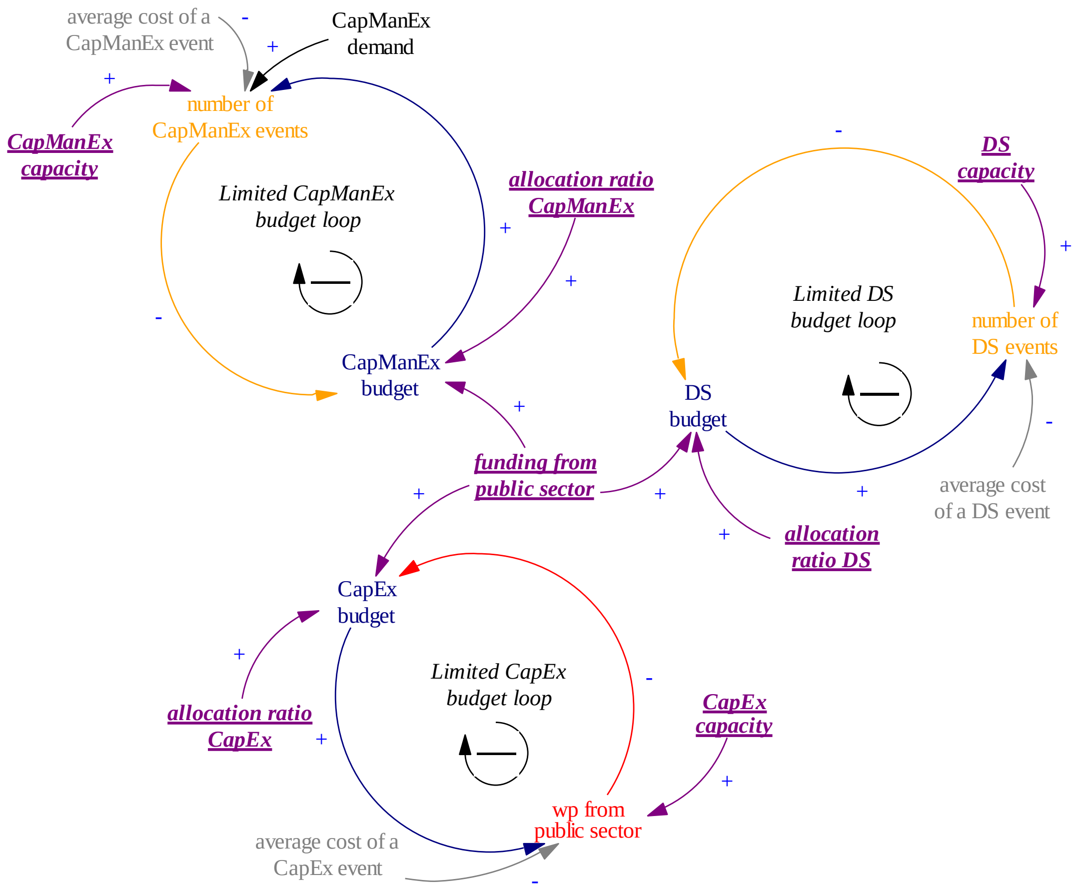


Figure 16 Aggregated causal loop diagram for Sub-system 4b: available budget for CapEx, CapManEx and DS

Dynamic hypothesis: the budget for each category remains constant over time, without depletion, when the *funding from public sector* and the rates at which events are executed also remain constant. These budgets can deplete when the capacity to execute events increases substantially. In contrast, the *Availability of OpEx funding* is likely to have a less predictable behavior, as it is highly dependent on *participation* and *user's budget constraints.* Its increase requires a continuous increase in *participation.*

Core assumptions: (1) the installation of new water points is not driven by demand of users. Instead, demand for new water points has already been expressed by potential users. (2) Likewise, provision of Direct Support is scheduled without requiring expressed demand from users. (3) *Availability of OpEx funding* depends on *participation* and *users' budget constraints*, the latter being unpredictable. (4) When *participation* is high, the collection of funding for operation and maintenance *(OpEx collecting)* is also higher. (5) High engagement in management leads to higher expenditures in operation and maintenance *(OpEx spending)*.

Key conceptualization choices: (1) the costs of a new water point, capital maintenance and operation and maintenance are considered external factors, modeled as constants.

5.1.5 Key Performance Indicators

A set of key performance indicators was selected to measure water service levels experienced by users, and the financial costs of changes in enabling and restricting conditions of Community-based Management systems. This set included the criteria defined in Chapter 5, as well as measures of the financial resources spent in the system.

First, the criteria represent the water service levels (Figure 17, top): *reliability* is the measure of the water points that are non-functional at any point in time; *accessibility* is the number of persons per water point; and *quantity* is the liters per person per day. *New water points, older water points* and *failed water points* provide a different amount of liters per day, depending on their quality state.

Second, the financial costs (Figure 17, bottom). The *total expenditures* are divided into the expenditures from operation and maintenance (*OpEx spent)*, funded by local users, and *expenditures from public sector.* The latter depends on the funding spent on new water points (*CapEx spent),* repairs, renewals and rehabilitations (*CapManEx spent),* and direct support (*DS spent).*

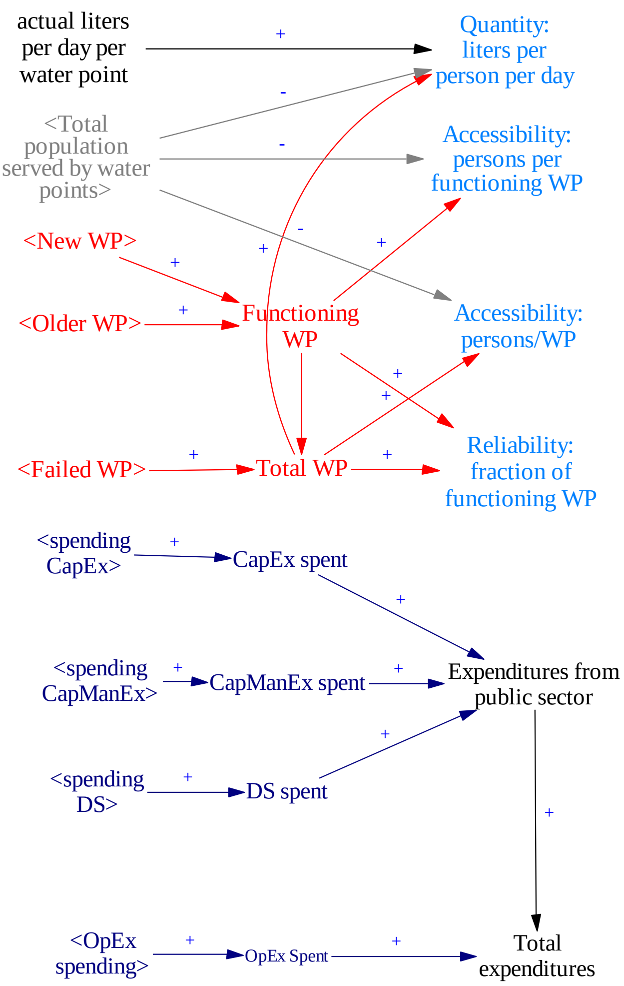


Figure 17 Causal loop diagram for the key performance indicators: water service levels and expenditures

5.2 Expert validation process

Formulating the qualitative system dynamics model was an iterative process. After the first version of the *aggregated causal-loop diagrams* was completed, three experts on CBM systems who participated in Step 1 were consulted to check the model's validity. In the same interview, they were asked to provide inputs for the subsequent quantitative system dynamics model, and for its corresponding validation. Thus, in structured interviews, each expert was asked to provide their expert input on three issues:

(1) whether the qualitative system dynamics model was an accurate representation of the system;

(2) educated guesses for the values that certain variables in the model could adopt;

(3) and how the system would behave in the real-world, under different conditions.

After the interviews, expert's input was used to adapt the initial *aggregated causal-loop diagrams* into the versions that were presented in the previous section (5.1), and translate the qualitative model into a quantitative one.

5.2.1 Questions on the validity of the qualitative model

Interviewees were presented with a set of statements regarding the causal relations in the qualitative model. Then, they were requested to use a Likert scale to define the extent at which they agreed with those statements (strongly agree, agree, neutral, disagree and strongly disagree). Because the objective of using the scale was simply to organize the discussion on the model structures, interviewees were allowed to add comments to their answers, refuse to answer a question, or provide comments instead of using the scale. A summary of these interviews is available in Appendix 3.

5.2.2 Main findings from the interviews

Main findings for each sub-system are summarized below.

Sub-system 1: physical infrastructure

No changes were incorporated for this sub-system. In one of the initial interviews, a preliminary conceptualization was presented, and an extensive discussion on the ageing process of water points took place. Insights from this discussion served as input for the qualitative model and its quantitative version.

Sub-system 2: demand and need

First, the definitions of operation and maintenance (Op), and capital maintenance (CapMan) were detailed further: in the model, a water point requires CapMan when its water flow has considerably decreased and is therefore considered to be non-functional.

Second, while in the initial conceptualization only the public sector could decrease CapManEx demand, in the current model local managers can also decrease it without the public sector intervening in capital maintenance activities.

Third, the construction of new water points is no longer driven by the demand for CapEx that local users express to the public sector: the current model assumes that this demand already exists and construction is not driven by demand. In the real-world, the Demand Responsive Approach is not driving the implementation of CBM systems. Instead, construction of water points depends largely on availability of funding and human capacity.

Sub-system 3: management and participation

Availability of funding is not the only factor driving the construction or maintenance of water points. Human capacity, such as capacity and availability of hand-pump mechanics, also plays a role. Thus, three variables were added to the model: *CapEx capacity*, *CapManEx capacity* and *DS capacity*. These variables represent the resources, in addition to funding, that are available for a certain activity.

Sub-systems 4 and 5: budget and allocation

The initial model conceptualization had a set of conditions for budget allocation: if all the demands for new water points had been satisfied, the remaining funding would be allocated for capital maintenance, after which, the remaining funding could be used to provide direct support. Instead, the current model includes deterministic allocation ratios for the three expenditures, instead of a conditional system of priorities.

Chapter 5 in a nutshell

Qualitative model and analysis

- Conceptual relations within the systems diagram are made explicit.
- For each sub-system in the diagram, dynamic hypothesis, core assumptions and key conceptualization choices are presented.

Expert validation process

- In addition to insights from the literature, three experts on CBM systems participated in the validation of the qualitative model.
- After a set of structured interviews, the initial model was modified into its current version. Some of the key findings from these interviews are listed below.

– When resources are available, local managers can perform capital maintenance on water points, instead of being an activity exclusively performed by the public sector.

– While the implementation of the CBM paradigm requires users to express their need for a new water point during its first phase (the Demand Responsive Approach), in reality, the system is not driven by demand: the public sector is usually aware that demand already exists, and whether new water points are built depends on the availability of financial resources and human capital.

– Availability of funding is not the only factor driving the construction or maintenance of water points. Human capacity, such as capacity and availability of hand-pump mechanics, also plays a role.

– Allocation policies are often fixed instead of adaptive: a percentage of the total budget is set for each type of activity, which is not necessarily linked to the actual need for each of them.

6 Build: quantitative system dynamics modeling

The qualitative system dynamics model presented in Chapter 5 was translated into a quantitative one. This model consists of sets of differential equations with two main components: stocks and flows (Sterman, 2000, Rahmandad and Sterman, 2008). Stocks represent accumulation of material and information and flows represent their changes over time. In mathematical terms, the former are integrals over time, and the latter their rates of change. The solution of these sets, given by both components and auxiliary variables, describe the state of the system, which changes continuously over time and depends on its own previous states.

This model was built in the software Vensim DSS®. Then, it was verified through four different methods (units check, changes in numerical method and time step, and an automatic check in Vensimm DSS®) and a consultation with an expert who provided suggestions for its improvement from a methodological perspective. Then, direct structure and structure-oriented tests were conducted to build confidence in the model. These tests included face validation with the three experts on CBM systems who provided insights for previous steps of the research.

In the first section of this chapter, key choices in the formulation of the qualitative model are explained. Then, in the second section, the process of testing the model and key insights from the experts on system dynamics and CBM systems are discussed. Moreover, recommendations for model use an improvement are provided.

Chapter 6: a reader's key

Background

Based on the systems diagram of the problem situation (Figure 9) a qualitative system dynamics model was built (Chapter 5).

Objective

To formulate, verify and validate a quantitative system dynamics model, based on the qualitative one presented in Chapter 5.

Sections

Key formulation choices

Model testing

Highlights

Main sources of uncertainty are discussed in Section 6.2.2, along with recommendations for model use and improvement.

6.1 Key formulation choices

The conceptualization of the model was transferred into the model formulation through an iterative process. As the research progressed, the first model prototype was refined in several occasions. After a preliminary version of the model was completed, an interview was conducted with a system dynamics expert. The objective of this interview was to identify areas of improvement in the model, including choice of numerical method and time step. Feedback from this interview was incorporated into the final model. A complete summary of this interview is available in Appendix 3.

The following paragraphs elaborate on the key formulation choices for each sub-system of the model. They aim at providing an overview of the model specification. To complement the description, stock and flows diagrams are provided. These diagrams are a snapshot of the model in Vensim DSS® and differentiate the variables by type: levels (in boxes), flows entering or leaving a stock (in double lined arrows) and auxiliaries and constants (no boxes nor arrows). Furthermore, for each sub-system, key parameters and structures that require further testing are summarized.

6.1.1 Sub-system 1: Physical Infrastructure

This sub-system was formulated as an ageing chain of water points (Figure 18). Decreases in the level variables *New WP* and *Older WP* were specified as the ratio of the value of the stock [water points] and the lifespan of that category of water points [years]. The lifespan of a water point is estimated as the product of the *max lifespan* and *modifier.* The variable *modifier* accounts for the effect of operation and minor maintenance on the lifespan of *New WP* and *Older WP.* It is formulated as a linear equation with the following structure:

Modifier = OpEx effect on lifespan
+ fraction of wp that recently received an OpEx event
*** (1 – OpEx effect on lifespan)**

The equation indicates that when no operation or maintenance is conducted, the lifespan of a water point is reduced to the product of itself and *OpEx effect on lifespan.*

The variable *wp from charities* was specified through a *ratio from charities to public sector.* The value of this variable is highly uncertain. While it is known that these donations occur, little is known about its actual value. Therefore, implementing this variable as a ratio enables further testing of the model sensitivity to changes in the *wp from charities.*

On the other hand, decreases in the variable *Failed WP* were formulated as the *fixes by managers* (from sub-system 3) and the *CapManEx events being executed* (from sub-system 2).

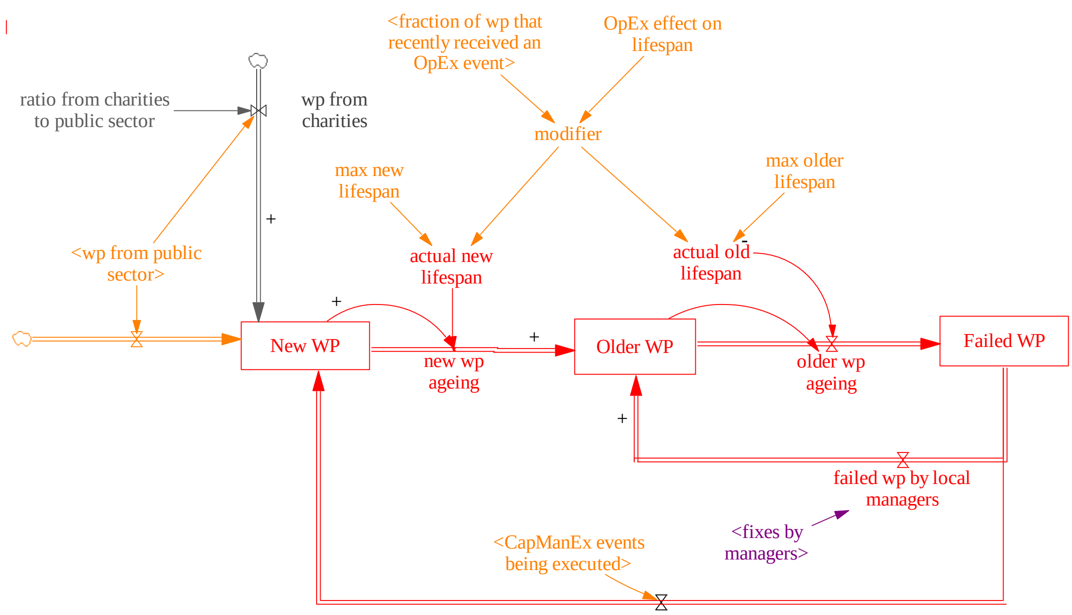


Figure 18 Stock and flow diagram of Sub-system 1: physical infrastructure

Key structures: the ageing chain, which was validated in a conversation with the first interviewee, during the first set of interviews.

Key parameters: ratio from charities to public sector, max new lifespan, max older lifespan, OpEx effect on lifespan.

6.1.2 Sub-system 2: Demand and Need

The first part of this sub-system assigns the value of level variables (*Total WP* and *Failed WP*, respectively) to estimate the *water points needing operation or maintenance* (OpEx) and the *water points needing repair, renew or rehabilitation* (CapManEx). To estimate the *new water points needed*, the model estimates the gap between the actual *Accessibility: persons/WP* and *Accessibility target: persons/water point*. Then, the product of this *Accessibility gap* and the *Total WP* produces the *persons needing a WP.* Finally, the *new water points needed* is the product of the *persons needing a water point* and the *Accessibility target: persons/water point*, which is the maximum desirable number of persons using the same water point. While the value of the *Accessibility target* is not uncertain, as it is usually stated in regulations, it is a major influence on the calculation of the *new WP needed,* and might be highly influential in the overall model.

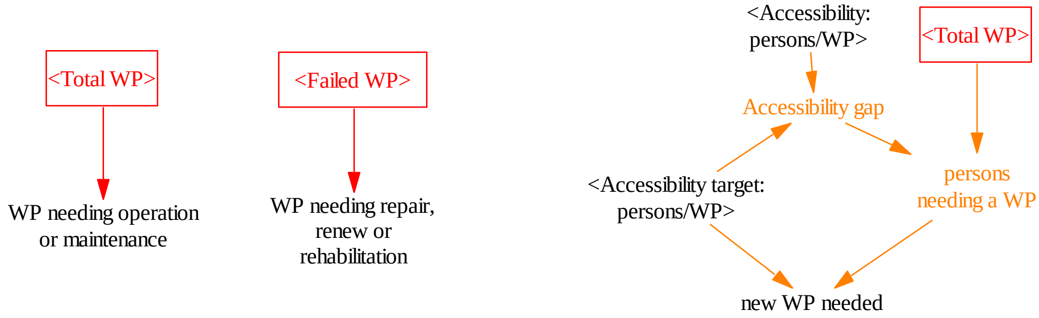


Figure 19 Stock and flow diagram for Sub-system 2: CapEx, CapManEx and OpEx need

Total population is formulated as a level variable that changes as a function of the product of itself and *new population growth,* which in turn is a function of the *annual net population growth rate*. The value of the level *Total population* is used to calculate the *Total population served by water points* through the product of *Total population* and the *fraction of the population served by water points.*

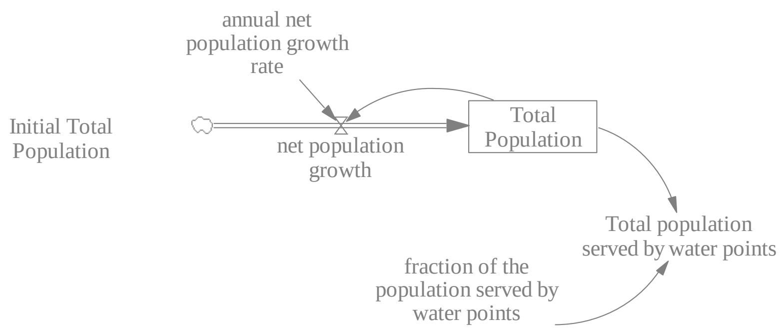


Figure 20 Stock and flow diagram for Sub-system 2: total population served by water points

Finally, the demand for repairs, renewals and rehabilitations (*CapManEx demand*) is formulated as a level variable, which increases through the *actual CapManEx requests being filed* and decreases through the *fixes by managers* and the *CapManEx events being executed.* On the one hand, the *actual CapManEx requests being filed* is the ratio of the *ideal CapManEx requests* and the *time to file a CapManEx request.* The *time to file a CapManEx request* decreases when technical solutions for early information are in place. In this case, a special “IF THEN ELSE” function is used:

time to file a CapManEx request = IF THEN ELSE ("Technical solutions? " = 1, time to file a CapManEx request with Technical solutions, standard time to file a CapManEx request)

This function indicates that when Technical solutions are in place, the time to file a CapManEx request is shorter and equals the time to file a CapManEx request with Technical solutions. In contrast, when these Technical solutions are not in place, it equals the standard time to file a CapManEx request. The choice of Euler as the numerical method to solve the equations enables the software to cope with this discrete function.

On the other hand, the demand for repairs, renewals and rehabilitations (*CapManEx demand*) decreases through the *fixes by managers* and the *CapManEx events being executed.* First, *fixes by managers* are the ratio of *local capacity* and the *time to repair a water point.* Local capacity, in turn, is the product of *training to repair a water point* and *ratio of OpEx funding available,* implying that recent DS events build capacity to fix a water point, which is enabled by the availability of funding to undertake this activity. Second, *CapManEx events being executed* depends on the *standard CapManEx execution, the CapManEx capacity,* and the *max CapManEx per time step.* The *standard CapManEx execution* represents the normal rate of events that can be conducted, depending on the number of *funded repairs, renewals or rehabilitation* and the *time to repair a WP.* The *max CapManEx per time step* represents the maximum number of events that can be executed if the *CapManEx capacity* is increased. The *CapManEx capacity* represents the work force that the public sector allocates for this activity, with a value of 1 corresponding to the capacity to execute one CapManEx event at once. A special "MIN" function is therefore used to calculate *WP receiving CapManEx:*

WP receiving CapManEx = MIN(max CapManEx per time step,
CapManEx capacity*standard CapManEx execution)

Thus, WP receiving CapManEx increases when the CapManEx capacity increases, but is constrained by the max CapManEx per time step, which is turn defined by funded repairs, renewals or rehabilitations.

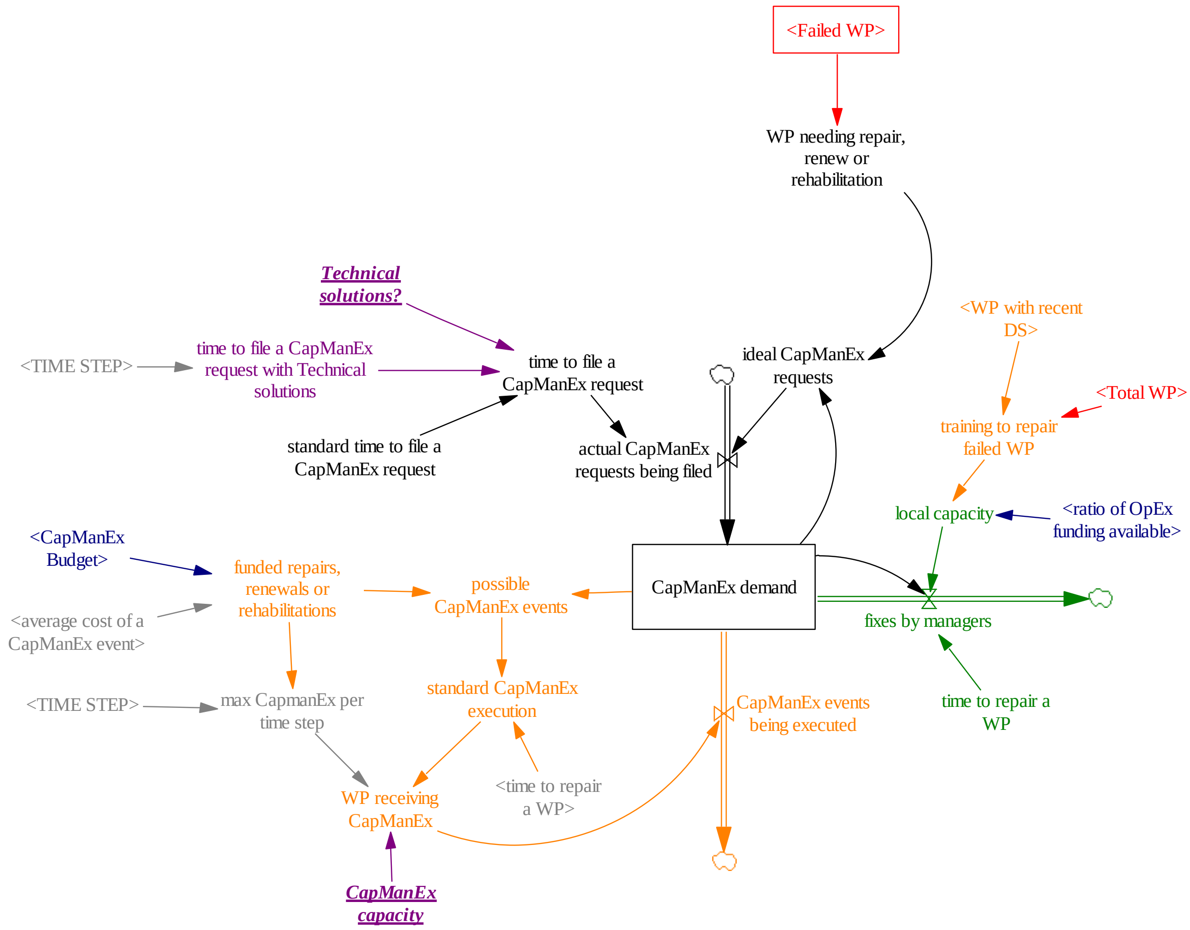


Figure 21 Stock and flow diagram for Sub-system 2: CapManEx demand

Key parameters: Accessibility target: persons/water point, annual net population growth rate, fraction of the population served by water points, standard time to file a CapManEx request, time to repair a WP, CapManEx capacity.

Key structures: new WP needed, local capacity.

6.1.3 Sub-system 3: Management and Participation

Management is formulated as a level variable that increases with the execution of DS events and with the funding available for operation and maintenance. The *increase in management from DS* is formulated as the ratio between the *fraction of water points that recently received a DS event* and the *delay of involvement.* The *delay of involvement* represents the time that local managers require to increase their activities after they have received a stimuli, such as Direct Support or availability of funding. Then, the *increase in management from OpEx* is formulated as the ratio between the *ratio of OpEx funding available* and the *delay of involvement.* The *ratio of OpEx funding available* represents the *Funding for OpEx* that is available compared to the *financial need for OpEx.* The *decrease in management* represents the loss of motivation from managers or the time that the effect of Direct Support or available funding lasts. It is formulated as the ratio of *Management* and *management's expiration time.*

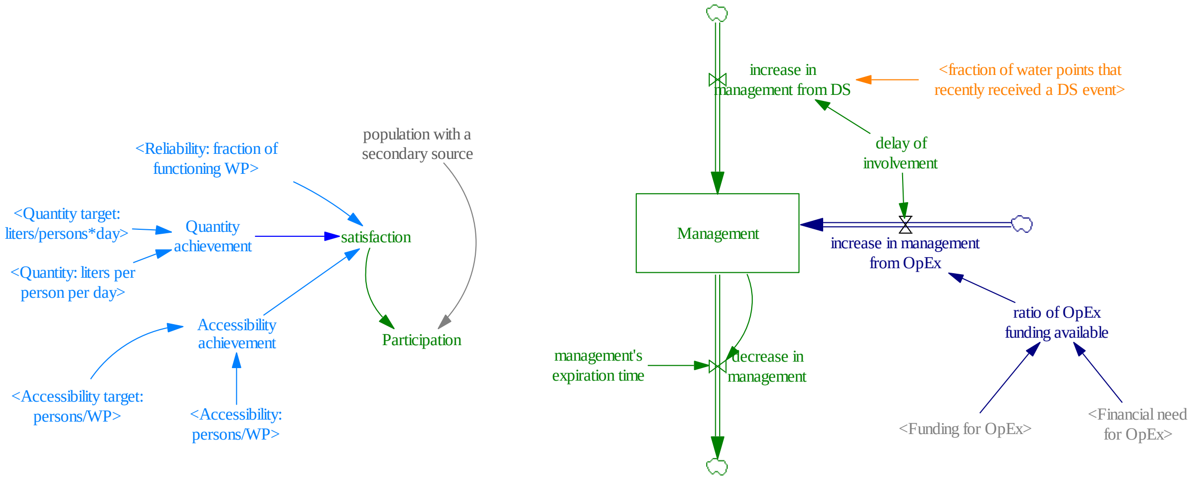


Figure 22 Stock and flow diagram for Sub-system 3: management and participation

Participation is formulated as the product of *satisfaction* and the population without a secondary source, estimated as "1 - the ratio of *population with a secondary source*". The *population with a secondary source* is formulated as a constant. In contrast, *satisfaction* reflects the services experienced by users, in terms of reliability, accessibility and quantity.

First, reliability is formulated as the *fraction of functioning water points.*

Second, accessibility is formulated as the Accessibility achievement, a table function of the ratio of Accessibility: persons/WP and Accessibility target: persons/WP (Figure 23). The shape of the table function indicates that when the actual Accessibility equals the Accessibility target, the Accessibility achievement is equal to 1, or 100%. When there are more persons per water point than expected (Accessibility > Accessibility target), the Accessibility achievement decreases. The current values indicate that when there is 10% of overcrowding in a water point (10% more persons than specified by the target), the Accessibility achievement decreases to 50%. When there is 20% of overcrowding, to 25%. When there is 30% of overcrowding, to 12.5%. Overall, the function indicates that overcrowding produces a rapid decrease in the Accessibility achievement.

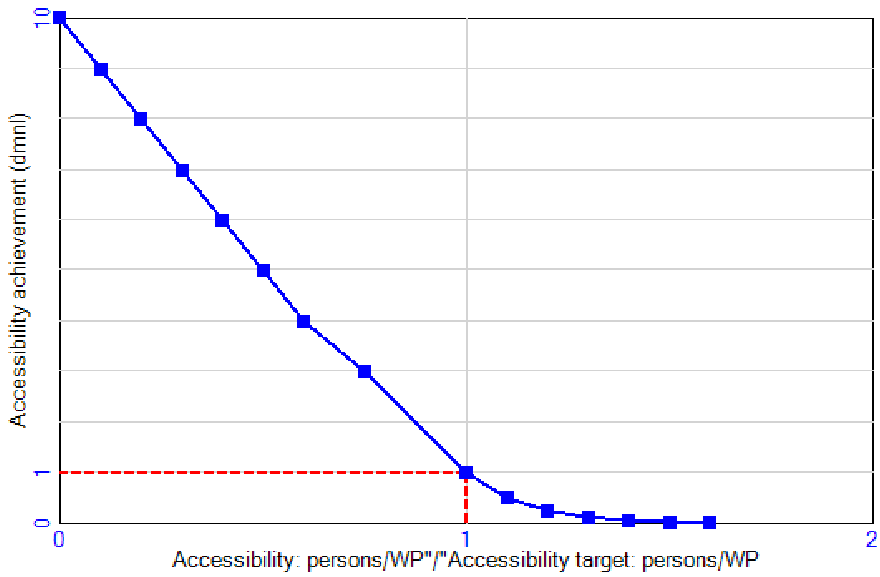


Figure 23 Table function of Accessibility achievement

Finally, *Quantity achievement* is formulated as a table function of the ratio of *Quantity: liters per person per day* and *Quantity target: liters/person*day.* When the liters per person per day equals the target liters per person per day (*Quantity* = *Quantity target),* the *Quantity achievement* is 1 or 100%. When no water is provided at all, the *Quantity achievement* is 0. The values in between are formulated as a linear function.

Exceeding the target value does not result in higher *Quantity achievement*. In reality, there is a limited amount of water that users can collect from a water point due to constraints of distance or crowding. Therefore, any ratios higher than 1 result in a *Quantity achievement* of 1 as well.

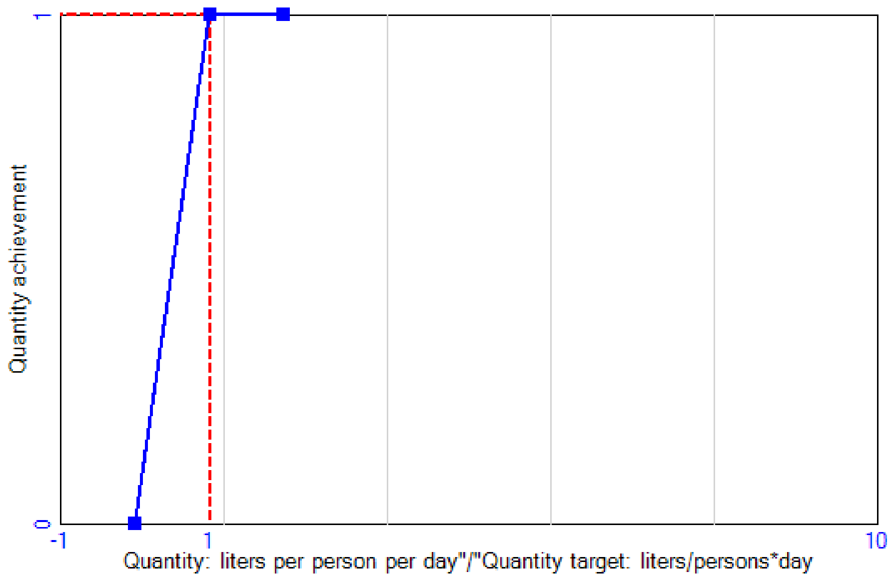


Figure 24 Table function of Quantity achievement

Key parameters: delay of involvement, management's expiration time, population with a secondary source, accessibility target, quantity target.

Key structures: Accessibility achievement, Quantity achievement.

6.1.4 Sub-systems 4 and 5: Budget and Allocation and execution

Funding from the public sector is a ratio of the size in dollars of the *public periodic allocation* and the *return period of the allocation* (Figure 25). These resources are allocated to the *CapManEx Budget, CapEx Budget* and *DS Budget* through the *allocation ratio CapManEx, allocation ratio CapEx* and *allocation ratio DS budget*, respectively. Thus, the *budget to CapManEx* is the ratio of the *funding from public sector* and the *allocation ratio CapManEx;* the *budget to CapEx* is the ratio of the *funding from public sector* and the *allocation ratio CapEx;* and the *budget to DS* is the ratio of *funding from public sector* and the *allocation ratio DS.*

The three budgets are level variables. *CapManEx Budget* decreases with the *spending CapManEx,* which is the ratio of *CapManEx events being executed* (previously detailed in Figure 21) and *average cost of a CapManEx event. CapManEx events being executed* is formulated as the outflow of *CapManEx demand,* detailed in the previous Section 4.3.2.

CapEx Budget decreases with *spending CapEx,* which is the ratio of *water points from public sector* (detailed further in Figure 26) and the *average cost of a CapEx event. Water points from public sector* is the product of the *standard new WP,* the *CapEx capacity* and the *max new water points per time step.* The *standard new WP* represents the normal rate of events that can be conducted, depending on the number of *funded new WPs.* The *max new WP per time step* represents the maximum number of events that can be executed if the *CapEx capacity* is increased. The *CapEx capacity* represents the work force that the public sector allocates for this activity, with a value of 1 corresponding to the capacity to execute one CapEx event at once. A special "MIN" function is therefore used to calculate *wp from public sector:*

wp from public sector = MIN(max new WP per time step,
CapEx capacity*standard new WP)

This function indicates that the *wp from public sector* increases when the *CapEx capacity* increases, but is constrained by the *max new WP per time step,* which is in turn based on the *funded new WPs.*

DS Budget decreases with spending DS, which is the ratio of WP receiving DS and average cost of a DS event. The WP receiving DS is the product of the standard DS execution, the DS capacity and the max DS per time step. The standard DS execution represents the normal rate of events that can be conducted, depending on the number of funded DS events. The max DS per time step represents the maximum number of events that can be executed if the DS capacity is increased. The DS capacity represents the work force that the public sector allocates for this activity, with a value of 1 corresponding to the capacity to execute one DS event at once. A special "MIN" function is therefore used to calculate WP receiving DS:

WP receiving DS = MIN(max DS per time step, DS capacity*standard DS execution)

This function indicates that the *WP receiving DS* increases when the *DS capacity* increases, but is constrained by the *max DS per time step,* which is in turn based on the *funded DS events.* Furthermore, the *WP receiving DS* is used as the inflow to the level variable *WP with recent DS.* This level accounts for the CBM systems that have recently received Direct Support. *WP with recent DS* decreases by means of *DS expiring,* which is the ratio of *WP with recent DS* and the *effective time of DS.* The *effective time of DS* represents the period that the support provided remains effective.

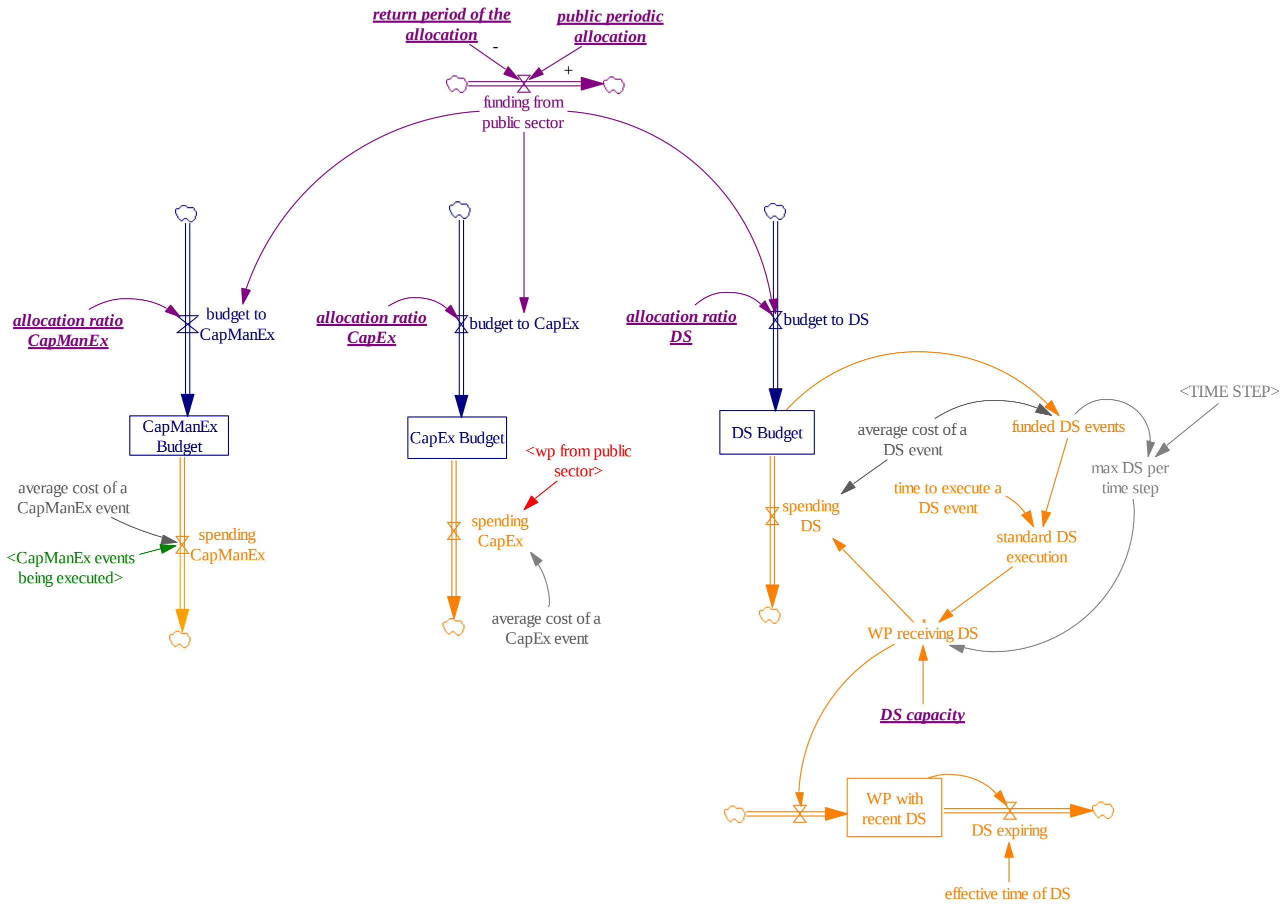


Figure 25 Stock and flow diagram for Sub-system 4 and 5: Budget and Allocation and execution

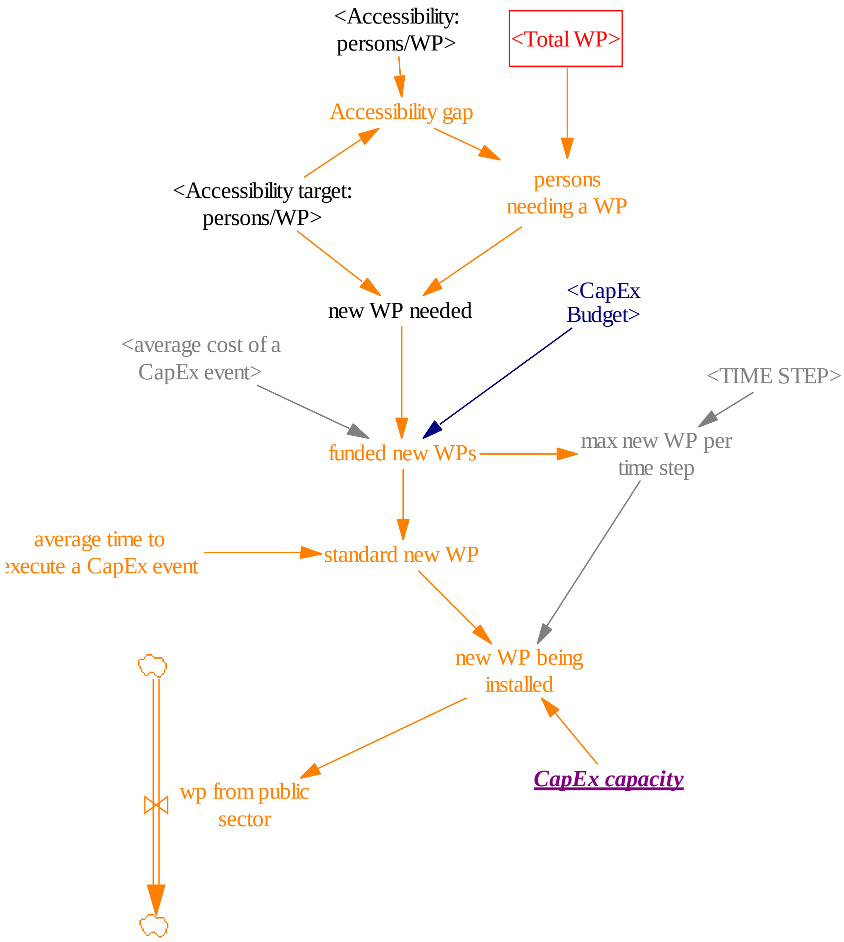


Figure 26 Stock and flow diagram for Sub-system 4 and 5: execution of CapEx

Key parameters: return period of the allocation, public periodic allocation, average cost of a CapManEx event, average cost of a CapEx event, average cost of a DS event, average time to execute a CapEx event, time to execute a DS event, DS Capacity, CapEx capacity, allocation ratio CapManEx, allocation ratio CapEx, allocation ratio DS.

Key structures: provision of direct support.

6.1.5 Key Performance Indicators

First, key performance indicators of water service levels: reliability, accessibility and quantity.

The variable *Reliability: fraction of functioning WP* is formulated as the ratio of Functioning WP and Total WP.

Accessibility is measured by means of two variables. First, *Accessibility: persons per functioning WP* excludes from the calculation water points that are failed. It is the ratio of *Total population served by water points* and the *Functioning WP*. Second, *Accessibility: persons/WP* is the ratio of *Total population served by water points* and *Total WP.*

Quantity: liters per person per day is formulated as the ratio of the product of actual liters per day per water point and the total WP, and the population served by water points.

The actual liters per day per water point is the product of the standard liters per day per WP and the WP's performance index.

The standard liters per day per WP is the measure of the water flow that a single water point can deliver in one day. The WP's performance index aims at reflecting the quality of the service that a water point can provide, depending on its age. In other words, a new water point provides the standard liters per day per WP, while older and failed WPs provide less liters. Therefore, the WP's performance index is the sum of the weighted new WP performance, weighted older WP performance and weighted failed WP's performance. Each weighted performance variable is the product of the water point's performance (percentage of the standard liters per day per WP) and the ratio between the number of new, older or failed water points and the Total WP.

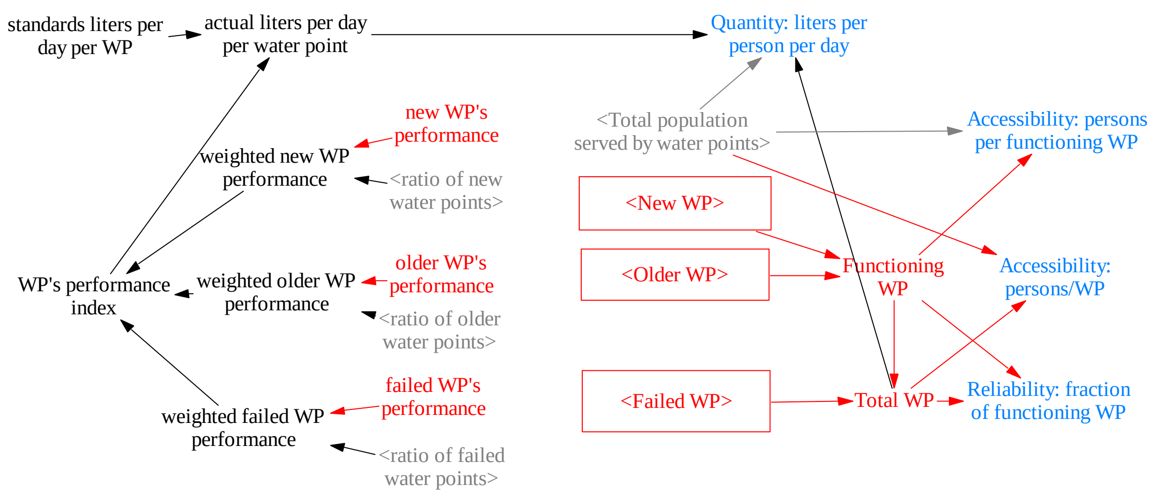


Figure 27 Stock and flow diagram for the key performance indicators: water service levels

Second, key performance indicators of the financial costs. *Total expenditures* is the sum of the expenditures from operation and maintenance (*OpEx spent)*, funded by local users, and *expenditures from public sector.* The latter is the accumulation of the funding spent on new water points (*CapEx spent),* on repairs, renewals and rehabilitations (*CapManEx spent),* and the funding spent on direct support (*DS spent).*

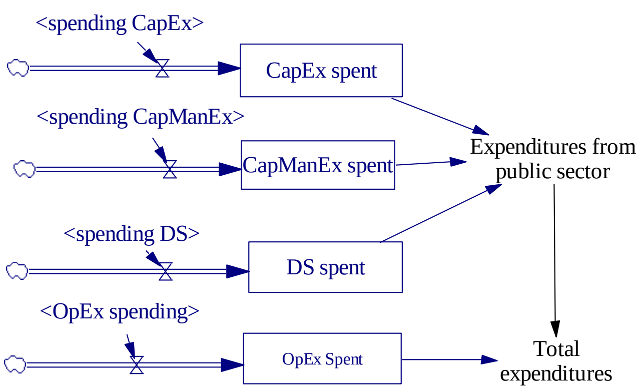


Figure 28 Stock and flow diagram for the key performance indicators: financial indicators

Key parameters: new and older WPs performance, failed WPs performance, standard liters per day per water point.

Key structures: WP's performance index.

6.2 Model testing

The model was verified and validated by undertaking different tests. Verification checked that the model was coded correctly, that it is dimensionally consistent and that an appropriate numerical integration method with a correct time step has been chosen. Validation aimed at building confidence in the model by checking that it appropriately represented the problem. As part of this process, interviewees were conducted with problem owners that participated in the initial interviews. The following paragraphs elaborate further on the tests that were conducted.

6.2.1 Verification

Three basic tests (units check, numerical method, changing the time step) and an expert consultation served to verify the model formulation. These methods are detailed below.

Units check: the dimensional consistency of the model was checked using the "Units check" tool of Vensim DSS®. This tool identifies variables without specified units, as well as dimensional consistency problems. These errors were tracked back to their origin and the missing units were added to the variable. When the "Units check" warned about units that were inconsistent, the equations were checked and updated. Thus, in some cases, errors in dimensional consistency were the symptom of errors in the coding of the model, and the latter were subsequently corrected.

Numerical method: Euler was chosen as the numerical method to solve the system of equations, along with a time step of 10% of the smallest time interval in the model. Using the Euler method to solve a system that is essentially continuous gives shocks to the system and can highlight errors in the model coding. In this case, the model ran smoothly.

Changing the time step: the selected time step (10% of the smallest time interval in the model) was decreased to assess if this change modified the behavior of the model. If that had been the case, a smaller time step would have been selected for subsequent simulations.

Automatic model check: Vensim DSS® provides a standardized tool to check the model. This tool scans for variables that are part of the model, but do not serve as input for any other system of equations. This test can highlight errors in the coding, such as using the incorrect variable in an equation. In the model, only two variables are not used: *Accessibility: persons per functioning WP* and *Total expenditures.* These variables are included in the model only to facilitate comparisons when analyzing the results.

Expert consultation: an interview with an expert on system dynamics methodology was held, in which a general assessment of the quantitative model was conducted. Discussion points included variables with dimensionless units, use of time step, embedded data, lookup functions, inclusion of discrete equations, complex formulations, time frame of the model and the use of random noise. Based on these points, necessary actions were identified and the model improved. A summary of this interview is provided in Appendix 4.

6.2.2 Building confidence on the model

Two main types of tests were applied to validate the structure and the behavior of the model: direct structure tests and structure oriented tests. The first ones aim at assessing whether the structure of the model is adequate by studying the relations between variables. While the second type of tests have the same objective, the structure is assessed indirectly by calculating the model and studying the results. The following paragraphs elaborate on the tests that were conducted.

Direct structure tests

Empirical structure: the formulation of the qualitative model and the quantitative one were based on insights from the literature (Chapter 3) and experts on CBM systems and system dynamics for water management (Chapter 3 and 5, and Appendix 1 and 3).

Parameter confirmation: as part of the second set of interviews (Chapter 5 and Appendix 2), experts on CBM systems provided educated guesses about possible values of parameters in the model, for any give case.

Boundary adequacy of structure: the model structure was designed with the systems diagram as a basis (Figure 9), in which the system boundaries were defined in advance.

Structure-oriented behavior tests

Extreme value test: the model equations were calculated under extreme conditions. The objective was to assess whether the resulting values reflected the conditions that could occur in a real situation.

Sensitivity analysis: the objective of this test is to determine the variables that when changed, have a major influence on the model behavior. To conduct this test, the model was parameterized with the values reported in Annex 2. While these values correspond to the case study of Kabarole district, reported in Chapter 7, model parameters and input values were changed to explore not only developments for this case, but also for CBM systems that have different characteristics: greater or smaller populations, higher or lower initial reliability, or a different number of initial water points. corresponding to this particular case, but also for initial or input variables.

Its results are classified according to the type of sensitivity that the model exhibits: numerical or behavioral. The former sensitivity consists of numerical changes in the model key performance indicators (KPI). The latter is exhibited when the overarching behavior of one or more KPI is modified. Behavioral sensitivity indicates can indicate uncertainties associated to the problem situation i.e. annual net population growth rate, or fertile ground for policy design i.e. allocation policy.

In Table 7, the main sources of behavioral sensitivity are summarized, and a complete report of this test is include in Appendix 4. In the next section, a discussion of its implications for model use and improvement is presented.

Table 7 Sources of behavioral sensitivity

Parameter	Description	Influenced KPI
Initial water points	The initial number of water points influences quantity and accessibility: if the target accessibility has not been reached, new ones will be built.	Quantity, Reliability*, Accessibility OpEx Spent*, CapEx Spent*
Annual net population growth rate	Negative values lead to higher service levels. Directly, they reduce the number of persons per water point and increase the quantity of water per person. Indirectly, they increases satisfaction, maintenance and as a result, reliability.	Quantity, Reliability, Accessibility OpEx Spent, CapEx Spent*
Accessibility target	Persons per water point target that determines the number of new water points that should be built.	Quantity, Reliability*, Accessibility* OpEx Spent, CapEx Spent*
Allocation policy	Three parameters that determine the budget allocated for new water points, capital maintenance or direct support. They remain constant over the simulation time.	Quantity, Reliability, Accessibility OpEx Spent, CapEx Spent* CapManEx Spent*, DS Spent*
OpEx effect on lifespan	Influence of operation and regular maintenance on water point's lifespan and probability to fail.	Quantity, Reliability OpEx Spent

*Effect on these variables is only numerical.

Face validation: In this study, attention was paid to building confidence in the model not only from the modeler's perspective but also from the viewpoint of its potential users. Therefore, as part of the second set of interviews (Chapter 5 and Appendix 2), the behavior produced by a preliminary model was discussed and the experts commented on the extent at which it represented a real world situation.

6.2.3 Recommendations for model use

One of the outcomes expected from this research is to provide guidelines for future users in the model. These guidelines are specified below and later, in Chapter 7, they are applied to a particular case study.

1. **Regarding the research design.** When using the model, a case study research design is recommended. Analyzing a particular situation instead of the generality allows users to gain context-specific insights. On the one hand, the model can be parameterized with quantitative with data from that situation and the resulted behavior can be studied. On the other, the model can be used as a boundary object (van Waas et al., 2015): by engaging stakeholders in the study of the qualitative model and its quantitative formulation and modes of behavior, decision making and learning processes can be facilitated.

2. **Regarding the model assumptions.** Verify whether model assumptions are valid for the particular case. Understanding the core assumptions allows the user to interpret results in this light or to modify the model with context-specific assumptions.

3. **Regarding the model parameterization.** Use case-specific values for parameters and variables that reflect the initial state of the system. Pay special attention to the *initial water points, annual net population growth rate, OpEx effect on lifespan* and *allocation policy.*
   a. The initial water points (the sum of *new, older* and *aged* ones) indicate if the system requires new water points to reach the *accessibility target.* Experimenting with different values for this parameter enables the user to simulate systems that are closer or further away from reaching the persons per water point target.
   b. The *annual net population growth rate* determines if new water points are needed during the simulation time: when its value is zero or negative (no net population growth or the size of the population decreases) no additions are required; if its value is positive, more infrastructure is needed. When using the model, sensitivity analysis for this parameter should be run, as it real-world value is often unpredictable and constitutes an uncertainty under which decision makers must act.
   c. Different values for *accessibility target* represent the effect of setting different persons per water point targets on the system. Its effect is straight forward: lower targets result in lower service levels and expenditures. For future model use, it is recommended to use internationally accepted accessibility targets (United Nations, 2015, WHO, 2016, Moriarty et al., 2013) and if necessary, compare them with context-specific ones.
   d. Similarly, by changing the value of the three parameters accounted for in the *allocation policy,* different policies can be simulated. These changes enable the user to test the limits of what can be achieved with comparable budgets within the CBM paradigm.
   e. While the *OpEx effect on lifespan* changes the behavior of three KPI, no real-world value for was available for this study. When using the model to study specific cases, sensitivity analysis on this parameter should be run.

6.2.4 Recommendations for model improvement

Future model improvement should center, first, on a quantitative study of the influence that operation and minor maintenance have on water points' lifespan and reliability. For this purpose, three research questions have been formulated:

1. How do continuous operation and minor and preventive maintenance influence water points' lifespan and reliability?
2. How do local participation and management influence continuous operation and minor and preventive maintenance of water points?
3. How does direct support influence local participation and management?

Statistical analysis of data regarding the lifespan and operation and minor maintenance of water points is the proposed research method to answer these questions. More specifically, for a given CBM system, three regression models can be estimated:

1. Water point's lifespan as a function of continuous operation and minor and preventive maintenance.
2. Water point's continuous operation and minor and preventive maintenance as a function of participation and management.
3. Local participation and management as a function of direct support.

Together, these regression models can provide insights on the quantitative interaction between the physical and social components in the system, and can serve to validate and modify the structure of the quantitative system dynamics model. Furthermore, they can provide further information on the return of investment of the provision of direct support as a means of increasing water points' lifespan and reliability.

A second point of interest for future improvement is the simplification of the current structures into more aggregated ones. While the formulation of the current model was based on its quantitative counterpart, further analysis can shed light on the quantitative structures driving its behavior. In turn, these findings can in turn lead to the re-design of the qualitative model, and even the systems diagram.

Chapter 6 in a nutshell

Key formulation choices

- Key choices in the formulation of the qualitative mdodel were explained.
- Key structures and parameters were identified for further testing or study.

Model testing

- Three basic tests and an expert consultation served to verify the model formulation.
- Main sources of model uncertainty were identified and discussed: initial water points, annual net population growth rate, accessibility target, allocation policy, OpEx effect on lifespan.

Recommendations for model use

1. Use a case study research design.

- Analyzing a particular situation allows users to gain context-specific insights.
- By engaging stakeholders in the study of the qualitative model and its quantitative formulation and modes of behavior, decision making and learning processes can be facilitated.

2. Verify whether model assumptions are valid for the particular case.

- Understanding the core assumptions allows the user to interpret results in this light or to modify the model with context-specific assumptions.

3. Parameterize the model and study its resulting behavior.

- Use case-specific values for parameters and variables that reflect the initial state of the system.
- Use internationally accepted accessibility targets and if necessary, compare them with context-specific values.
- Experiment with different initial water points to simulate systems in different stages of development.
- Conduct sensitivity analysis for annual net population growth rate and for OpEx effect on lifespan.
- Experiment with different values for allocation policy to test the limits of what can be achieved with comparable budgets within the CBM paradigm.

Part IV

Apply and Re-learn: making insights and recommendations explicit

7 Apply: a closer look into a CBM system

Kabarole district, in Uganda, was selected as a case study to have a closer look into CBM systems. Three rationales support the use of one case instead of multiple ones (Yin, 2009): (1) when the case is representative; (2) extreme; or (3) to test a well-formulated theory through the study of a critical case. The case of Kabarole is representative and critical.

As a country, Uganda is a representative case. While access to drinking water in Sub-Saharan Africa is estimated to be 68% (Unicef, 2015), in this country it is estimated to be 64% (Republic of Uganda, 2013, 2014, 2015). Nonetheless, because service levels vary greatly within Uganda, the smaller scale of the district was selected for this study.

As a district, Kabarole is a critical case. On the one side, the proportion of its rural population with access to safe water is estimated to be 86% to 90% (Biteete et al., 2013, IRC Uganda, 2015), which is in average, 20 percentual points higher than the national estimate. However, the actual level of service is below standard (IRC Uganda, 2015), a critical situation that is common to other Sub-Saharan locations. Thus, Kabarole's characteristics make it a suitable case to test the model and gain insights regarding CBM systems. Furthermore, the choice of this district was motivated by the availability of recent and local data (Biteete et al., 2013, IRC Uganda, 2015), which made possible to validate the model behavior.

In the first section, rural water delivery in Uganda is contextualized, and additional information regarding Kabarole is provided. In the second section, the application of the model and its findings are reported. Finally, in the third section, an assessment of the system dynamics model is presented, based on its functional requirements.

Chapter 7: a reader's key

Background

Based on the qualitative system dynamics, model, a quantitative one was formulated.

Objective

To have a closer look into a CBM system and test the suitability of the quantitative system dynamics model to gain insights on the case.

Sections

Rural water delivery in Kabarole, Uganda

Simulating Kabarole

Assessing the system dynamics model

Highlights

In section 7.3, an assessment of the model is presented by comparing its capabilities to the functional requirements from section 4.2.

7.1 Rural water delivery in Kabarole, Uganda

Since it was first introduced in the national water policy in 1999, CBM has been the predominant paradigm for the provision of safe water in rural areas of Uganda (Mugumya, 2013). During the previous decade, the adoption of CBM was championed by the United Nations Children's Emergency Fund (UNICEF) (MWE, 2011a) and influenced by the 1980 International Drinking Water Supply and Sanitation Decade (IDWSSD) and 1992 Rio Summit's Agenda 21 (United Nations, 1992). Ever since, its goal has been to increase rural safe water supply by reducing public expenditure, allowing market liberalization and government decentralization (Mugumya, 2013).

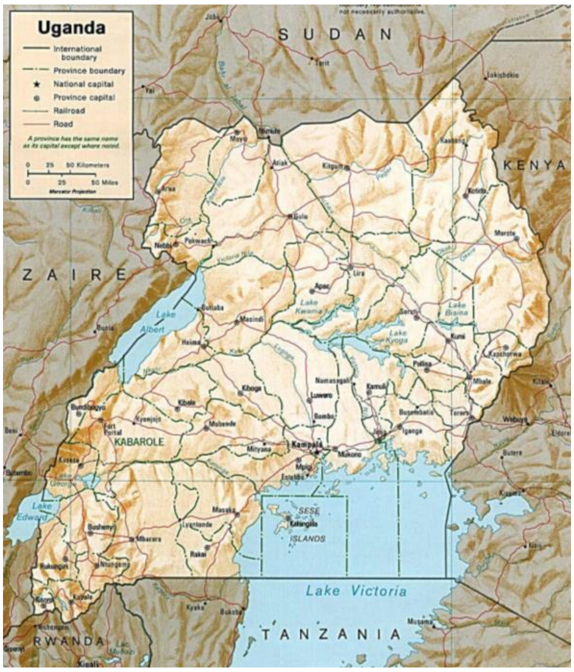


Figure 29 Map of the Republic of Uganda

7.1.1 Multi-level governance of rural water delivery in Uganda

In the country, areas with populations below 2000 are typically served by water points (Republic of Uganda, 2013), and the main actors and institutions who participate in rural water delivery can be studied at three levels (Mugumya, 2013, van Tongeren, 2014): macro, meso and micro-level.

Macro-level

At a macro-level, the Ministry of Water and Environment (MWE) is in charge of the development of national water policies and standards, regulation and management of resources and agenda setting for developments of the sector. The MWE, which is part of the Government of Uganda (GoU), monitors the effectiveness of water policies by means of annual sector performance reports (Republic of Uganda, 2013, Republic of Uganda, 2014, Republic of Uganda, 2015). Moreover, it coordinates its activities with other central governmental institutions, including Ministries and Directorates.

In particular, the Directorate of Water Development (DWD) is in charge for the delivery of domestic rural water services. Along with large and medium size private actors, donors and development partners, including non-governmental institutions (NGO's), the DWD acts at a national level (Mugumya, 2013). Currently, the contributions of donors and development partners are aligned with national objectives through the Sector-Wide Approaches to Planning (SWAP) (Nimanya et al., 2011), which enables common decisions regarding individual projects. Thus, donors and development partners, along with Ministry of Finance, Planning and Economic Development (MoFPED), are the main source of funding for the development and implementation of national policies. In 2015, development partners contributed with 34% to the national funding (Republic of Uganda, 2015).

Meso-level

At a meso-level, the Directorate of Water Development operates through one hundred and eleven District Water Offices (DWO), which represent the districts and their corresponding sub-counties. The DWO's are in charge of planning, monitoring, installing and conducting major repairs on water points (Republic of Uganda, 2013). To fulfill these tasks, they receive a District Conditional Grant from the national government on an annual basis; nonetheless, their resources and staffing are often reported to be insufficient (Republic of Uganda, 2013, van Tongeren, 2014).

Other relevant actors at a meso-level are small private firms and service providers, such as the Hand Pump Mechanics (HPM) (Mugumya, 2013, Republic of Uganda, 2013). Small private firms deal spare parts for water points and HPM's provide their services to the DWO's and to local managers to conduct capital maintenance that exceeds local capabilities (Republic of Uganda, 2013). They receive assistance from Technical Support Units that depend on the Ministry of Water and Environment (Mugumya, 2013, Republic of Uganda, 2013).

When a water point fails and the budget needed for its repair is low, local managers can directly hire the HPM and pay for the repair with funding collected from local users. When the budget needed is higher, it can be funded by the District Water Offices, whenever funding is available at that time of the year. Otherwise, the request for the repair will be submitted by the District Water Office to the Directorate of Water Development for next year's budget (van Tongeren, 2014).

Micro-level

At a micro-level, the main water service delivery model for rural domestic water supply is CBM of water points (Nimanya et al., 2011). Thus, actors at a micro-level include the community of water users and the local managers organized in the Water User Committee, elected by users themselves (Mugumya, 2013).

In spite of efforts at the three levels to provide sustainable water services for all Ugandans, over the last few years, water coverage in this country has remained stagnated around 64%, and functionality has been reported to remain 83% (Biteete et al., 2013, Republic of Uganda, 2015). Some of the factors that have influenced this stagnation include a rapidly increasing rural population (Republic of Uganda, 2014), increasing per capita costs to connect new users to the service (Republic of Uganda, 2014), insufficient funding (Republic of Uganda, 2014, Republic of Uganda, 2015) and lack of maintenance of water points (Republic of Uganda, 2014). Overall, there is a lack of insight on which changes in the current water service delivery model can lead to a breakthrough in national water coverage, and in the water service levels.

7.1.2 Rural water delivery in Kabarole

Information and statistics for this case were obtained from a report prepared for the Triple-S Uganda Initiative, at IRC International Water and Sanitation Center (Biteete et al., 2013).

Kabarole, depicted in orange in the figure[7] to the left, is a Ugandan district located in the center-west of the Western Region of Uganda. This district reports that functionality and access to safe water are approximately 80% and 90%, respectively, and empirical research has revealed that about 30% of water points have an active Water User Committee.

By 2013, Kabarole's projected population was slightly more than 415000, with a rural population accounting for 78.8%. The district's annual population growth rate was estimated to be 1.53%. From the district's rural population, 77% were served by water points, a number equivalent to 60% of the total population in the district. Moreover, 13% of the total population had access to a second water point.

Figure 30 Map of the Republic of Uganda, depicting Kabarole District in orange

By 2013, the district had 1308 rural domestic water points: 88 boreholes, 658 shallow wells with hand pumps, and 562 protected springs. In that year, Kabarole received a District Conditional Grant of 180000 USD, 70% of which was used on the installation of new water points, a percentage recommended by the national government. After these expenses, the district was left with less than 10% of the lowest benchmark for recurrent costs.

Overall, water service levels in Kabarole have been described as below-standard, in spite of having encouragingly high rates of functionality and access to safe water. Based on this situation, two questions were formulated:

How can Kabarole provide standard or above-standard water service levels?

Can this goal be achieved within the CBM paradigm?

[7] Image: *Kabarole District Uganda,* by Slomox. Licensed by Creative Commons Attribution-Share Alike 3.0 Unported license. Uploaded to Wikipedia on 9 June 2005. License: http://creativecommons.org/licenses/by-sa/3.0/
Image: https://commons.wikimedia.org/wiki/File:Kabarole_District_Uganda.png.

7.2 Simulating Kabarole

To answer the previous questions, the quantitative system dynamics model was used, following recommendations presented in sub-section 4.2:

1. **Parameterize the model.** Case-specific values were used for both, parameters and variables that reflect the state of Kabarole in 2013. Numerical values, units and sources are reported in Annex 2.

   Additionally, a change in the structure of the model was made to more accurately reflect the situation in the district. In the standard model, after the accessibility target has been reached, no more water points are funded or built. In this case study, however, it is uncertain how the public sector decides on the number on new water points that should be built. Therefore, in the model used for this case, water points continue to be built until all the budget allocated for this activity has been spent, even if the accessibility gap has already been bridged.

2. **Produce a reference run.** After being parameterized, a reference scenario was produced by simulating the model for 30 years, with simulation year zero corresponding to 2013. This scenario represents a future in which parameters in the model remain constant and no new policies are introduced.

3. **Set up contextual scenarios.** A sensitivity analysis was conducted for the reference run by testing different values for the *annual population growth rate* and the effect that operation and maintenance have on the lifespan of the water points (*OpEx effect on lifespan)*. These variables were reported to be 1.53% and 25% in Kabarole in 2013 and the model was solved 1000 times with combinations of values within the ranges [0%, 4%] and [0%, 80%].

4. **Design and test policies.** Two policies were designed with the objective of increasing the service levels in the simulated district.

   First, the *Accessibility Policy* changed the rule to decide the number of water points that are built in the district. Instead of adding infrastructure until the budget is depleted, only the water points that are needed to bridge the accessibility gap are built. In the real-world equivalent of this policy, the district would have to return the unspent budget to the national government at the end of the year.

   Second, *Adaptive policy* made an addition to the *Accessibility Policy:* instead of returning the unspent budget, this amount was used to repair failed water points and when resources were sufficient, direct support was provided.

   To test a change in a fundamental principle of the CBM paradigm, the *Adaptive policy* was simulated with a maximum of 10% of the budget allocated to direct support. This scenario run represents a situation in which the public sector provides not only the funding needed for capital maintenance, but also guarantees that this maintenance is indeed executed. Thus, it implies lower investments in building local capacity and represents either a *quasi*-return to the state-led era, or the integration of alternative business models for capital maintenance.

The remaining parts of this section describe the results of this simulation. Then, a discussion of their implications in a real-world situation is presented.

7.2.1 Reference behavior

After the first simulation year, the three water service levels remained above average: quantity increased, reliability reached almost 100% and accessibility was less than 200 persons per water point (Figure 31). At first glance, this situation seems to indicate that no action is required in the simulated district: if contextual factors and policies remain unchanged, above-standard services levels will be provided.

At second glance, however, the origin of this continuous improvement can be tracked back to the non-stopping installation of new water points. Currently, the district allocates 70% of its annual funding to the construction of new infrastructure, an allocation policy that is problematic for three reasons.

First, in the model, high reliability is indirectly caused by an increase in quantity and an improvement in accessibility. As the latter service levels increase, so do management and participation, resulting in sufficient funds and capacity for local managers to fix non-functional water points. Nevertheless, whether this causal chain holds is yet to be tested.

Second, in the real-world, a non-stop increase in new water points can result in apparently high reliability rates: as the total number of water points increases, the proportion of non-functional ones becomes smaller. Therefore, in addition to tracking the reliability of a system, the total number of water points should also be monitored.

Third, when districts report an improvement in their service levels, the annual funding that they will receive the next year is likely to decrease. Thus, they are often not able to maintain their expenditures equally high over time. In the model, the amount of this funding is considered to be an external factor because its value depends not on the district's performance alone, but on the relative one compared to the national average.

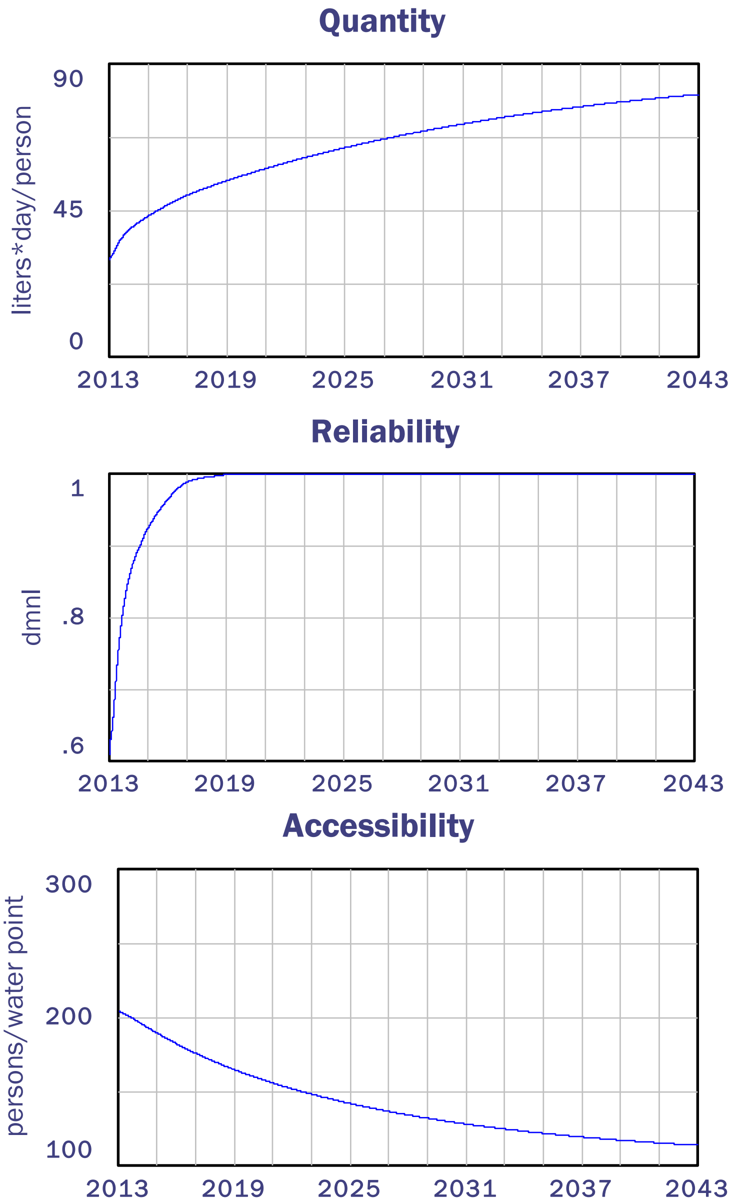


Figure 31 Reference run: water service levels

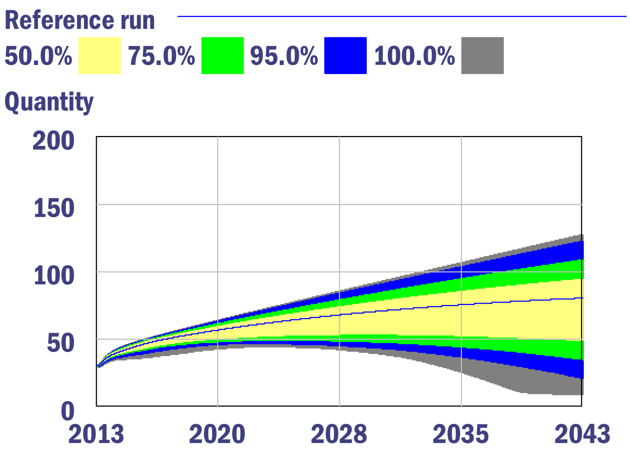
7.2.2 Contextual scenarios

In the reference run, water service levels are sensitive to changes in *annual net population growth rate* and *OpEx effect on lifespan*. In the sensitivity plots (Figure 32), the proportion of simulation runs that fell within certain confidence bounds are indicated by the shaded areas: 50% of the runs produced values in the yellow area for a given time step, 75% in green, 95% in blue, and 100% in grey 100%.

As previously explained in sub-section 6.2.2 and Table 7, negative population growth rates result in increased water quantity per person and improved accessibility. Moreover, they indirectly influence reliability through the causal chain discussed in the previous sub-section (increased satisfaction, management and participation, and non-functional water points fixed by local managers).

Similarly, *OpEx effect on lifespan* influences these KPI, as increased management and participation result in higher operation and minor maintenance, and as a result, in extended lifespan of water points and less failures.

Thus, two implications can be identified for policy design. First, the high service levels must be achieved at the lowest possible cost, as improvements in their values can result in decreased annual funding for next year. Second, service levels are largely dependent on management and participation, which in turn depend indirectly on population growth. Therefore, policies must be able to achieve their objectives under different population growth scenarios.



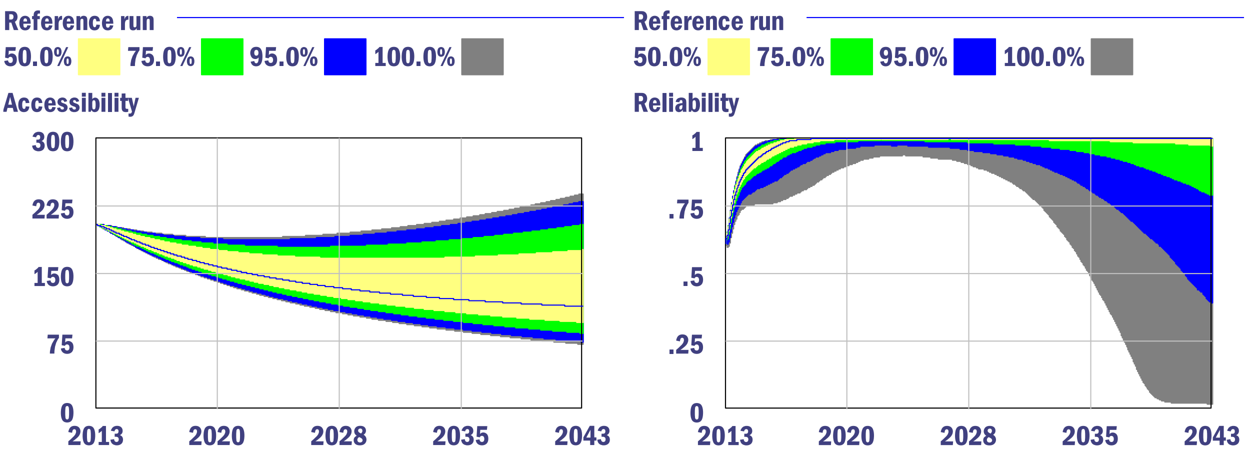


Figure 32 Reference run with sensitivity analysis: water service levels

7.2.3 Policy scenarios

Accessibility policy

This policy scenario resulted in high quantity and standard accessibility, although both service levels were lower than those of the Reference run. While reliability remained higher than 70% in most of the simulation time, it exhibited decreasing behavior. This behavior is explained by the new rule to allocate the district's budget: water points were only built when there was an accessibility gap and the remaining budget was not allocated to maintain non-functional water points. Instead, only 20% of the budget was used for capital maintenance, a proportion that is not enough to repair failed water points.

In terms of expenditures, the accessibility target was achieved with about one third of the budget spent on new water points under the Reference run. This shows that there is no need to allocate 70% of the budget to the construction of new water points because, in the simulated district, maintaining high reliability is a bigger challenge than achieving the accessibility and quantity targets.

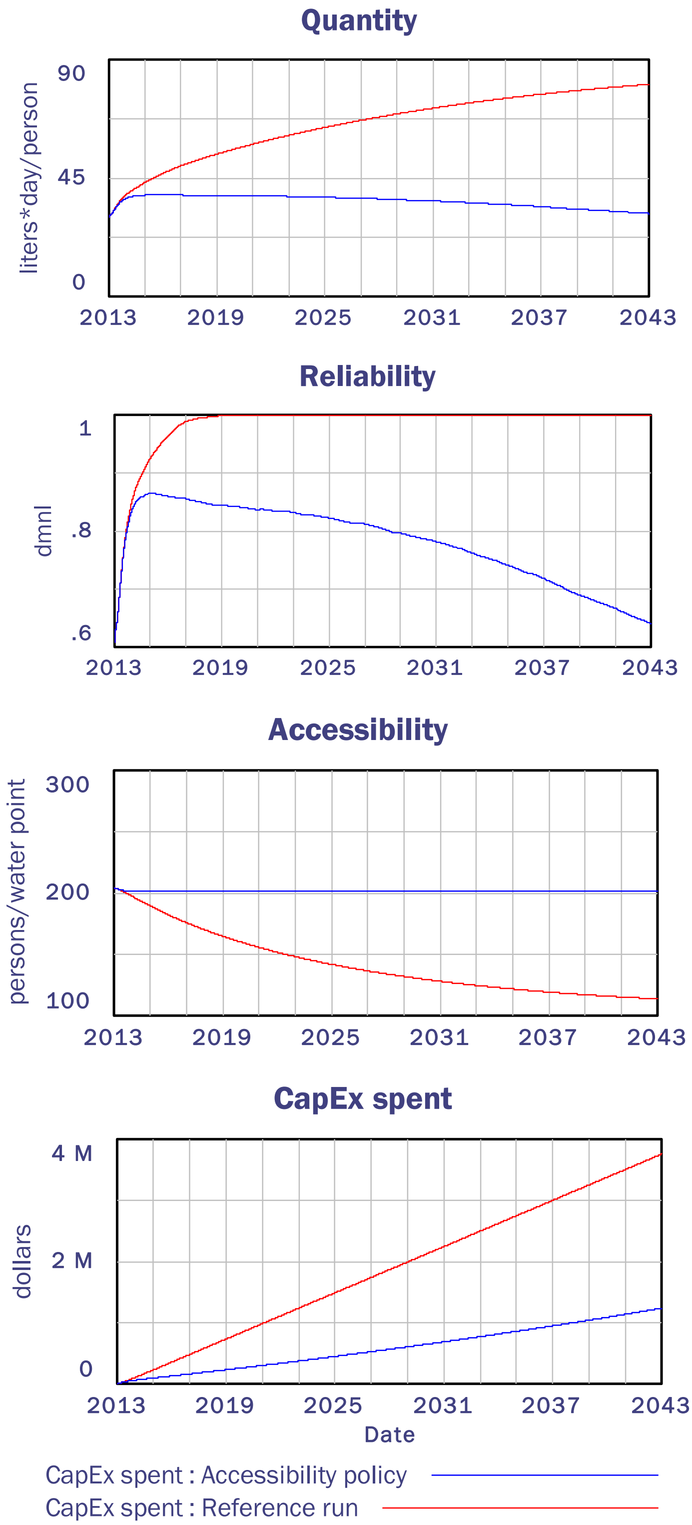


Figure 33 Accessibility policy: water service levels and expenditures

Adaptive policy

Results from this policy differ from the Accessibility policy in three ways. First, a higher investment in capital maintenance takes place at the beginning of the simulation in order to repair the non-functional water points. Second, after this initial investment, reliability over or close to 90%. Finally, most of the funding was allocated to direct support because the accessibility gap was bridged and non-functional water points repaired.

To test whether comparably successful results could be obtained with lower expenditures in direct support, the rules to allocate funding were modified and the proportion of the budget that could be used in this activity could not be higher than 10%. As a result, the three service levels, expenditures in operation and minor maintenance and in new water points remained fairly equal. While capital maintenance expenditures (CapManEx) increased, the cumulative expenditures were about one third lower.

These results suggest that water services could be improved to standard levels with possibly 75% of the current budget. Moreover, more budget is required for repairing non-functional water points than for constructing new ones.

Color-coding for lines in Figure 34

Adaptive policy
Adaptive policy +10% direct support
Accessibility policy
Reference run

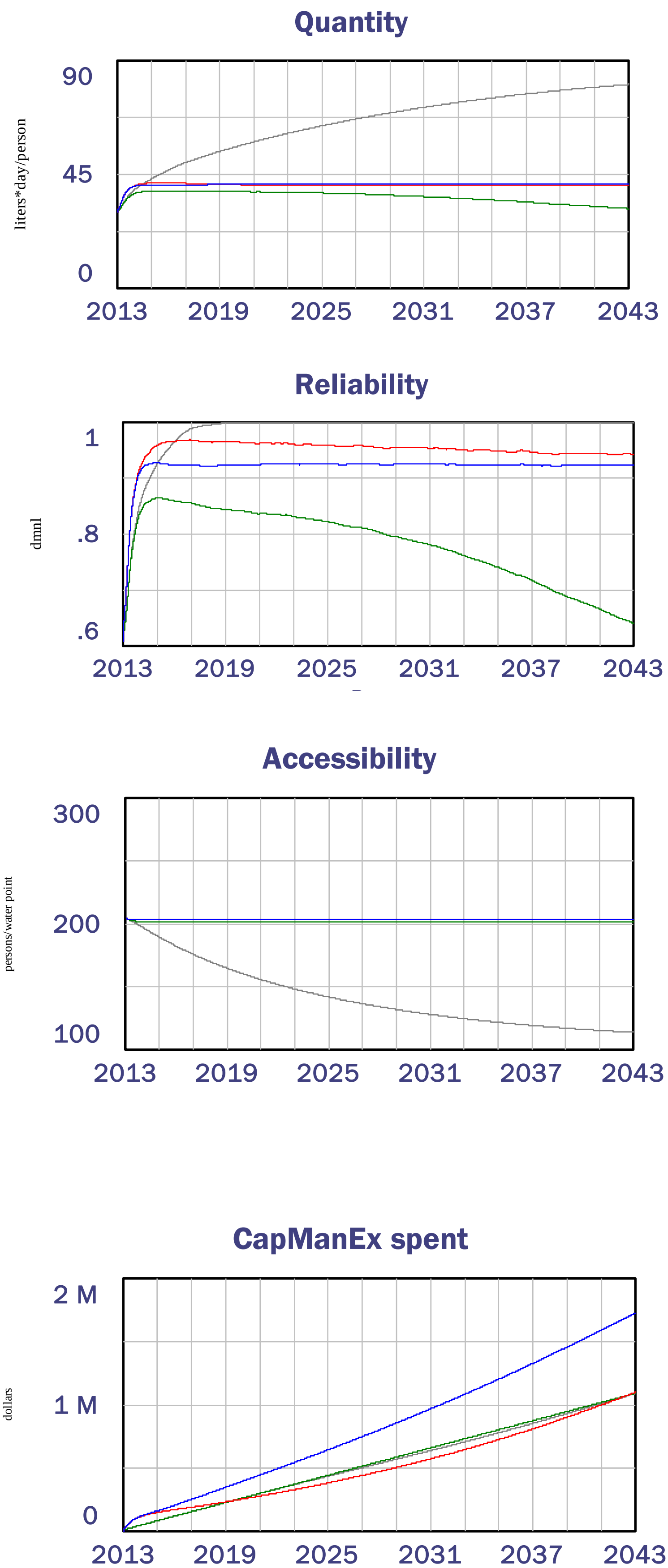


Figure 34 Accessibility policy: water service levels and expenditures

The robustness of the Adaptive Policy with a 10% roof for direct support was tested under multiple scenarios. While quantity and reliability exhibited behavioral sensitivity, accessibility exhibited only numerical changes. The origin of this sensitivity are the different values for the *annual population growth rate.* In scenarios in which this variable has a higher value, most of the budget is allocated to the construction of new water points, leaving limited funds to address failed water points.

In the real-world, however, an increase in its population would possibly result in greater funds being allocated to the district for the following year. Therefore, this sensitivity is caused by the modeling choice of representing the budget received by the district as an external factor.

7.2.4 Validation of findings

The validity of these findings was confirmed by two means. First, they were compared to descriptions found in the literature regarding service levels in Kabarole (IRC Uganda, 2015, Biteete et al., 2013) and CBM systems in Uganda (Mugumya, 2013). Then an open interview was held with the author of a doctoral dissertation on the topic Mugumya (2013).

7.2.5 Insights regarding the case study

Results from this study indicate that Kabarole is close to bridging the accessibility gap: the water points that have already been constructed in the district will be sufficient to achieve the maximum persons per water point target. However, the same cannot be said regarding reliability. At first glance, it may seem that functionality rates are not a problem, but a second glance reveals that these high numbers result from the construction of more water points than needed, an activity that consumes 70% of the district's annual budget. As the ageing process of existing water points continues, a crisis of non-functional water points approaches. Thus, the focus of decision makers should be on maintaining the existing infrastructure and adding water points only to close the remaining accessibility gap.

Further, it was found that standard or above-standard service levels are plausible without increasing the annual budget received by the district. Instead of using 70% of the available budget to construct new water points, funding should be allocated according to up-to-date needs of the system. For Kabarole, this strategy would significantly deliver more enduring services than continuing with the current policy and increasing the number of water points in the system.

Moreover, the simulation study makes evident that users and local managers play a crucial role in maintaining high reliability levels in CBM systems. If funding is re-allocated and capital maintenance strengthened, these changes will not necessarily deliver better results when management and participation are not sufficient. The repair of water points depends at a large extent on the willingness and capacity of local users and managers to participate. Therefore, the success of a policy that re-allocates funding from capital investment to capital maintenance depends on factors that are outside the control of decision makers: this type of policy is designed at the meso-level of the district but its success depends on developments at the micro-level of users and managers.

Finally, answers are provided for this case's research questions:

How can Kabarole provide standard or above-standard water service levels?
Findings from this study reveal that simulated Kabarole can achieve standard or above-standard water service levels by planning and executing life-cycle expenditures based on the most up-to-date state of the system, without necessarily increasing its annual budget. The current tendency to allocate most of the resources to the installation of new water points is likely to lead to a rapid decrease in reliability as the ageing process of water points continues and failures will most likely be on the rise. Thus, attention must be re-allocated to maintaining functioning water points and repairing non-functional ones.

Can this goal be achieved within the CBM paradigm?
The success of the previously described policy depends, at a great extent, on the engagement of users and local representatives in participation and management. Therefore, increasing the resources for capital maintenance will not necessarily result in successful outcomes, as long as the role of these local actors remains essential to complete the task. While decentralizing, managing and delivering services at the closest possible level from their final users is one of the principles of the CBM paradigm, the success of this strategy depends largely on factors that are outside the control of decision makers.

7.3 Assessing the system dynamics model

Based on the functional requirements that were previously specified, an assessment of the model was conducted by identifying the aspects of the CBM paradigm and CBM systems that it represents.

In the following sub-sections, a description of how the model accounts for each functional requirement is presented, and in Annex 3, each aspect is specified further.

7.3.1 Functional requirement 1

First, the system dynamics model should represent the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts.

- The first phase in the implementation of the CBM paradigm, the **Demand Responsive Approach,** is not explicitly included in the model. As explained in sub-section 5.2.2, in the expert validation it was found that demand for water points is not the primary driver of their construction. Usually, the demand for more infrastructure already exists and the limiting factor is the availability of resources to satisfy it.
- The model includes the second phase in the implementation of the CBM paradigm: the **Post-Construction Phase**. After a water point is installed, operation and minor maintenance depend on participation and management, which in turn interact with other sectors of the model.
- The model accounts for the **life-cycle expenses of CBM systems** by using Capital Expenditures, Capital Maintenance Expenditures, Operation and Minor Maintenance Expenditures, Expenditures in Direct Support, Expenditures in Indirect Support, and Costs of Capital as the system's key performance indicators.

7.3.2 Functional requirement 2

Second, the system dynamics model should be suitable to represent how changes in CBM systems influence service levels.

- The model structure includes **enabling conditions** such as promotion of collective action and enhancement of local capacity, provision of support during the Post-Construction Phase (PCP), and technical solutions for early information. Moreover, indirect causes of the lack of operation and maintenance (social, political, historical, geographical and implementation) are aggregated in the level of management and community participation.
- **Restricting conditions**: lack of funding, mismatch between services demanded by potential users and services received, and lack of direct support are all part of the model structure. Moreover, the assumption that groups of users behave as communities is tested by including participation and management as functions of satisfaction, direct support, and funding available for operation and minor maintenance.

7.3.3 Functional requirement 3

Third, it should enable the assessment of the financial costs of policy interventions.

- In the model, it is possible to simulate **policies within the CBM paradigm** by modifying the public allocation for life-cycle expenditures of water points. These policies include constructing new water points, repairing non-functional ones, and investing in the promotion collective action and enhancement of local capacity.

- Moreover, the structure of the model can be easily modified to test **changes in the CBM paradigm,** which are also account for by the life-cycle expenditures. In the case study, for instance, a run was simulated with lower provision of direct support to communities, but high execution of capital maintenance. This run represents a scenario in which the public sector not only provides funding but also takes full responsibility for repairing non-functional water points. This scenario contradicts a fundamental principle of the CBM paradigm: that users should be responsible for the management, operation and maintenance of infrastructure.

Chapter 7 in a nutshell

Rural water delivery in Uganda and Kabarole

The Ugandan district of Kabarole was selected as a case study for two reasons:
- Uganda's access to safe water is close to the Sub-Saharan average.
- The district is a critical case because while the reported proportion of the rural population using safe water is high, the actual level of service is below standard.

Thus, two questions were formulated for this case study:
- How can Kabarole provide standard or above-standard water service levels?
- Can this goal be achieved within the CBM paradigm?

Simulating Kabarole

Based on the recommendations for model use formulated in sub-section 6.2.3, findings from the simulations were used to answer the case-specific questions.

How can Kabarole provide standard or above-standard water service levels?
- Simulated Kabarole can achieve standard or above-standard water service levels by planning and executing life-cycle expenditures based on the most up-to-date state of the system. The current tendency to allocate most of the resources to the installation of new water points is likely to lead to a rapid decrease in reliability, as the ageing process of water points continues and failures will most likely be on the rise.

Can this goal be achieved within the CBM paradigm?
- The success of the previously described policy depends, at a great extent, on the engagement of users and local representatives in participation and management. Therefore, increasing the resources for capital maintenance will not necessarily result in successful outcomes, as long as the role of these local actors remains essential to complete the task. While decentralizing, managing and delivering services at the closest possible level from their final users is one of the principles of the CBM paradigm, standard or above-standard service levels could be also be achieved under (a) different or complementary approach(es).

Assessing the system dynamics model

The case study showed that the model meets its three functional requirements:
- First, it represents the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts.
- Second, it is suitable to represent how changes in CBM systems influence service levels.
- Third, it enables the assessment of the financial costs of policy interventions.

8 Re-learn: concluding and recommending

The objective of this study was to deepen insights regarding how changes in the CBM paradigm for rural water delivery can influence water service levels in Sub-Saharan Africa, and what financial costs would be associated to these changes. Thus, this step aimed at looking beyond the case study and using its findings to draw broader conclusions and recommendations.

In the first section of this chapter, the case of Kabarole served as a basis to reflect on CBM systems and the CBM paradigm. For CBM systems, two phases in their development are described: Phase 1, before sufficient water points have been constructed to reach the target proportion of the population using safe water, and Phase 2, after this number has been reached. Furthermore, their implications for policy making are discussed. For the CBM paradigm, a reflection is presented on whether water and sanitation for all can indeed be achieved under this approach.

Then, in the second section, conclusions are provided by re-visiting the research question and the outcomes, limitations of the overarching methodology are discussed, and recommendations for future research are presented.

Chapter 8: a reader's key

Background

The model was applied to study the case of Kabarole district, in Uganda, and assessed based on its functional requirements.

Objective

To present insights regarding CBM systems and the CBM paradigm, as well as conclusions and recommendations.

Sections

Looking beyond the case study

Making conclusions and recommendations explicit

Highlights

In Section 8.1.1, tipping points in community-based management are explained.

8.1 Looking beyond the case study

Based on the case of Kabarole, presented in Chapter 7, reflections regarding CBM systems and the CBM paradigm are presented in the following sub-sections.

8.1.1 Reflections and recommendations regarding CBM systems

In the simulated Kabarole, the *accessibility gap* determined the success of a given policy in the district: if the district were yet to achieve the maximum persons per water point target, spending 70% of its annual budget in new water points would be a rational choice; however, as Kabarole comes closer to achieving its target, the same policy is leading the district into a crisis of low reliability.

Thus, while more funds should be allocated to capital maintenance of the district's water points, the focus of its allocation policy continues to be the construction of new ones. Changing this policy to a more cost-effective alternative would enable the district to achieve standard or above-standard service levels.

The previous findings led to the following reflections:

1. **Phases of CBM systems**
   There are two phases in the development of CBM systems: Phase 1, before sufficient water points have been constructed to reach the target proportion of the population using safe water, and Phase 2, after this number has been reached.
2. **Phase 1 Policy**
   For a system in Phase 1, the construction of water points is a priority and allocating a high proportion of its resources to this activity is a rational choice.
3. **Phase 2 State of crisis**
   For a system in Phase 2, a non-stop increase in the number of water points does not improve service levels in the long term. If insufficient capital maintenance is provided, water points will continuously fail and a state of crisis will be reached: the system will have low functionality rates and require overinvestment in new infrastructure to prevent the collapse of its service levels.
4. **Tipping point of CBM systems**
   Thus, there is a tipping point in the transition from Phase 1 to Phase 2 after which a policy that increased service levels can lead to their sudden decrease.
5. **Phase 2 Policy**
   For a system in Phase 2, allocating a high proportion of its resources to the construction of water points is no longer necessary; instead, policies should be modified according to up-to-date needs of the system.

Based on the previous reflections, three policy challenges were identified:

First, quantifying the *accessibility gap* is not straight forward. Instead, deciding what is the number of water points that are needed in a given system is complex. On the one hand, the number of persons per water point is not the only real-world factor influencing accessibility: other factors include distance, time, topographic and even weather conditions under which users have to walk to fetch water. On the other hand, actors in a CBM system may not have the same perception regarding the persons per water point target that should be pursued, and related decisions are likely to be contested.

Second, in practice, identifying a system's tipping point is not a simple task. On the one side, if no persons per water point target is defined for a CBM system, decision makers can miss the signals indicating the transition from Phase 1 to Phase 2. As a result, allocation policies will remain unchanged. On the other side, its identification requires sound statistics on the state of the system, such as total water points, reliability and demographic data. These numbers are not always monitored and may be unavailable.

Finally, the effectiveness of a Phase 2 policy with high investments in capital maintenance levels depends not only on the availability of financial resources, but also on human capital to perform the necessary activities. In CBM systems, this type of capital is often outside the control of the public sector, which means that the success of Phase 2 policies depends, at a great extent, on context-specific management and participation.

8.1.2 Reflections and recommendations regarding the CBM paradigm

Theoretically, CBM systems in Phase 2 can achieve standard or above-standard service levels under the CBM paradigm: by making use of up-to-date information, they can adapt their policies to their changing situations and prevent reliability crises by directing resources and attention to capital maintenance.

Nevertheless, as explained by an interviewees, one of the principles of the CBM paradigm is that *"[…] communities are in charge of the management, the operation and maintenance, of the facility."* (Fourth interviewee, page 149). The implication of this principle for Phase 2 policies is that their success will be largely dependent on local willingness and capacity to take ownership and responsibility of water points. In practice, it *"[…] is a bit unfair to expect from them to be able to solve all issues*." (Fourth interviewee, page Table 28), and previous research has shown that this principle is not always met.

Therefore, while the CBM paradigm was invaluable for providing first-time access to safe water in rural areas, it does not seem to be suitable for achieving sustainable water services for all. As CBM systems approach their tipping points, operation, minor and capital maintenance become crucial for preventing a reliability crisis and the collapse of their service levels. Thus, different or complementary approaches must be engineered.

In the wider picture, findings from this study are relevant for good and services, other than rural water, that are also provided under the CBM paradigm. They suggest that policies at high levels, i.e. countries or regions, should not be designed with the CBM paradigm as a requirement. As previously explained, the performance of CBM systems depends largely on the actions of users and managers at a local level. This implies that while this paradigm might be appropriate for a particular case, it might not deliver on its promises in a different context. Therefore, the success of policies designed under the CBM paradigm at high levels of government is, at a great extent, outside the control of decision makers. Thus, establishing a CBM system should be a local decision instead of a national or regional one, and decision makers should enable opportunities to select or design management models that are appropriate to the local context.

8.2 Making conclusions and recommendations explicit

The research question addressed in this study is: *How changes in the Community-based Management paradigm for domestic rural water points influence the water service levels experienced by participating communities in Sub-Saharan Africa, and what are their associated costs?*

To answer this question, an exploratory scope was defined and a systems model of the problem was conceptualized, built and validated. Further, this model was tested by applying it to study a case, and insights were used to reflect on CBM systems and the CBM paradigm. Thus, answers to this question are provided in the form of four research outcomes and conclusions, and recommendations for future research.

8.2.1 Outcomes and conclusions

The first outcome is the systems model, which consists of three parts: a systems diagram, a qualitative and a quantitative system dynamics model.

First, the systems diagram (Chapter 4) was built, based on insights from collected literature (Chapter 3) and from interviews with experts in CBM systems and system dynamics modeling (Chapter 3 and Appendix 1). This diagram clarified the elements that required further investigation, and classified them into four main components: system variables; policy actions; external factors; and criteria.

Second, a conceptual or qualitative system dynamics model made explicit the relations between the components of the system diagram. This model was based on insights presented in Chapter 3 and underwent an expert validation process. In this process, three of the experts in CBM systems who were previously interviewed were asked to judge whether the model represented real-world CBM systems. They were also asked to provide suggestions for its improvement. Based on their answers, the model was adapted into the version presented in Chapter 5.

Third, a quantitative system dynamics model that fulfills three functional requirements was built: (1) the model represents the CBM paradigm for domestic rural water points in Sub-Saharan Africa and its central concepts; (2) is suitable to represent how changes in CBM systems influence service levels; and (3) enables the assessment of the financial costs of policy interventions. This model was improved as part of an iterative testing process which included a consultation with a system dynamics expert.

The second outcome consists of recommendations for model use. In section 6.2.3, three main recommendations for future users were drawn.

First, adopt a case study research design. Analyzing a particular situation instead of the generality allows users to gain context-specific insights. The model can be used both, quantitatively to simulate different scenarios, or qualitatively, as a boundary object in discussions with stakeholders.

Second, verify whether model assumptions are valid for a given case. Understanding its core assumptions allows the user to interpret results in this light or to modify the model with context-specific assumptions.

Finally, regarding the model parameterization, pay particular attention to the initial number of water points, *annual net population growth rate, accessibility target, allocation policy* and *OpEx effect on lifespan.* Conducting sensitivity analysis for these variables is recommended.

The third outcome are recommendations for model improvement. In section 6.2.4, two main recommendations were drawn, as summarized below.

First, the quantitative effect that operation and minor maintenance have on water points' lifespan and reliability should be clarified, possibly by means of statistical analysis. More specifically, the investigation of three causal relations is recommended: (1) water point's lifespan as a function of continuous operation and minor and preventive maintenance; (2) water point's continuous operation and minor and preventive maintenance as a function of participation and management; and (3) local participation and management as a function of direct support.

Second, the current model could be simplified into a more aggregated version. Further analysis and validation can reveal further details on the structures that govern its behavior and help define an different level of granularity.

Finally, the fourth outcome are insights regarding the problem situation, which were presented at three levels: the case study of Kabarole district (section 7.2.4), reflections on CBM systems (section 8.1.1) and on the CBM paradigm (section 8.1.2).

Regarding Kabarole, it was found that the district has already reached its accessibility target, but maintains an allocation of 70% of its annual budget for the construction of new water points. In contrast, the funding allocated for capital maintenance is insufficient to repair the majority of non-functioning water points. Thus, a change in its allocation policy, instead of an increase in its annual budget, might be sufficient to tackle Kabarole's problem of low water point reliability.

Regarding CBM systems, two stages were found in their development: before sufficient water points have been constructed to reach the target proportion of the population using safe water (Phase 1), and after this number has been reached (Phase 2). For a system in Phase 2, insufficient capital maintenance will produce a state of crisis in which the system will have low functionality rates and require overinvestment in new infrastructure to prevent the collapse of its service levels. Thus, decision makers must be aware of the tipping-point between Phase 1 and Phase 2, and implement policies that can be rapidly adapted according to the needs of the system.

Finally, the CBM paradigm was not found to be suitable for achieving sustainable water services for all. For CBM systems in Phase 2, ongoing operation and maintenance become crucial for maintaining standard service levels. As long as rural water delivery adheres to the principles of the CBM paradigm, the success of policy interventions will depend largely on factors outside the control of decision makers, such as context-specific management and participation. While components of the CBM paradigm continue to be operational and relevant, the future of rural water delivery lies beyond the paradigm's boundaries. Thus, a more resilient approach that produces the expected outcomes in a reliable manner needs to be designed.

8.2.2 Limitations of the overarching methodology

A complexity-informed modeling process was designed as overarching methodology for this study. It was applied with two requirements in mind: to produce valid and reliable results and to integrate not only the researcher's perspective and insights, but also those of stakeholders in the socio-technical system of water delivery. While valuable insights were gained through this process, a critique is due for each of its steps.

Step 1: Learn. Interviews with stakeholders from the system were held only with problem owners. This research relied on their vast experience with rural water delivery and their generous sharing of knowledge. However, due to resources constrains, first-hand perspectives from other stakeholders, were not included.

Step 2: Plan. The functional requirements of the model did not include the representation of the underlying local dynamics that enable or restrict participation and management. Instead, these variables were conceptualized at a highly aggregated level. Ethnographic and anthropological tools required for this analysis exceed the scope and objective of this study.

Step 3: Design. The conceptual model could have been built either with a greater or lower level of detail. Greater level of detail could have captured more effects but would have come at the cost of difficult interpretation. In contrast, a more aggregated form would concentrate on the main effects and be suitable for communication purposes at the risk of leaving out relevant components or oversimplifying the problem. The chosen level of detail, however, aimed at reaching an appropriate balance between these trade-offs.

Step 4: Build. System dynamics was the modeling and simulation method selected for this study. However, other techniques could have been used to analyze the problem. Thus, the model incorporates a large number of variables and feedback effects in a tractable manner but excludes disaggregated, spatial and discrete components.

Step 5: Apply. A single-case research design was selected for this step. The case study was both, representative of the problem and critical. However, studying multiple cases with different conditions could have generated additional insights. Further, the research design did not engage stakeholders such as problem owners or decision-makers from the district.

Step 6: Re-Learn. Problem owners and stakeholders from the system were not engaged in this step, which limits the impact of this study.

8.2.3 Recommendations for future research

Recommendations for future research are drawn at three levels: (1) model improvement; (2) validation of findings; (3) rural water delivery; (4) the CBM paradigm. The second and third levels are detailed below, as recommendations for model improvement were presented in 6.2.4.

Recommendations on the validation of findings aim at addressing limitations of the methodology, previously discussed in sub-section 8.2.3. First, future research should conduct interviews with stakeholders other than problem owners as part of Step 1, Step 3, Step 5 and Step 6. In particular, it should reach stakeholders from the case study. Second, it should diversify the portfolio of modeling and simulation methods to study the problem, with particular emphasis on hybrid approaches. Third, applying the system dynamics model to study multiple cases would produce additional insights for model improvement, CBM systems and the CBM paradigm.

Recommendations for research in rural water delivery concern the identification of tipping points in CBM systems, and the design of adaptive policies. Research at this level should center on the generation of timely knowledge on physical infrastructure, in order to identify the systems' transition from Phase 1 to Phase 2, and adapt policy strategies accordingly. In addition, future research should study the conditions under which new management models, local markets and sustainable supply chains for water points' spare parts, can emerge.

Finally, recommendations for research on the CBM paradigm center on studying the CBM systems of goods and services other than rural water. Through this sub-sequent research, findings from this study could be transferred and applied to policy analysis in similar problem situations.

Chapter 8 in a nutshell

Looking beyond the case study

CBM systems

- Two stages in their development were identified: Phase 1, before sufficient water points have been constructed to reach the target proportion of the population using safe water, and Phase 2, after this number has been reached.
- For a system in Phase 2, insufficient capital maintenance will produce a state of crisis in which the system will have low functionality rates and require overinvestment in new infrastructure to prevent the collapse of its service levels.
- Decision makers must identify the tipping-point between Phase 1 and Phase 2, and shape policies that can be rapidly modified according to the up-to-date needs of the system.

CBM paradigm

- As long as rural water delivery adheres to the principles of the CBM paradigm, the success of policy interventions will depend largely on factors outside the control of decision makers.
- Thus, the paradigm was not found to be a suitable rural water delivery model for achieving sustainable water services for all, and a more resilient approach that produces the expected outcomes in a reliable manner needs to be designed.
- These findings could also be applicable for CBM systems of goods and services other than water.

Making outcomes and conclusions explicit

- Four main outcomes were obtained from this research: a systems model, recommendations for future model use and improvement, and insights regarding the problem situation.
- While components of the CBM paradigm continue to be operational and relevant, the future of rural water delivery lies beyond the paradigm's boundaries.
- Future research should be conducted at three levels: (1) improving the system dynamics model; (3) improving the overarching methodology; (3) supporting the capacity of CBM systems to identify their own tipping points, design adaptive policies, and transition to more sustainable management paradigms; and (4) studying the extent at which these findings are applicable to CBM systems of goods and services other than water.

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10 Appendix 1. Initial Interviews

Hevner et al. (2004) and Bots (2007) explain that the design problem formulation is the translation of the client's problem into a set of functional requirements that guide the design and assessment of a model.

To distill empirical functional requirements and gather empirical information for further steps of the research, multiple interviews were conducted around five thematic blocks: B1) Building blocks of the Community-based paradigm for domestic rural water points; B2) Enabling and restricting conditions of CBM systems; B3) Looking beyond the CBM paradigm; B4) Modeling and simulation tools to study the problem; B5) The case of domestic rural water service provision by water points in Uganda. Each of these blocks, theoretically derived from Chapter 4, was decomposed into a set of questions, as reported below.

1. B1: Building blocks of the CBM paradigm
    a. How is the CBM paradigm implemented?
    b. What is the philosophy behind the CBM paradigm?
2. B2: Enabling and restricting conditions of CBM systems
    a. What are enabling conditions of CBM systems?
    b. What are restricting conditions of CBM systems?
3. B3: Looking beyond CBM for domestic rural water points
    a. What innovations have occurred in the water sector beyond CBM?
    b. What are foreseeable developments in the paradigms used for the provision of domestic rural water services?
4. B4: Modeling and simulation tools to study the problem
    a. What modeling and simulation tools are usually used to study the provision of rural water services?
    b. How can modeling and simulation tools be used to study enabling and restricting conditions of CBM systems?
5. B5: The case of rural water service provision by water points in Uganda
    a. What is the role of the CBM paradigm in the provision of water services by water points in rural Uganda?
    b. What levels of government are involved in the implementation of CBM systems?
    c. How are funds allocated for the implementation of CBM systems?
    d. How do communities file requests for new water points or for repair, renewal or rehabilitation of existing water points?
    e. What are plausible, and near changes in the provision rural water services in Uganda?
    f. What databases or statistics of these projects can be relevant for this research?

This Appendix constitutes a complete report of the interviews to define functional requirements and to conduct a preliminary exploration of the case study. First, the first section explains the type of interview and the methods used to gather, process and analyze the data. Next, the second section presents the analysis of the data. Finally, the forth section draws conclusions by answering the questions of the interview's five thematic blocks.

In the remaining of this Appendix, the concept *Community-based Water Resources Management* (CWRM) is used instead of *Community-based Management (CBM) of domestic rural water points.* The use of this concept was intended to inspire a broader discussion with the interviewees

10.1 Research Methods

The realization of the initial interviews was divided in five key steps: (1) Method selection; (2) Interview design; (3) Implementation; (4) Data processing; and (5) Data analysis. The methods applied to each of these key steps are explained in the sub-sections below.

10.1.1 Selecting a type of interview

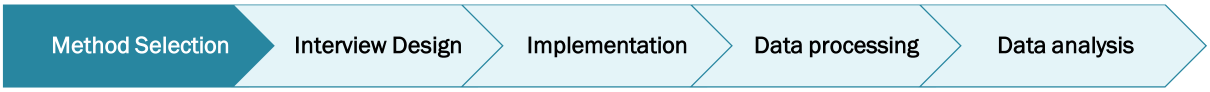


Figure 35 First key step in the realization of the interview process for Prototype and Case Study Planning

Interviews were the preferred data collection method for five main reasons. First, interviews enable a discussion beyond secondary sources. While secondary sources provide insights on the interviewee's work, they do not always include some interesting facts or details. The interview can help to unveil and discuss those details.

Second, the interviewer can request clarification of concepts. He or she can ask the respondent to provide more examples, or to provide further explanations.

Third, interviews make possible a more direct rapport between interviewee and interviewer. In addition to discussing the respondent's experience, there are opportunities to ask for his or her professional opinion.

Fourth, the interviewer can observe features that would remain unseen with any other means of communication. Body language, expressions, colored language, gestures, punctuality, willingness to answer, rapport or even the setting of the office are all ways of delivering non-explicit messages. The interview gives an opportunity to listen to much more than only words.

Finally, from the three main types of interviews (structured, semi-structured and open), the semi-structured type was selected. In a semi-structured interview, a set of guidelines indicates the direction of the conversation. Instead of having the rigid set of questions of the closed interview, this type enables diversion as well as open answers. While freedom to diverge from the guidelines can lead to findings by serendipity and can bring new ideas to the project, the interviewer can come back to those guidelines to check whether all the necessary data has been collected. Therefore, not all interviews addressed all questions reported in the protocol. Likewise, some interviews included additional questions.

10.1.2 Designing the interview

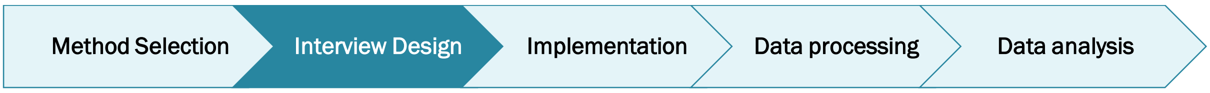


Figure 36 Second key step in the realization of the interview process for Prototype and Case Study Planning

Each interview consisted in three main parts. In the first part, the interviewer welcomed the interviewee, explained the objective of the interview, asked for permission to record the audio of the meeting, and explained the structure of the interview.

In the second part, the interviewer asked questions to gather data on the interviewee's professional and academic background, as well as expertise.

In the third part, the interviewer introduced discussion points that would encourage a discussion on one or more of the planned thematic blocks. Whilst the objective was to collect sufficient data to answer each question in the thematic blocks, these questions were not asked directly. Instead, a conversational environment was created to enable the interviewee to reveal his or her knowledge. To create this environment, an interview protocol (in section 1.2.1) was used to guide the conversation.

Paper, pens, pencils and color markers were available to the interviewees at all times during the meeting. Interviewees were encourage to sketch, write or draw at any time.

Textbox 3 Interview Protocol for Tool Planning and Case Study Initial Exploration

Interview Protocol for Tool Planning and Case Study Initial Exploration

Thank you for granting this interview. I would like to have a conversation on several aspects of your knowledge and expertise. This will be useful for my research project.

If it is comfortable for you, I would like to take notes during the interview. This helps me to remain an active listener and remember some of the points that you make. I would also like to record the audio of the conversation. This will help to in future analysis of the transcript.

The interview is structured as follows. First, I will ask some questions about your professional and academic background, as well as expertise. Then, I would like as the questions related to your experience and my research.

Social-demographic variables ________________

Institution and Position: ________________

Description of the position: ________________

Years in the water sector: ________________

Academic background: ________________

Please explain how you came to be in the position that you currently have.

Community-based Water Resources Management

1 What do you understand by Community-based Water Resources Management?
2 Can you give me some examples of this type of projects?
3 For those projects, can you explain:
    a. Who was involved?
    b. Governance arrangements/institutional settings?
    c. How the project was organized?
4 What was your role in those projects?
5 What implementation issues were there and why?

6. What successes were there in the project and why?
7. Why do you think these projects can be considered CWRM?
    a. Why? Why not?
8. What is your most significant learning in these projects?
9. Do you have any other reflections on the role of CWRM in reaching the sustainability goals?
10. How do you think these projects, and rural water provision will change in a close future?

Modeling and simulation

11. Do you have any reflections of experiences along this line? Can you tell me about it?
12. What kind of decision-making does it support? At what level?

Case study questions: CWRM in Uganda

13. Can you describe the role of water points in rural Uganda, in the provision of water services?
14. How is a water point typically managed?
15. What levels of government are involved in its life-cycle?
16. For those projects, can you explain:
    a. Who was involved?
    b. Governance arrangements/institutional settings?
    c. How the project was organized?
17. What was your role in those projects?
18. What implementation issues were there and why?
19. What successes were there in the project and why?
20. Once that a district receives the District Conditional Grant, is this money managed by the sub-counties or by the districts?
21. How long does it take for this money to be available to the sub-counties or to the district?
22. When a request to install a water point is filed, is it filed to the district or to what level?
23. When a request to repair, renew or rehabilitate a water point is filed, is it filed to the district or to what level?
24. How long does it take for a request to be approved after it has been filed?
25. Is there an estimate of the percentage of the District Conditional Grant that is actually exercised?
26. How do you think that the provision of water services in rural Uganda will change in the following years?
27. Are there any databases or statistics related to these projects to which we could have access?

10.1.3 Conducting the interviews

Figure 37 Third key step in the realization of the interview process for Prototype and Case Study Planning

Because the objective of the interviews was to collect data on five thematic blocks, potential interviewees should have knowledge on at least one of those thematic blocks.

Thus, for any potential interviewee, at least one of the following three statements should be true:

1. Has worked in rural water management projects in or for Sub-Saharan Africa.
2. Has used modeling and simulation tools to study a water-related problem.
3. Has worked in or for a project concerning the provision of rural water services in Uganda.

Four potential interviewees were selected from the academic network of the interviewer or her first supervisor. Each candidate was contacted individually, via email, to request a one-hour appointment. All interviewees accepted to participate, and all appointments were scheduled at quiet locations that allowed to record of the audio of the interview. Table 8 presents a brief professional biography of the interviewees, while Table 9 presents the selection criteria that they fulfilled. Then, Table 10 specifies the thematic blocks that each interview aimed at addressing. Finally, Table 11 specifies the date, place and duration of each interview.

Table 8 Selection of interviewees for initial interviews

Interviewee	Brief professional biography
Jai	Researcher with more than four years of experience in Integrated Water Resources Management. Recently obtained a PhD degree in South Africa. His primary research methods draw from ethnographic, institutional and systems analysis in a trans-disciplinary action research framework. Trained and experienced in the use of system dynamics.
Deirdre	Programme manager, trainer, researcher and PhD candidate with more than 17 years of experience in domestic water, sanitation and hygiene services in Africa and Asia. Her research focuses on governance of WASH services, organizational and individual capacity development and sector change processes with the aim of achieving universal coverage.
Patrick	Manager at a water, sanitation and hygiene services NGO with headquarters in The Hague, The Netherlands. He has over twenty years of experience in a broad range of issues around water, its management and its use in improving human well-being, mainly in Africa and South Asia. His main area of interested is how to ignite and support sector wide change to achieve more sustainable water use and improved services for all.
Valérie	Water and sanitation engineer and social anthropologist with more than ten years of experience in the water, sanitation and hygiene sector in Africa and Latin America. Her work has centered on research, facilitation of learning processes, monitoring and capacity building of NGO's and local governments. Currently, she is taking steps to widen her work to other non-profit sectors domains, such as human rights, education, renewable energies, environmental protection or immigration and integration.

Table 9 Criteria fulfilled by the interviewees for initial interviews

Interviewee	Has worked in rural water management projects in or for Sub-Saharan Africa.	Has used modeling and simulation tools to study a water-related problem.	Has worked in, or for, a project concerning the provision of rural water services in Uganda.
Jai	X	X	
Deirdre	X	X	X
Patrick	X	X	X
Valérie	X		X

Table 10 Thematic blocks addressed in each initial interview

Interviewee	Thematic Blocks 1 – 3	Thematic Block 4	Thematic Block 5
Jai	X	X	
Deirdre	X	X	X
Patrick		X	X
Valérie	X		X

Table 11 Date, place and duration of the initial interviews

Interviewee	Date and time	Place	Duration
Jai	2016. March 22 10:00h	Delft, The Netherlands	55 minutes
Deirdre	2016. April 1 9:30h	Delft, The Netherlands	1 hour 20 minutes
Patrick	2016. April 8 11:30h	The Hague, The Netherlands	52 minutes
Valérie	2016. April 11 14:00h	The Hague, The Netherlands.	45 minutes

10.1.4 Processing the data

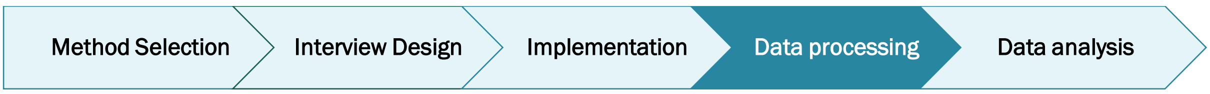


Figure 38 Fourth key step in the realization of the interview process for Prototype and Case Study Planning

In order to process the data of each interview, the recording of each interview was transcribed manually. The resulting transcripts account of most of the words in the conversation, and text in italics corresponds to the interviewer, while text with no additional formatting corresponds to the interviewee. When a word in the recording was incomprehensible to the interviewer, it was marked with these symbols and color: ***. The transcripts do not necessarily capture pauses in the speech, hesitation or onomatopoeias. Likewise, features such as intonation or emotion were not included.

10.1.5 Analyzing the Data

Method Selection > Interview Design > Implementation > Data processing > **Data analysis**

Figure 39 Fifth key step in the realization of the interview process for Prototype and Case Study Planning

After completing the transcripts, each document was coded thematically according to the method proposed by Saldaña (2009). Each of the interview's five theoretically defined thematic blocks was assigned a different color (Block 1: blue; Block 2: orange; Block 3: green; Block 4: yellow; Block 5: purple). Each of the questions in a thematic block was assigned a different shade of the specific color. When a fragment of the transcript provided insights to answer a particular question, the fragment was highlighted with the corresponding shade. Any additional topics that emerged during the interview, and that could not be classified adequately using the previous thematic code were left out of the analysis. The color code is specified further in Table 12. Below the table, the interview's five thematic blocks are highlighted according to the color code.

Applying this method to process the data from the interviews delineates a traceable route from qualitative data to its interpretation. In Chapter 3, quotations are used to confirm or emphasize the findings.

Table 12 Thematic color-coding to process data from the interviews' transcripts

Block Number	Question	Color	Color model	Shade of Red	Shade of Green	Shade of Blue
B1	A	Blue	RGB	222	234	246
B2	B	Blue	RGB	156	194	229
B2	A	Orange	RGB	251	228	213
B2	B	Orange	RGB	244	176	131
B3	A	Green	RGB	226	239	217
B3	B	Green	RGB	168	208	141
B4	A	Yellow	RGB	255	242	204
B4	B	Yellow	RGB	255	217	102
B5	All questions*	Purple	RGB	234	220	244
Block A1**	NA	Turquoise	RGB	0	215	210
Block A2**	NA	Pink	RGB	252	142	176
Block A3**	NA	Grey	RGB	208	206	206

* Unlike the other thematic blocks, all questions from Block 5 were colored with the same shade.
** Three additional thematic blocks were included. Block A1 highlights answers that elaborate on the problem addressed by the research, and that do not fit the description of thematic blocks 1 to 5. Block A2 highlights answers that make direct mention of how to conceptualize or parameterize the modeling and simulation tool. Block A3 highlights sources of information suggested by the interviewees.

1. B1: Building blocks of the CWRM paradigm
   a. How is the CWRM paradigm implemented?
   b. What is the philosophy behind the CWRM paradigm?
2. B2: Enabling and restricting conditions of CWRM systems
   a. What are enabling conditions of CWRM systems?
   b. What are restricting conditions of CWRM systems?
3. B3: Looking beyond Community-based Water Resources Management
   a. What innovations have occurred in the water sector beyond the CWRM paradigm?
   b. What are foreseeable developments in the paradigms used for the provision of rural water services?
4. B4: Modeling and simulation tools to study the problem
   a. What modeling and simulation tools are usually used to study the provision of rural water services?
   b. How can modeling and simulation tools be used to study enabling and restricting conditions of CWRM systems?
5. B5: The case of rural water service provision by water points in Uganda
   a. What is the role of the CWRM paradigm in the provision of water services by water points in rural Uganda?
   b. What levels of government are involved in the implementation of CWRM systems?
   c. How are funds allocated for the implementation of CWRM systems?
   d. How do communities file requests for new water points or for repair, renewal or rehabilitation of existing water points?
   e. What are plausible, and near changes in the provision rural water services in Uganda?
   f. What databases or statistics of these projects can be relevant for this research?

Following the completion of the processing of the data, data from each interview was extracted according to its thematic coding, for Thematic Blocks 1 to 4. All the fragments of texts belong to the same interview and to the same question were grouped in a table. Each of these fragments of text was then interpreted by the researcher into a resulting statement. Afterwards, resulting statements from all the interviewees belonging to the same question were grouped together in a list that constituted the answer of each specific question. These answers are reported in the conclusions of this Appendix.

10.2 Data Analysis

The data from the interviews –the transcript– was analyzed by means of a color coding system. The first sub-section addresses each of the questions answered by the interviews. For each respondent, all text fragments that contribute to answering a question are reported in a corresponding table. Each text fragment was then interpreted into a statement, also reported in each table.

Next, the second subsection presents and numbers the resulting statements.

10.2.1 Text fragments and resulting statements

10.2.1.1 B1: Building blocks of the CWRM paradigm

1.1.1.1.1 How is the CWRM paradigm implemented?

Table 13 B1.a. Interviewee 1

Text Fragment	Resulting Statement
On a rain water tanks project: "Now, that was very hands on, I mean that was, you know how to get those rain water tanks out there, and continue to manage them, finance, finance them, work with local community groups, and groups deciding where they go, all of that kind of stuff."	The design of CWRM systems should consider the complete life cycle of water infrastructures.
On a rain water tanks project: "Galela Amanzi? That was a student run project that was implemented as a student society out of the Community Engagement Unit at Rhodes University."	Stakeholders external to the community take part in the design and implementation some CWRM systems.
On a rain water tanks project: "A range of public and private actors, ah, I call corporate fundings, from big corporates in South Africa. They would fund let's say five to ten tanks at a time. I also got funding from small, small philanthropy, philanthropists or like civil society organizations. Everything from Rhodes *** clubs to, just small organizations in Grahamstown. Business, business forums, but it wasn't just the tanks. It was the base, the base… it was the whole installation of it. And it is the installation of it that was far more expensive than the tank itself. So the tank was just the obvious thing to fund, but we achieved, sourced the funding then, did the whole process of often installing gutters in buildings that didn't have gutters, uhm, that whole thing."	Stakeholders external to the community take part in the funding of some CWRM projects.
On a rain water tanks project: "Well it wasn't for, it was, it depended on, 'cause they were always at some sort of community site. So they would be at a community hall, a clinic, a primary school, a pre-school, or a high school. They were never on private, individuals' properties."	The design of CWRM systems usually targets shared locations instead of individual properties.
On a rain water tanks project: "When I, when I got involved in that, there were no governance structures, there was almost no funding, there was one rain water tank and one idea."	Stakeholders external to the community initiate the design of some CWRM systems.

Table 14 B1.a. Interviewee 2

Text Fragment	Resulting Statement
On the type of fieldwork she has conducted: "[...] So service provision is at community level, when you have the community-based management thing, and then you go and you look at the infrastructure, at the quality of it, at how was built. And then you talk to the people that get the role in managing it, and paying for it, users, and you, I have done some really participatory evaluation techniques to get in transect walks, when you speak about GIS and mapping, the walk is really the walk through the area and hear people tell you what you're looking at. What you're seeing. What worked, what didn't work. [...]"	Users of infrastructure managed by CWRM systems are expected to pay and manage those infrastructures.
On the type of fieldwork she has conducted: "[...] But you also go and you speak at the authority level. Because they're responsible for supporting communities that got new services, or improved services and find out did, institutional and organizational development really take place there. Are they now better able to support those communities? So that's part of the fieldwork too."	In CWRM systems, authorities are responsible for supporting communities that are managing infrastructures.
On the central assumptions of the CWRM paradigm: "What are the three.... That communities with very little training would be able to manage in the full sense of the word, technically, financially, equitably, a water infrastructure under extremely thriving circumstances. I mean, we're not On well-off communities. The communities that have the resources can pay someone to get the water or the toilets there and get the waste water away."	CWRM systems assume that a project can be managed by communities with little training. In CWRM systems, communities are expected to manage a water infrastructure technically, financially and equitably under extremely thriving circumstances. In CWRM systems, communities are expected to have the necessary funds to finance the life-cycle of the infrastructure.
On the origin of funding in the CWRM paradigm:	In CWRM systems, communities are

"Then the assumption in there was that people would have the money to pay for it [...] Direct users. In that model, yes."	expected to have the necessary funds to finance the life-cycle of the infrastructure.
"I mean there's kind of an official story that you can probably see if you look in the setting of Uganda, at District, and at sub-county, and at parish level, that would show you all these things have been set up in these communities. We have, we know our water user committees are, and blah blah blah. But if you went to evaluate it, let's say, like in programs where I've gone as an evaluator, you would expect to see a water user committee, I mean again, it's a bit textbook and it's a bit ticking boxes. You would see a financial sort of logbook or record of expenditures, payments from users, expenditure for maintenance, and say and, tools, and, uhm... caretaker... salary let's say, it's not really salary but it's kind of a nominal bit of money. So financial, log, you would expect, so if you had community-based... this is sort of the institutional aspects of a committee, financial... records, ehm... I mean, in a lot of places what you'll see physically are lots and lots of these boards, assigned boards along the roads with the logos of all the different development agencies, and the ministry of water, proclaiming that they spent money on establishment of the infrastructure or the committee. So, people's taking claim there. And then, you'll probably be able to see that every structure itself, and it might be just a simple water pump, there might be a taps stamp attached to it, you know, whatever the superstructure and the, the... a protected well or spring, so again, more the physical elements of it, or a toilet block let's say in some cases they build lots of latrines in one block in a central place. [...] Uhm... you would probably be taken to the village school, because part of if it's there, or the local school, or some other communal meeting area, because that's, you know, they would want you to see what it, you know, there's often a school, water and sanitation element in a community project because it's got lots of implications. What other traits would you expect to see? Uhm... a lot of times they'll troch out the women on the committee."	CWRM systems require Water User Committees. CWRM systems require users to pay for the services of a water infrastructure. CWRM systems require local managers to keep records of expenditure and maintenance. CWRM systems require caretakers for water infrastructures. These caretakers do not receive a salary but receive a small nominal amount of money. Stakeholders external to the community, such as development agencies and governmental bodies, take part in the design and implementation some CWRM systems. CWRM systems involve water infrastructures. CWRM systems' water

	infrastructures are installed in communal locations. CWRM systems try to include gender perspective.

Table 15 B1.a. Interviewee 3

Text Fragment	Resulting Statement
"Indirect Support is macro-level expenses. Is there a policy, is there, uhm, is, yeah. Stuff like that. Or is there a national groundwater inventory, is there, so that… has somebody ever developed a groundwater map, so that we know which areas are high yield, and which area is low yield, stuff like that. […] Indirect Support is normally something, isn't normally in our conceptualization, it's something much more linked to the national level."	Indirect Support, or macro-level expenses, are typically spent at a national level, and not by communities.

Table 16 B1.a. Interviewee 4

Text Fragment	Resulting Statement
On the features that CWRM systems exhibit: "[…] The main feature is indeed that the responsibility lies in the community who usually are representative, roughly representative, the water point committee for instance. Or ehm, if it's instead of point source, if, if it's a piped scheme, then they may have a small board with the staff, the, who gathers members from different communities."	In CWRM system, a water point committee, usually roughly representative of the community, is responsible for the management of the water infrastructure.
On the Water Point Committees: "[…] because in the end is a voluntary work […]"	In CWRM systems, members of the Water Point Committee managing the water infrastructure work on a volunteer basis.

1.1.1.1.2 What is the philosophy behind the CWRM paradigm?

Table 17 B1.b. Interviewee 1

Text Fragment	Resulting Statement
On community-based natural resources management: "It's, it should be a key part of integrated water resources management, IWRM, but my understanding is that it simply tries to say that if you are going to be involved, or if you are, you as a designer, planner, policy maker or decision maker, if you are doing something that impacts on people in a particular space, and there are communities within that space, or either are people living there, then you should in some way try and involve them in the conceptualizing, planning, designing and implementation of water resource management projects and at the operational level that there is some decision making participation. That they are involved in decision making."	People who will be affected by a CWRM system should be involved in its conceptualization, planning, designing and implementation. People affected by a CWRM system should have decision-making power over the system.
"Community-based water resource management. Uhm, probably I am must closely align it to the principles and practices of community-based natural resources management, CBNRM."	CWRM is close to the principles and practices of community-based natural resources management.

Table 18 B1.b. Interviewee 2

Text Fragment	Resulting Statement
On what comes to her mind when she thinks of CWRM: “That there is… that the intention was good, the notion of having services delivered, managed and delivered at the level closest to the end user came from a desire to democratize the ways that we provide public services to our citizens, and support them to attain their highest attainable level of developments. It was a good one. There are many good intentions in there, more involvement and empowerment of women. And inclusiveness for the poor, or other marginalized groups. Marginalized because of ethnicity, or faith, or physical ability, right? So when you decentralize services and the authority and the… choices around what a service could and should look like, it sounds good. Right?”	CWRM aims at having services delivered and managed at the level closest to their end users. CWRM aims at democratizing the provision of public services to citizens. CWRM aims at supporting citizens in attaining the highest attainable level of development. CWRM aims at including gender perspective by involving and empowering women. CWRM aims at including marginalized groups, such as those marginalized because of ethnicity, faith or physical ability.

Table 19 B1.b. Interviewee 3

Text Fragment	Resulting Statement
Vacant	Vacant

Table 20 B1.b. Interviewee 4

Text Fragment	Resulting Statement
About a project in Malawi: "It was a rural area, a rural project. So, so community-based management, very decentralized."	CWRM aims at decentralizing the provision of water services in rural areas.
On the features of CWRM systems: "Well, the idea is that the communities are in charge of the management, the operation and maintenance, of the facility. Does not always mean full ownership even though you try to promote this sense of ownership. But then depending on the legislation in the country, the assets belong to the community or not. So, yeah. The main feature is indeed that the responsibility lies in the community"	CWRM aims at promoting a sense of ownership of the infrastructure, in the community. In CWRM system, the community is responsible for the management of the water infrastructure.

10.2.1.2 B2: Enabling and restricting conditions of CWRM systems

1.1.1.1.3 What are enabling conditions of CWRM systems?

Table 21 B2.a. Interviewee 1

Text Fragment	Resulting Statement
On development induced displacement: "It's a whole field that tries to take the bull by the horns and then admit how quite difficult this is to do but it's why they then say you need to have good grounded ethnographic work in the communities that are being affected."	Good-grounded ethnographic work in the communities affected by development projects can improve the outcome of those development projects.
"So an anthropologists, would go and spend a year doing fieldwork in a community, and then we will say, alright, here are some of the social dynamics, social dynamics that I have observed over the course of this year. Now that's grounded research."	Fieldwork and research in communities affected by a development project should be based in well-grounded social science, such as anthropology.
On a rain water tanks project: "[...] But also for, also used in, for cooking. So the big thing was that all of those sites, the clinics or the primary schools, they all did meals, produced meals, for school kids or young kids. And so it was water for meals."	Collective benefits, such as using water for community sites (clinics or primary schools) motivate participants of CWRM systems to keep the system running.

Table 22 B2.a. Interviewee 2

Text Fragment	Resulting Statement
On the CWRM paradigm: “It works in the North and in the West, where we have reasonably well functioning institutions and governance settings.”	CWRM projects have had functioning institutions and governance settings.
On the CWRM paradigm: “And where it succeeded it was because there was good technical system, support, more reasonably functioning authority relationship with the district, or whatever local level of government was in place, good mechanisms in place to support the communities or just really, reliable repeat investment from international aid and development.”	Successful CWRM projects have had technical support, functioning relationships between multiple governance levels, reliable support for communities, or reliable and repeated investment from international aid and development.

Table 23 B2.a. Interviewee 3

Text Fragment	Resulting Statement
On the link between Direct Support and functionality: “Particularly with the Direct Support. Because Direct Support is… is saying, in terms of your model, again, come back, so let’s say, let’s say that you begin to put OpEx and the effect of that OpEx. Direct Support, particularly has a role on that, because it’s part of: “Do people know how to do the OpEx? Do they have access to the spare parts they need to do the OpEx? Is somebody, you know… who… so you have OpEx, ok. Which then lead to functionality. *** But maybe also pump mechanic, hand pump mechanic.”	Direct Support can increase the functionality of a water point by facilitating training for the community and supporting regular repairs of the water infrastructure.
On the link between Direct Support and functionality: “So basically, Direct Support has an impact to the communities, because Direct Support should be doing things like institutional models and stuff, to make sure that your water user group, whatever it is, is there. Direct Support should be supporting whether your hand pump mechanic is able to do that job or not. And Direct Support, and the hand pump mechanics ability to do the job is also done *** by spare parts, right? And the payability of the *** and the Direct Support can have a role to play here. Ok?”	Direct Support has an impact on communities by strengthening institutional arrangements and capacity building for repairing the water infrastructure.

Table 24 B2.a. Interviewee 4

Text Fragment	Resulting Statement
On the mismatch between the CWRM paradigm and the realities on the ground: “I did work in Malawi but also for my thesis in anthropology I went back to the area where I had done the project. So, so looking at how, it was three… no, in 2006, it was two, three years later, yeah. Three years later, see how, if the system was still working, and also whether the management inst- system that we are putting in place, whether it was still working. And in some communities usually, the smallest one who were actually extended family who were managing together the facility then it was still working well.”	CWRM systems with users that are extended family are more likely to succeed than those CWRM systems with users who do not share family bonds.
On problems common to CWRM systems: “And in doesn’t always means having to, yeah, that the service authority has to go there always, just to solve problems. But just what they saw in Malawi, and also I’ve read from other authors in other areas, so just a regular visit, maybe once a quarter, to the committee and just see how things go and ask them if they need support in anything, that’s a very, that’s a sort, a strong motivation factor to stay functioning. Because in the end is a voluntary work, maybe not always very rewarding, so some committee members have to sometimes, they may not see the value or feel a bit alone. Yeah, it’s like, it’s the same for us here, actually. So having some motivation…”	Regular visits from external stakeholders to CWRM systems can be a strong motivation factor for the committee members to continue their work.
On factors that lead to successful CWRM systems: “Well as I said, the example of Malawi for instance, indeed when the system was really managed by members of the same family, then, yeah. The incentive is bigger and indeed, if there was issue with the water system then as a family, extended family then you have elders who have a say and who just get the other members of the family to do something if needed.”	CWRM systems with users that are extended family are more likely to succeed than those CWRM systems with users who do not share family bonds.
On factors that lead to successful CWRM systems: “So from the design actually, who is going to use it, and it’s not always possible to decide, of course.”	CWRM systems are more successful wen the end users are explicitly considered in the design of the system.
On factors that lead to successful CWRM systems: “The regular visits, supporting visits, and also, I will talk again about Malawi, but that’s also the example I know more in depth. What I saw also is that in villages where the traditional leaderships, so there you have leader chiefs, where the chiefs were very strong, then also were able to motivate the people to take good care of the facilities. In areas where the chiefs were less strong, then it would be different.”	Regular visits from external stakeholders to CWRM systems can be a strong motivation factor for the committee

	members to continue their work. Traditional leaderships, such as local chiefs, can exert a strong motivation on the community to take good care of the water infrastructure.
On the effects of Direct Support on a CWRM system: “No, yeah, indeed in the Direct Support would be more the regular visits to the communities. Just keeping them motivated. [...] Well, I... it’s more I guess motivation of the water committee itself, to be self-motivating them to go and ask to collect the fees... [...] Yeah, for the running operation or maintenance. Uhm... also discussing with the, again with the, like in the case of Uganda you have also, kind of chiefs, but a bit different roles than in Malawi. Local chiefs in villages, who can also be helpful or local politicians or so, who can also be helpful in mobilizing people so that they contribute for the water.”	Direct Support has an impact on communities by maintaining the Water Point Committee motivated to collect the fees from the users and to operate and maintain the water infrastructure. Local politicians can exert a strong motivation on the community to pay their contributions to maintain the water point.

1.1.1.1.4 What are restricting conditions of CWRM systems?

Table 25 B2.b. Interviewee 1

Text Fragment	Resulting Statement
"I, uhm, the term community is often very problematic though, because it makes it sound like in a single place, there is a single community. One of my backgrounds is in anthropology. And in anthropology you talk very quickly, very soon, and using very hard lessons, about how many development projects have gotten that wrong and continue to get that wrong because they walk into a single place and act like, just because there is one community that's down on paper, that that is a community of people and not that it's a single group that has… or not that it's a group of people were there are significant intro and inter political issues in group dynamics. So I find a lot of community-based natural resource management to be very naïve from a social dynamics perspective. Uhm, so my understanding of it is that I support it in principle but in practice a lot of it is implemented very poorly, and with very *** social science."	From an anthropological perspective, the term *community* is problematic, because it assumes that certain formal and informal institutions exist, which is not necessarily the case.
On a report of the World Commission on Dams: "That report is a great example of development-based, of a, of a good development study that looked at the ways in which people, even when they are supposedly interviewed and, and, and involved in natural resource management, are often, it's often the most vulnerable groups are the ones who are most screwed over."	Development projects do not always include the most vulnerable groups.
On development induced displacement: "So don't come on with a clipboard and run a single workshop and then expect that you are gonna understand the dynamics. That's stupid. We wouldn't do that to scientists in any other field. To think that just because you go and you ask a few people a few questions that they're gonna give you their honest answers straight out."	Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.
On long-term anthropological fieldwork in communities: "And if you, and if that that kind of work isn't being done, if there's a fly in fly out, *** a consultancy model of stakeholder engagement, and you tell me that that's community-based natural resources management, no it isn't. That's community-based natural resources management, or community-based water resource management that works for consultancies. It doesn't work actually to involve people enough, not with a single workshop or a single survey. I feel quite strongly about that. That's partly the reason why I live and work in the places that I do and I don't work for the big consultancies that do this work. 'Cause I believe that their *** problematic, mostly."	Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.
On a rain water tanks project: "But then the tank wasn't used as, shouldn't have been used as the main source of drinking water. They often were the only	Some CWRM systems are implemented in

source of drinking water, but that's not how it should've worked. [...] So the rainwater tanks were supposed to be just a backup, but were often used as primary form of supply, but the design was, of it was setup, that the water could be used for watering small veggie gardens to then increase self-sufficiency. [...]"	settings where failed water-related projects exist.
On the primary water sources to which the beneficiaries of a rain water tanks project should have had access, bud did not have: "The potable, the potable water supply, the drinking water system that was supposed to supply them with water."	Some CWRM systems are implemented in settings where failed water-related projects exist.
On the trade-off between long-term fieldwork in communities and external constrains: "[...] so that's always the balance. But just bec, if you're making a strategic decision, do you make that decision on the basis of consultant that comes and says I've done two workshops and one survey or a consultant, or a consultancy that says we've got on, and we have fieldworkers on the ground for a year and here is the analysis that we come up with. Which of, if you, if you, know I'm On, you have a point. If you have a choice to commissioning two studies, which study would you want to commission."	Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.

Table 26 B2.b. Interviewee 2

Text Fragment	Resulting Statement
On what comes to her mind when she thinks of *CWRM*: "I think that there were so many assumptions and... unknowns in this drive to decentralize, and it happened in the context of big austerity programs imposed by the international financing bodies, the World Bank the IMF, that it couldn't achieve it's potential, and there were.... Partially because of the lack of the functioning, good functioning governance and institutional structures in certain countries, and in other countries just persistent conflict and lack of functioning governments, let alone governance."	The design of CWRM systems includes assumptions that often do not hold. Stakeholders external to the community initiate the design and implementation of some CWRM systems without local support. Lack of good functioning governance and institutional structures drive CWRM systems to failure.

On the implementation of the *CWRM* paradigm: “So, in that setting it kind of sets communities up for greater burdens that what they could realistically carry. And that was a big Aha in the late nineties, two thousands, that they just can’t do it alone. And there, there, it, it’s unreasonable, it’s unrealistic and it’s unreasonable to just say, we filled the infrastructure, we settled a community-based management system with them as the owners, and the providers, and they’ll manage it, and they’ll keep it working for the designed life of the infrastructure. Good luck! Cut the ribbon, have a ceremony, install your new committee, and go away. And when you go back, you see de-funct systems, the people who are trained have left, they’re gone to pursue other jobs where they get actual income instead of this volunteer positions.”	CWRM systems set communities up for greater burdens that what they could realistically carry. The design of some CWRM systems do not consider the complete life cycle of water infrastructures. Some community members who are trained to be part of CWRM systems leave their volunteer positions in order to pursue remunerated jobs.
On what comes to her mind when she thinks of *CWRM*: “[…] So you start to see all the assumptions exposed. And that, because we didn’t take enough consideration of those assumptions, it didn’t result in the desired dream of actual equitable inclusive services for all. It’s been very patchy.”	The design of CWRM systems includes assumptions that often do not hold. The design of CWRM systems does not evaluate whether the initial assumptions held.
On the expectation of investment of international aid and development: “And that’s not a sustainable way of doing it. It’s one day they will leave.”	Some CWRM systems are not self-sustained and depend on international aid and development.
On what comes to her mind when she thinks of *CWRM*: “So, just through me injecting money through international aid channels, is allowing everybody who has a responsibility in this scenario to sit back and go, “Ah! The French will bring more money. Ah! The British will bring more money.””	Some CWRM systems are not self-sustained and depend on international aid and development. The dependence of CWRM systems on international aid

	motivates relevant stakeholders to avoid taking responsibility for seeking the financial independence of those projects.
On the central assumptions of the CWRM paradigm: "The reality is the community-based management system is largely happening in settings where there, people really don't have a lot of reserves to spend in these things. So then you see, oh! we have to fix, fix the whole by putting in rotating saving systems. There is so much more that needs to come to make the CBM as, so, so…"	Communities do not have enough money to maintain CWRM systems running.
On direct users having to pay for water services: "They don't have the money. […] They do but they have to do many choices between many things. Healthcare for their kids, school supplies for their kids. You know, all sorts of things."	Communities do not have enough money to maintain CWRM systems running.
On assumptions of the CWRM paradigm: "There was an assumption about the sense of ownership by a community. And the assumption that they would have under very little training that I mentioned, all the necessary skills to keep an infrastructure working, which was faulty because they don't. They don't have all of the means to keep the system working, the infrastructure system. Whereby, people don't feel that they should be paying their user fees, because the infrastructure is failing them and they're having to go back to traditional sources, so they're gonna choose to spend their money on other things that then deliver what they feel is value for money. So there's assumptions that they're all inextricably linked in there, about who should pay, or why they should pay if the thing is not working."	The design of CWRM systems assumed that communities would develop a sense of ownership of water infrastructures. The design of CWRM systems assumed that communities with very little training would have all the necessary skills to maintain water infrastructures functional. Communities do not have enough resources to maintain CWRM systems running. Community members do not feel that they should be paying user fees

	because water infrastructures have high downtimes. Community members do not feel that they should be paying user fees because they can and often do obtain water from alternative sources.
On water points failing: “Well, the thing is not working because half a day maintenance and caretaker training isn’t helping to actually keep the thing working on the long term, and especially when you don’t have the tools, or the tools walk away.”	The training received by caretakers of water infrastructures is not sufficient to maintain CWRM systems running in the long term. Some community members who are trained to be part of CWRM systems leave their volunteer positions. Communities do not have enough tools to maintain CWRM systems running.
On the role of the CWRM paradigm in the provision of rural water services in developing countries: Martin Watsisi is my colleague in IRC Uganda, who worked, walked with me on this whole learning, research, action research over these last seven years. And he said, “Deirdre, we’ve given them evidence on the community-based management model, and where it’s working, where it’s not working, why it’s not working.” I can get the, some of the research reports to you. It’s some of the stuff by Valerie Bey and Martin Watsisi. And, just ***. And he said, “So they have the evidence but they’re still choosing to keep that as the predominant model because they can’t think of what else it should be there, as the…””	Governmental actors are not willing to change the CWRM paradigm as the *status quo* of the provision of rural water services. Governmental actors do not have an alternative to the CWRM paradigm for the provision of rural water services.
On field evaluations of CWRM systems:	Field evaluations do not always capture

"Ehm… if you went to look obviously, then community members would be able to validate it for you, and sometimes you might be taken off on the side by someone who might say: "No, this is just a façade, you know, the community, the committee hasn't met for, the users committee hasn't met since the time we cut the ribbon and lunched the system."	the actual state of CWRM systems. In some CWRM systems, Water Point Committees do not meet nor manage the water infrastructure.
On the traits that characterize a CWRM systems: "There may only be women on the committee but, you know, they'll want you to see that they did a gender and equity kind of approach. So you'll get sort of the, the… they'll bring all these women who should, would otherwise probably supposed to be working and doing other things, but they have to sit there in the hot sun while you're being welcomed as the evaluator, so it's a bit, you'll see things that you have to question and think, is this…[…] is this the theatre that you're doing so that more money will come? Or is this really because you're showing, we are, you know…"	Field evaluations do not always capture the actual state of CWRM systems.
On field evaluations of CWRM systems: "I've been where they build the fence around the water point the day before. The one that is meant to keep the animals away, and stop people from washing their laundry at the tap. And you can see that it's just been freshly put there."	Field evaluations do not always capture the actual state of CWRM systems. Some regulations to protect water sources are not enforced.
On field evaluations of CWRM systems: "Because obviously they take you to the ones where it's functioning and working well. They don't take you to see the ones where it's falling apart."	Field evaluations do not always capture the actual state of CWRM systems.

Table 27 B2.b. Interviewee 3

Text Fragment	Resulting Statement
On boreholes drilled in unsuitable locations: “You know… how incompetent is the driller, how corrupt is the driller, how… lot’s of boreholes… I mean, it’s an issue… boreholes fail because of poor water quality, point sources… because of poor water quality. They fail because they dry out and they, it’s typically that they dry, they dry in the dry season… that’s a classic. And that’s because someone developed it, just after the rainy season, and they did the pump test and it looked like it was great, so they put the thing on and they didn’t, they’re not doing it, they’re not there to monitor it over ten years. It’s a shallow groundwater system and it’s, you know, in… after ten years below average rain *** is chopped down below it, or they’re not monitoring that somebody its just you there, you know, submersed, pumping to irrigate their farm, you know, hundred meters away. That’s ***, you know. But you’re into much more complex dynamics then-”	Boreholes can dry, owing to the dry season in combination with poor borehole development and unauthorized water uses.

Table 28 B2.b. Interviewee 4

Text Fragment	Resulting Statement
On the traits that characterize a CWRM system: “So, but what I’ve also realized, also through my studies in anthropology, what we call, we always say community-based management, but… Often, people who have to manage together a system are not part of the same community. There is a kind of mismatch between the model that we want to promote and the realities on the ground.”	From an anthropological perspective, the term *community* is problematic, because it assumes that certain formal and informal institutions exist, which is not necessarily the case. The design of CWRM systems includes assumptions that often do not hold.
On the traits that characterize a CWRM system: “We often have the assumptions that the communities so to say, with the manager of the water system, that’s, they receive, that they are cohesive, that they are happy to work together, that they see that it is in their common interest to maintain the water facility but it’s not always the case.”	From an anthropological perspective, the term *community* is problematic, because it assumes that certain formal and informal

	institutions exist, which is not necessarily the case. The design of CWRM systems includes assumptions that often do not hold.
On the traits that characterize a CWRM system: “When I worked in Malawi, for instance, we could see where water systems usually, their design was supposed to be managed by sixty families, but in some areas were you had much, very, bigger population growth in small urban centers, rural centers, it would quickly become way more than that. And those systems were also not as well managed.”	The design of CWRM systems includes assumptions that often do not hold. Unanticipated population growth tends to have a negative influence on the management of CWRM systems.
On the mismatch between the CWRM paradigm and the realities on the ground: “And others which were less communities in their own view, it was, the cohesion was not there, and some people started stopping to pay, and then it was less successful.”	In CWRM systems whose communities lack cohesion, community members stop paying their fees, which in turn worsens the functionality of the water infrastructure.
On problems common to CWRM systems: “Not being so much based in the existing functioning of the people, the society there… ehm, so, yeah. In the end, development projects often have also something to do with power. So, so maybe some people in power, and projects may… destabilize this, or create new power, create new incentives and interests.”	The design of CWRM does not always consider local realities. CWRM systems are complex because they involve stakeholders with potentially diverging incentives and interests.
On problems common to CWRM systems: “One problem about the management is indeed that, yeah, maybe the management structure was not well thought about, about the representations in the committee.”	CWRM systems do not always have Water Point Committees that are

	representative of the community.
On problems common to CWRM systems: "So in Malawi, specially, at least ten years ago, I don't know now, very often the construction of the water system was very poor.	Water infrastructures are very often poorly built.
On problems common to CWRM systems: "Yeah, for the borehole still. So it would happen that the borehole would just brake down after few months but not… the problem was not so much about the management but about the quality of the facility."	Water infrastructures are very often poorly built.
On problems common to CWRM systems: "Hmm… and what is often a problem, and that's also what IRC was trying to go against is that very often once you have installed the water management committee, it very much stays on its own. It doesn't get any support or very little support from outside."	Often, Water Point Committees receive very little support from stakeholders external to the community after the water infrastructure is installed.
On problems common to CWRM systems: "A committee, a water management committee is a bit unfair to expect from them to be able to solve all issues."	Often, Water Point Committees are not able to solve all issues related to a CWRM system.
On problems common to CWRM systems: "So, if there is a serious technical issue, for instance, then it's out of the hands, out of the hands of the community to be able to raise money and maybe make the repair."	In CWRM systems, communities do not have sufficient money to solve serious technical issues.
On problems common to CWRM systems: "But also, if there is conflict within the, within the committee, or between the committee and the community, then you need often an external person to come and help to solve that conflict. So, when you have no support from, what in IRC we call the service authorities, so maybe in Uganda the districts, then, yeah, they are very much left on their own. And the problem just stays like this."	In CWRM systems, external stakeholders are needed to facilitate conflict resolution within the Water Point Committee or between the Water point Committee and the community.
On systems managed by members of the same family: "It was working much better than when you have a collection of individuals from different backgrounds and different interests."	CWRM systems which users are a collection of individuals from different backgrounds and different interests are likely to fail.

On factors that lead to successful CWRM systems: “Specially in urban areas, or peri-urban, very often it’s not, it’s less traditional settings. So there are sort of people who come and go, arrive and go. Then the, yeah, indeed.”	In CWRM systems in non-traditional settings, members of the community arrive and depart relatively often.
On factors that lead to successful CWRM systems: “And I was also interested to see when I went back there. What we intended to do in that project at that time also, is that if the chief was not cooperative you would just bypass it and say, well this project is for the people in the end. And did it work? Yeah, but short term. So, as soon as the project left, then the chiefs, then, could… some were extremely clever. Some also went to the, because they had understood how the system was: so community contributions, and this and that. And each water system had its small maintenance funds for operation and maintenance, and repairs. But they starting making up things like saying: “oh, well, just give me the money because I just set up, I just have the mechanic that I’m going to pay to do the repairs.” And even though people did know that it was not true, they could not say no to the chief just because of his power, spiritual power. So, but it was also interesting, not nice, but interesting to see how the chief managed to use the language and the approach of the project to their own interest. So yeah. Just to say, yeah, bypassing the local authority worked on the short term, but once the project is over, and also because there was no regular visits then from the local authorities, from the service authority, on the governmental district then, it just, it just went wrong…”	Bypassing non-cooperative traditional authorities in order to implement a CWRM systems is not effective in the long term. Non-cooperative traditional authorities can deviate resources from the CWRM system.

10.2.1.3 B3: Looking beyond Community-based Water Resources Management

1.1.1.1.5 What innovations have occurred in the water sector beyond CWRM?

Table 29 B3.a. Interviewee 1

Text Fragment	Resulting Statement
Vacant	Vacant

Table 30 B3.a. Interviewee 2

Text Fragment	Resulting Statement
On the role of the CWRM paradigm in the provision of rural water services in developing countries: “What role is it playing? It’s still the predominant model. Let’s take Uganda again. That is the nationally determined management model for the country […]”	The CWRM paradigm is the predominant model for the provision of rural water services in developing countries.
On the role of the CWRM paradigm in the provision of rural water services in developing countries: “We talked, so yesterday again at IRC, I heard the colleagues, they were speaking about District system strengthening, and national system strengthening. So, irrespective of how we feel about corruption, transparency, etc., because those are often the counterarguments why we shouldn’t strengthen… What essentially our government led systems for delivery of public services; you can’t circumnavigate government in a given country where it’s democratically working, for all intents and purposes. I mean, you can have a great discussion on whether it’s democratic or not, but where there is a government apparatus, and that is in principle the lead in the governance arrangements, acknowledging that you have multi-stakeholder, civil society actors, international development aid, agencies, blah blah blah blah blah, the remaining thing apart from the citizens, will always be the government, until it falls. So they talk about strengthening the systems at districts level and at national level. So while the government’s in the lead, so national level, district level, it’s strengthening a bit the ability of the government actor to be able to drawn in, and learn from, and work with in the action research processes all those different actors and stakeholders. And do it in an effective way, with a lovely process, so that’s back to the process I was describing in the beginning, with the visioning, and the problem analysis, and the testing, that this system at district level is in place to support the communities in there, because the paradigm is still community-based management is provision, district is authority.”	Efforts to improve the provision of rural water services in developing countries focus on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes. Efforts to improve the provision of rural water services in developing countries are not innovating beyond the CWRM paradigm.

Table 31 B3.a. Interviewee 3

Text Fragment	Resulting Statement
Vacant	Vacant

Table 32 B3.a. Interviewee 4

Text Fragment	Resulting Statement
Vacant	Vacant

1.1.1.1.6 What are foreseeable developments in the paradigms used for the provision of rural water services?

Table 33 B3.b. Interviewee 1

Text Fragment	Resulting Statement
On the trade-off between long-term fieldwork in communities and external constrains: “As is the world. That’s resource constraint. I fully agree with you. I, that’s my whole life. Having to make, professional life. Having to make some of those difficult judgments, by whether or not you fund someone to be on the ground for six months, or whether you fund a consultant to fly in for two workshops. The point is that there are, and I do fiercely believe that there are *** better ways of doing research that just inconvenience a lot of the people who do that, do that research. And I don’t believe that that should be the reason to not have good grounded analyses. Doesn’t mean you need to have people with, all these PhD’s and engineers, they are in the field for a year. Of course not. That’s not practical. But it is possible to do better versions of your work that, that strike a balance between the survey type and fly-in fly-out model, and the, you know, deeply, deeply embedded anthropological model. There are in betweens. But the in-between is certainly not the clip-board model that a lot of the consultancies and research groups do.”	Fieldwork and research in communities affected by a development project should be based in well-grounded social science, such as anthropology.

Table 34 B3.b. Interviewee 2

Text Fragment	Resulting Statement
On what comes to her mind when she thinks of CWRM: "So, it had potential, it's not there yet, and I think we need to actually fundamentally reconsider community-based management as the mode of delivering the services. I don't think it's doing what it needs to do."	The CWRM paradigm needs to be reconsidered as the predominant model for the provision of rural water services in developing countries.
On whether CWRM will continue to be the most common model for the provision of rural water services: "Until such a time that they're honest and admit to themselves that they really need to take on the job themselves. I think. Eventually we will go there. But for know it's to give better support and back staffing to the CBM, the community-based management system."	Efforts to improve the provision of rural water services in developing countries are not innovating beyond the CWRM paradigm.
On whether the sector will return to the state-led era: "It will depend on how it is rolled out in different contexts. If they're clever and want to learn from the last twenty, thirty years, they'll go for a governance approach, which means governments in the driving seat. But they can't do it without all of these other actors that are anyway present and involved in supporting communities to live with the water services. So there's the NGO's, the CBO's, the different levels of sub-districts, government are there, technicians, the Hand Pump Mechanic associations is a relatively new body in Uganda. They need to work with them on help connect the dots between what all those different agents, acting in a geographical location, are doing that contribute to lifting up the water service levels. So if they're clever, they will embrace the fact that it's governance, and not government. But the resources that they do have as government should be spent on driving inclusive processes that empower these agents to do their jobs, to support the communities."	Future efforts to improve the provision of rural water services in developing countries should strengthen the position of governmental institutions as the leaders of those projects. Efforts to improve the provision of rural water services in developing countries focus on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes.

Table 35 B3.b. Interviewee 3

Text Fragment	Resulting Statement
Vacant	Vacant

Table 36 B3.b. Interviewee 4

Text Fragment	Resulting Statement
“Well, I think and hope indeed that we should now be going in the direction of having more is called I think the CBM+. Still CBM, community-based management but with support from the service authority. I think for, yeah, many areas you cannot move away from community-based management…”	CWRM systems need support from governmental institutions. CWRM will continue to be the paradigm for the provision or rural water services.
On the impossibility to abandon CWRM systems: “Well, for instance in some areas of Malawi, where, which are very remote, which don’t have a district office so close by. I mean if they can visit once in a quarter that’s very nice, but… Or you could then even have indeed the alternative to that is privatization, but yeah, you need also the incentive for that. And water is maybe not the most…. Maybe not… a sector where you have a lot of money to be done in a scattered area, just because the number of people are not so many. Yes. So then the incentive, the skills or so, that’s people *** a private company that someone can run it”	CWRM will continue to be the paradigm for the provision or rural water services, because rural areas are remote and do not have district offices close by. Privatization of the provision of rural water services is not a likely alternative because areas are scattered and budget is limited.
On the likelihood of privately managed systems substituting CWRM systems: “Well it depends on the context I think. You can’t, it’s not possible I think to make one… yeah. To say for everywhere… yeah. To say for all, for everyone…”	Privatization of the provision of rural water services is not a likely alternative, but its feasibility depends on each individual case.
On the necessary conditions for the emergence of privately managed systems: “Yeah I guess you need to have enough people to serve, I think a certain number of people to serve, so that it’s attractive enough from a financial point of view, or for a private operator to do that. Of course when it’s a piped scheme it’s also maybe a little bit easier, because then you have one system to look at. Where, there are also, so there is also talking about getting	Privatization of the provision of rural water services would require a good business case, which would be difficult to produce.

private operators for different boreholes and water points. So, kind of in charge of an area. Yeah. It's very much depends on the context, so… it's, I find it a bit difficult…"	

10.2.1.4 B4: Modeling and simulation tools to study the problem

1.1.1.1.7 What modeling and simulation tools are usually used to study this problem?

Table 37 B4.a. Interviewee 1

Text Fragment	Resulting Statement
On his professional training: "[…] and then also system dynamics modeling short courses, certificate courses, advanced courses, and that's, and none of those were done through my degree they all were done separately. Because again we don't offer system dynamics at Rhodes University, formal training in it."	System dynamics
On his experience with modeling and simulation tools: "I have personally used system dynamics modeling. But I have worked with and worked as part of projects where there's a lot of spatial modelling. A lot of GIS based modeling. People use INVEST, ***, a bunch of other processes there. And also some discrete event modelling, and some econometric modeling. […] Just all the standard hydrological modelling. Hydrological modelling and water quality modelling. Hydrological modelling is mainly, well it's differential equation based, but it is system dynamics but they never refer to the system dynamics modelling. It's 'cause they don't use any of the SDM in terms of graphical use and the interface, but it's differential equations that are there. And so I've worked, I myself have directly modelled with system dynamics but we've also, in the *** grant, the *** doing hybrid modelling that draws from the spatial and econometric, and from hydrological modelling, in, and then uses, and then we withdraw each of those using SD as an integrative tool."	System dynamics Spatial modeling (GIS modeling) Discrete-event modeling Econometric modeling Hydrological modeling
On modeling and simulation tools with which he was not directly worked but that have been used in teams of which he is part: "Discrete, there's been components, some of the water quality modeling you are interested in, in the discrete event of a water, of uhm, what's an example. Point source and non-point source pollution and discharges with unintended effects and unintended discharges. […]there's land transi, some of the spatial models also have an artificial intelligence component, because they are probabilistic models that can be say, that likelihood of one transition, of a transition from this crop type to that crop type, or this land cover to that land cover. […]INVEST is the modeling platform that is typically used for that. You know,	Discrete-event modeling

***. Do you know INVEST? […]And the hydrological modeling explicitly integrates spatial and temporal. I mean, one of them is actually called SPATSIM, which is the S-P-A-T-S-I-M, which is the spatial, SPA is the spatial, SPA is spatial and TSIM is temporal integration modeling platform.”	

Table 38 B4.a. Interviewee 2

Text Fragment	Resulting Statement
On the use of modeling and simulation tools in the water sector: “In the WASH sector… I have been at many… let’s say conferences and symposia where it’s been presented as a tool that could be promising and helpful as a decision making tool, including myself. I have stood there in, you know, gallery type setups and presented models that we built here at TPM and said, guys! This is exciting possibility! It’s never yet been really embraced as a solution for instance I can ex-, compare it with GIS, that was cutting edge and new in the 90s, and people were like: “Oh! Oh! Oh! That’s so highly technical that we don’t know if it may or it may not”…. But it’s now sort of…. Of course it’s always used. Of course it’s available as some sort of problem analysis information to help inform decisions, and I feel like modeling needs to catch up. Or at least simulation, agent-based simulation is still regarded as this mysterious technical thing. And part of my research is how do we bring it in as something that people don’t think is obscure. […]”	Spatial modeling (GIS modeling) Agent-based modeling

Table 39 B4.a. Interviewee 3

Text Fragment	Resulting Statement
“So, I’ve worked with Bayesian networks, Bayesian belief networks. […] And I’ve worked with, before that, I’ve worked with sort of physically based ground water models in particular. […] Ground water models.”	Bayesian belief networks Physically based ground water models
“So people use models to, to vali-, networks, hydraulic models you know, people use groundwater modeling to think about resource constraint. People use hydrological modeling to think about surface water constraints. People use integration land-use models, so, you know, there’s lots of physical, there’s lot of physically based modeling used in some aspects of the water sector.”	Physically based ground water models Hydrological modeling Land-use models
“And then a specific interest that I’ve had is, ehm, in particular agent-based modeling, was what I’d been looking for to continue all that interest from a long time ago.”	Agent-based modeling

Table 40 B4.a. Interviewee 4

Text Fragment	Resulting Statement
"- [...] So, regarding modeling and simulation tools, what kind of models have you used in your work? You mean really simulation models, or... - Any kind. No... I don't think... I haven't really used models, I mean... well yeah, indeed. Principles like about how things could be or should be organized, but not really models that are kind of trying to predict what's going to happen. - Computational models? No. I was not involved in that. Other colleagues in IRC like Deirdre... she told you about Kristoff? - No. He was also, but, they were working, some work on agent-based I think. But I was not involved. - And what modeling methods have you heard about that can be applied for this kind of problems? I've heard about the agent based model, but that's about it. I must say I'm just not... - Not familiar. Also not familiar with how they can be applied? No... sorry!"	Vacant

1.1.1.1.8 How can modeling and simulation tools be used to study the problems, barriers and solutions to Community-based Water Resources Management?

Table 41 B4.b. Interviewee 1

Text Fragment	Resulting Statement
On his experience with modeling and simulation tools: "But the whole way in which I used models, my beginning, the beginning and the end of my interest with all models and simulation is that they are tools to be used as slaves in a process. And the process generates through, through using them in a process we generate some products and artifacts and so there are models that come out of that, but the insights from those models are useful to me, only if those insights can feed back into an, and be worked as part of the modeling process. When they, when creating the model itself isn't the goal. So creating a good model that the system dynamics guys at the conference you know, here say, yey! that's a very good model. If it's not useful, then I don't think, from, as far as I am concerned that's not a good model for my purposes, or any of the processes and project that I've work with. I actually don't mind if the project is not that classically good, the model, is not that good, I mean if it's, and of course it must be verified and validated to some of the basic processes. But if it can be a tool to be used to help facilitate learning and discussion. And to do	Models can be used as tools to create a facilitation environment that triggers processes to learn, discuss, build and foster collaborative action.

that in a way that builds collaborative action, that fosters collaborative action, if it's used as a tool that I can use in a facilitation environment. If I can help develop, if I can work with stakeholders to develop causal loop diagrams then the qualitative renderings that we can take forward into simulation models. And we can then use the simulation models to explore the different scenarios of change under different conditions. And we can do that in a way that is gear to learning, gear towards learning, and gear towards building collaboration. That, that's interesting."	
On his experience with modeling and simulation tools: "But that, then, we are interested in modelers as bricoleurs. And researchers, and modelers as researchers and action researchers. And, and, when you get interested at that point, then, when you work under that point, then, then whether I ascribe to the group model building group school or the participatory modeling school, or, you know Marjan van den Belt mediated modeling, all are doing the same thing as far as I'm concerned. It's all trying to involve people in a modeling process. And no one can, no stakeholders, no group of, no heterogeneous group of stakeholders can be involved right into, through a modeling process so there's always tradeoffs between the public participation side, and the practicality of actually getting a model to then a modelling, getting a model developed and then a modelling process right. I am far more interested in thinking in modelling as an activity, than I am in model building."	In some cases, fostering participatory processes has priority over producing a technically advanced model.
On models that integrate spatial and temporal components: "So, yeah. Which of course in system dynamics is really difficult, yeah. And I don't actually think that it's the best use of SD, at all. The best use of SD is strategically, often quite small models, but insightful models. And Jill and I are in agreement, largely in agreement in that regard."	System dynamics is best suited to study problems at a strategic level, through small yet insightful models.
"See the companion modeling approach. Have you seen that? [...] The book it's called the Companion Modeling. Michele Etienne. It's a 2014 book. Just make a note for me to send you the reference, I actually have a copy of the e-book, it's a Springer book. C-I-R-A-T, Jill knows them, in France. So they pioneered, they argue that they have this other thing, which is like, it's like the agent-based modeling equivalent of group model building. They call it Companion Modeling. And they use a combination of agent-based modeling that's done in a standard simulation. They have a platform called CORMAS, C-O-R-M-A-S, which they developed, and that's the kind of custom ABM platform. But then they also do like human agent-based modeling. They run like ga, what's here at TU Delft, or at TPM is like, serious gaming, that's, so they do that. And then they do that in tandem with the ABM modeling. And it's, they've got like	In addition to system dynamics, agent-based modeling can also be used to foster collaborative processes, including combinations with serious gaming.

virtual agents, and then put human agents, and they kind of play with both of them, and then try do learning and crossing between them.”	

Table 42 B4.b. Interviewee 2

Text Fragment	Resulting Statement
On barriers why modeling tools such as ABM and SD are not yet common in the water sector: “There are few reasons and one came up yesterday in the focus group discussion we had with IRC Uganda team. They heard model and they understood many different things. So first we had to actually be really clear what we meant by a simulation or a model. What its potential could be in aiding decision taking. Not as a predictive thing. So there’s somehow there, we hear it’s a thing that it’s gonna come with a blueprint that is then considered predictive and so it must follow everything. So it’s a bit of fear, not enough knowledge about what a model can offer, perhaps because we’re coming from an era of very linear thinking where you make a plan, you have a lot to call framework of how you think you’ll realize the implementation of the plan. Whether its organizational development or infrastructure development or policy implementation, with all of its assumptions and its *** we’ll do this and then this and… and a model sounds like a very fixed thing that tells you how to do that. And, so there’s almost this fear because people have really embraced the idea that the blueprints and the models and the logical frameworks didn’t get us where we need to be for services. So when they hear it, they go “Ehhhhh!!! (scared) No!!!” So there is lack… there’s awareness raising needed to understand that, that particularly something like agent-based modeling but also probably in collaboration of GIS and other forms, even serious games, offer us ways to explore the, the dynamics in complex unpredictable scenario. and when we find a way of kind of take away the fear, of “oh! You want us to do exactly what the model told us to do”, this model is to help you explore different scenarios, people kind of sit back and go, “Ok”. But then, we had gotten that far in our explanation yesterday, of like it’s not a predictive thing, it isn’t meant to tie you up and force you to follow exactly what the model tells you to do. It’s really for your own exploration of different parameters, different scenarios, and then the country director from IRC Uganda said, “I still can’t bring this to the Director of Water… Ehm, Development, Rural Water Development, because he will be frustrated that you’re coming with another tool.”	External facilitators should be clear on what is meant by modeling and simulation tools. External facilitators should be clear on what is the potential of modeling and simulation tools in aiding decision-making. External facilitators should explain to potential users that modeling and simulation tools do not necessarily have predictive power. Modeling and simulation tools can offer insights on the dynamics of complex and unpredictable scenarios.
On barriers why modeling tools such as ABM and SD are not yet common in the water sector: “International aid and development organizations, donors, academics, everybody is always coming with a tool that they	Stakeholders from governmental institutions are skeptical about the

promise will fix everything, and they call them “silver bullets”. And there’s this sort of allergy for another silver bullet that in the end they can’t use or do because they don’t have the technical skills. It’s something new developed in Europe or America. That was the problem with GIS in the 90s. The skills weren’t there. The technologies, the computers, the… what you needed to do the GIS development wasn’t available locally. It remained a fancy expensive thing that kept getting imported. Know they have the technology, and the skills, and the ways to do it. And this is again another thing that they hear like, “Great. You’re coming with another expensive technology that we don’t have the ability to control and use for our own purposes. But you want us to give you everything in order to adapt and apply the model? but we don’t understand it. We don’t see what its added value is. We don’t… we can’t even… manage it ourselves. But you want everything from us to go and do some academic study up there. Would you even come back and tell us what came out. And help us really understand what we could do differently. So there’s somehow that ownership and, and… in one way, innovation is a good thing, but it’s almost like, and I know the director of the Department of Water Development there, and he’s sort of like “don’t come with your tools and your toys until it’s really clear what added value it has for me to get water to the people who don’t have water”. I don’t know… it’s a long way of saying like…”	use of technical tools developed abroad if local stakeholders cannot manage them.
On her own view of modeling and simulation methods in future research: “There is so much more talking and interaction needed in these sort of smaller focus group discussions, showing them the power of what type of insights we can get from the modeling, so there’s a lot more exposure, awareness raising, capacity building about the tool necessary, before people can embrace the findings that come out. So, yesterday’s conversation was one I’ve been having this focus group discussions with this group from Uganda for almost three years. Yesterday was the first time one, the one team member that came by surprise from Uganda, one of the learning, sector learning facilitators who worked in Kabarole District, and at national level, that he said “but the beauty of this tool is the ability to understand what we consider a system and unexpected developments in it”. So, that’s three years of conversations with one person. And having done the big landscape picture that I have shown you before of Uganda, with all the layers of the learning platforms, he is one of my key informants that help me build that landscape. We’ve been on the whole journey so that when the model is there, he knows exactly what is in it. And what, what it therefore can help us probe and explore and learn. So that when there are findings he feels he gave inputs. But that’s three years of work with a really quite small team who have really close direct close access	Before modeling and simulation tools can be used with stakeholders from governmental institutions, stakeholders from governmental institutions need to receive exposure and build capacity to manage those tools. Stakeholders from governmental institutions can receive exposure and build capacity to manage modeling and simulation tools in collaborative processes and

to the direct, the Water, the Ministry of Water, but we need to grow that circle of engagements in some form of multi-stakeholder… yeah…. Focus group discussion. We need more of the, those process events that we spoke about first. Of gatherings, learning events, symposia, before they go, "Ok. Ok. This has a value." It's not enough to just show findings, when we don't know what in there. 'Cause that's just a black box. It's when it's their model. That's when it's going to take off."	learning environments.
On the role of external facilitators in the water sector, using modeling and simulation tools: "It's a very good question. And it's something I'm finding my way in it myself, because my mandate to come and do the doctoral research was build for IRC an agent-based model that would help us as a didactic tool for people to understand that, I just described that my colleague Martin from Uganda had yesterday, "Oh! This model with these inputs that I worked with you will help us understand when we make this choice, this scenario evolves. When we make that choice, that scenario evolves." And for three years I've been silently extremely stressed out. How could I take that team with me in the development of the model when I can't be traveling to Uganda every two months, and showing them every step of the way, and asking them to help me on making choices of what's in the model, what's not in the model, when I'm only learning myself what does it mean to do modeling. So some of is the responsibility of the, the person working with the innovation, the academic, the student, the professional developing a model, you have a sense that it will offer a new way to explore a problem. Your research is to A) explore the problem, but also to B), to question the tool. Is it really adding useful insights to help decision makers and policy makers. And that's an honest question you must always have for yourself in mind. If it's not, then there's no point in continuing with it. But it's also their responsibility to take people with you on the exploration of the value of the tool. Every time I go back to IRC, over these last three years I've had at least one or two sort of domain expert interactions per year. People who I think, even my own line managers, who, you know, approved the proposal for me to do this research, go, "But why a model?!" And I have to go back to stage one and not be frustrated. And feel, "Oh! You just don't appreciate my work." It's more like, I have, my responsibility is to make really clear why we think it's valuable to spend money and time on this. What it could offer, and to always double check is it actually delivering. Is it offering these new insights? And if not, is it because I am not making a translation well from academia and innovation, and new technology, to practitioners? Or is it because the thing really, just isn't suitable for making that bridge. So that's a job of every facilitator. To clear the way of, like, are we communicating well enough about what the tool is,	Modeling and simulation tools can be used as didactic tools to explore plausible scenarios. Modeling and simulation tools should serve not only to explore a problem, but also to aid decision-making. Relevant stakeholders should be involved in the exploration of the potential of modeling and simulation tools in aiding decision-making. External facilitators should be clear on what is the potential of modeling and simulation tools in aiding decision-making.

what it could help us understand, what's needed to build it. And it takes longer, it doesn't match perfectly with the tempo of that academic research perhaps, follows, that's what, why action research is more expensive, more painful, more time consuming, because it has to have these iterative loops that take the people who can use the tools, and that outcoming evidence with you. And they're busy. They're doing other things. And they're not academics. And… I don't know if that helps. You are asking great questions! And it's bringing a lot of the things, a lot of the struggles I'm having in the process of managing my research and keep it grounded in the practice."	
On the modeling and simulation tools that she has used: "And even when I was working at a training institute in South Africa for water and sanitation professionals, counselors, and officials, I was the one that went to the local water, you know the department of water at the province level to get the GIS maps of the local communities, of the local districts, the new districts. Because the people being trained didn't have a sense of, even just the geographical level of the land of where they were responsible for ensuring the services where delivered And I thought, "My gosh! They've got a GIS department, we can get these maps" And it's one tool for people to visualize if I am delivering a service that has to continually run and be affordable for people, what's the geographic challenge involved there, because these are previously unserved homelands. When there were no services, people were walking miles with buckets. And, so I know that's not modeling in the sense of what we speak about here in TPM though, but it's any graphic depiction that enables you to visualize, where do geographic, infrastructure, human settlements and key other features like roads and sources of water, and where is my, my works department for when repairs need being made. You know. So the overlay of human and social systems over the technical, over the geographic stuff is powerful. And I mean we were really working with people who couldn't read maps. They hadn't had formal education or that sort of learning. So just starting with that, mapping, it's for me essential."	Modeling and simulation tools can help relevant stakeholders to build a more accurate idea of the problem that they aim at managing.
On the modeling and simulation tools that she has used: "But then get people to draw that, the landscape of the map that we made, of the learning platforms in Uganda, for me that was the first landscape to get a sense of who are the agents involved in policy and decision taking around sector, water sector, institutions, formal and informal, laws, by laws, blah blah blah. So, whatever I find as a useful medium for helping people bring the collective vision analysis, problem solving, into a shared visual, that, then when they see it again they remember the conversation, and the problem they identified, and the, so, those are the type of models I most at home with. The paper and pencil and, cards with words on them, and, and then the	Conceptual modeling helps relevant stakeholders to build a common vision, or mental model, of a certain problem.

people have the opportunity to then work with such a model and put their domains of knowledge and expertise there and check, how does this align with that of other people? So you have the academic you have the politician, you have the implementer. And they start to see that things overlap. And that's when there is, you know, resource intensive paper and pens and tape and sticky stuff to keep it upon a wall and then you photograph it and you might digitalize it, but it becomes the model that you might share. They get a mental model."	
On the modeling and simulation tools that she has used: "And… I think it has tremendous potential as long as we're able as academics and practitioners to make that translation to what is it that it offers to people. And I'm familiar with GIS as well. I mean that, I told the story of the maps in South Africa. Other models, well, I love serious games, because I think in a way, more, possibly more than agent-based modeling, it allows, even in my own masters' degree in the nineties, serious games were a way that were, interactive way to sit down and think through a policy challenge. And they allow, if they're well designed as an experiential learning device, people to really puzzle through from their own perspectives, but then in a collective way, the different scenarios, the different potential outcomes that happen when we take different choices. So that's a different type of modeling. I consider modeling in a way, that allows us to, learn new things, try new things without real-world consequences, and very powerful. But, where the ABM will fit in allowing practitioners to play with parameters, scenarios, dates and see outcomes, I'm not sure yet, because it feels still as a scary technical thing for them. But I think that our job…"	Modeling and simulation tools designed as experiential learning devices allow people to engage in processes for collective learning. Examples include spatial modeling (GIS), serious gaming, and potentially agent-based modeling.

Table 43 B4.b. Interviewee 3

Text Fragment	Resulting Statement
"Yeah. I'm very interested in the modeling work you do, and in the back in the day which was, now, over ten years ago. When I was doing, when we were using Bayesian beliefs networks, it was, you know, in, I think a very similar way. We were trying to find a modeling system that was flexible enough to take all sorts of different inputs from experts' opinion, to hard data, but that was easy to put together representations of complex systems that made sense to people working in those systems. So that's what we did along with that, those Bayesian networks. Use and work with WASH engineers, managers, particularly in the Middle East. A lot in Egypt and Jordan, Palestine. And to help them to use the model to understand the implications of some of the decisions that they were, like, in theory be able to make or not make."	Models should be flexible enough to take inputs from experts opinion to hard data to produce representations of complex systems that can be used by people working in those systems. Modeling and simulation tools can be used to explore and explain the implications of policy alternatives.
"Why I like, why ***, why I like the Bayesian networks is that it was a water governance project, but we basically used, by the end of it, *** technique, five years or so, we were pushing at that kind of physical backbone, who was based in the physical system, and then we. But then we were looking at how social policy decisions impacted on the physical backbone and basically on the availability of water. And actually that was the reason why Bayesian networks were powerful, was to show them the, the… the devil of uncertainty behind any ***, you know, because we do this, then that will happen. And actually by modeling into the system you see that, you know, once that you have sort of 90 degrees in certainty go to five steps and you still get 50/50 by the end. You know, not so powerful insight for people to realize that they had much less control over the system than they thought they had."	Modeling and simulation can make explicit the effect that uncertainty and policy decisions have on physical systems.
"So people use models to, to vali-, networks, hydraulic models you know, people use groundwater modeling to think about resource constraint. People use hydrological modeling to think about surface water constraints. People use integration land-use models, so, you know, there's lots of physical, there's lot of physically based modeling used in some aspects of the water sector. So, and then, you have what's, I think, much less used is the sort of policy oriented decision support type models. Maybe that we've been looking out here."	Modeling and simulation tools can be physically based and policy oriented, depending on the objective of their use.
"The Bayesian networks is trying to look in a way of, of developing models that could be used and then, in a semi-, in a didactic way to get people to understand better, the complexity of the system to which they are part, on the one hand. And as in	Modeling and simulation tools can be used in a didactic way to

a can-… a sand box way, as somewhere that you could experiment with, which is a more classic use of models, right? To experiment with adjustments to a system so you that don't actually work in real time, so that's gonna take you ten years to see if anything happens, while you have the model that can help you to justify your intervention logic, and stuff like that."	understand complex systems. Modeling and simulation tools can be used as a sand box to experiment with a system without working in real time. Modeling and simulation tools can be used to justify an intervention logic.
"When we were modeling, as I said, we modeled a lot of stuff using Bayesian networks. And one of the challenges there is it doesn't allow causal. It's purely, it's all… it's probabilistic. So you are able to say things like: "well, if they maintain this, and they, I don't know… yeah. If you have OpEx and you have CapManEx, what's your most likelihood that your system is going to be working any one time."	Modeling and simulation can make explicit the effect that policy decisions have on physical systems.

Table 44 B4.b. Interviewee 4

Text Fragment	Resulting Statement
Vacant	Vacant

10.2.1.5 B5: The case of rural water service provision by water points in Uganda

Table 45 AB1. Interviewee 3

Text Fragment	Resulting Statement
"- Here we are assuming that a part of the funds that are not spent… Good! For whatever reason. - Yeah. For whatever reason. We don't go into detail. If… Is this percentage reasonable? Let's imagine… Yeah. - 10% maybe? Yeah."	
"But normally in the Ugandan, the OpEx, in the Ugandan setting is supposed to come from the community. In… that's almost, you can almost use that as a definition of things. If it's CapManEx, it's supposed to be payed by the districts. If it's OpEx, it's supposed to be payed by the community. In practice, it	

comes down to, you know, the hand pump mechanic comes, they look, they see if they can fix it. They say how much it's gonna cost. If the community feels it's too much they'll just say we cannot pay that. And then the hand pump mechanic will probably go to the district, and if the district has some money they might give it to them."	

1.1.1.1.9 AB1: mentions of the problem addressed by the research that do not belong to other thematic blocks

Table 46 AB1. Interviewee 1

Text Fragment	Resulting Statement
When asked to give an example of a CWRM system that goes wrong: "Ha! It's more like give me an example of them going right. Every single development project has and it, it, often, well, Ok."	CWRM systems go wrong most of the time.
On a rain water tanks project: "[...] The point is that these where places that did have taps, but the point is that although they had taps and supposedly access to water, as is the case in many parts of South Africa, there often isn't water flowing out of those taps. [...]"	In some locations in Sub-Saharan Africa, water infrastructures have been installed but does not operate.
"Macheke springs should be a protected spring because the consensus is that there's, if there's is pollution around, that gets in that spring and it all pollute the ground water which is currently, which is being treated or is being used by commercial farmers in the area. The irrigation has the kind of, the big backup, for when the river runs dry because of climate change, and because of mismanagement of the canal system. So that's part of what we are working with in the Selati, that's S-E-L-A-T-I, the Selati catchment."	In some locations in Sub-Saharan Africa, vulnerable sources of water for human consumption are not protected. Instead, water uses such as irrigation have priority.
On protected springs: "S-E-L-A-T-I. And the reason why the Macheke springs is so relevant now is that it looks like a housing development is on communal owned land, and it looks like a housing development is about to be put literally on, literally on top of the spring. [...] so the commercial farmers are getting very angry and want to go, almost go to war. But, so this community represents those, the lack of resource protection."	Some regulations to protect water sources are not enforced.
On a project that could potentially lead to the pollution of certain springs: "And there's no environmental impact assessment that was done, it does not look like the planning protocol was followed, so the commercial farmers are getting very angry and want to go, almost go to war. But, so this community represents those, the lack of resource protection."	Impact assessment procedures and other planning instruments are not always executed.

Table 47 AB1. Interviewee 2

Text Fragment	Resulting Statement
On the role of the CWRM paradigm in the provision of rural water services in developing countries: "Martin reiterated this to me yesterday. He said, "Deirdre, we've worked and giving them the evidence that the community are not managing to do this"…"	Communities are not managing to make CWRM systems succeed.
On field evaluations of CWRM systems: "It depends on what the purpose of the evaluation is. So in the case of the one that I did of Austrian aid, it was one off visit for a week, one week in Cape Verde, one week in Uganda, one week in Guatemala, one week in Bosnia Herzegovina, (laughs happily), it was very interesting 'cause… yeah, whatever. So it was rapid, quick, impressions. How many communities or, let's say, how many water points did you visit, more or less, in each of these… […] In Cape Verde… this was an interesting program because it was a resource protection and sustainability as well as community-based management systems. And the desired outputs of having well functioning management systems related to water services delivery. So let's say, in Cape Verde, we, we visited two different sources, and saw the source protection efforts in the river rehabilitation scheme. So that there would be water flowing to where the communities needed to manage the delivery. So then we would've seen, I wanna say we saw, let's say four villages. I would have to look back and see four out of how many. What the total of the scheme was. […]"	Some field evaluations are conducted during long periods of time, in multiple communities, and assess multiple aspects, such as natural resources protection and rehabilitation schemes.
On field evaluations of CWRM systems: "[…] Social scientists, engineers, teachers, the NGOs, where a critical player in the capacity building element of the community-based management project, so they were involved in supporting the technical building aspect, that's why there were engineers on board. But they were also extremely involved in helping built the capacity of the community-based organizations to do their CBM as to fulfill that role. […]"	The design of some CWRM systems include strong capacity building elements in their work with communities. The design of some CWRM systems include strong technical building aspects in their work with water infrastructures.

Table 48 AB1. Interviewee 3

Text Fragment	Resulting Statement
Vacant	Vacant

Table 49 AB1. Interviewee 4

Text Fragment	Resulting Statement
On the effects of Direct Support on a CWRM system: "I'm not so sure because actually, to be honest, what I've also, what we've also witnessed like in Uganda is that the investment in Direct Support was still very, very low."	Expenditures in Direct Support tend to be low.
On the levels of government involved in CWRM systems in Malawi: "So it was very much the national level still, and at the district... was it the district? No I'm mixing up the two... yeah, it was the district, there were also staff involved but the water resources department was very small, it was one or two persons. Actually, their involvement, and also the way the project was designed was still in that terms pretty much top down. More from national to... so it's not the best setup."	Some CWRM systems are designed from a top-down approach, leaded by district authorities.
On the levels of government involved in CWRM systems in Malawi: - But it's still from the national, some sort of regional or medium scale, and the local scale? Yes, so you have the national, you have indeed the more, the districts, and then each district is divided in what we call traditional authorities. But there, at that level you don't have any representative of the water dep-, the water ministry, so there the people that we were seeking support from were more the traditional leaders. Because there you have also chief at that level. And now you also have extension workers, also up to the village level, so you have for instance water monitoring assistance, or house surveillance assistants."	CWRM systems involve national, district and traditional authorities. Some CWRM systems are assisted by extension workers or house surveillance assistants who are permanently in the community.
On extension workers in Malawi staying permanently at a community: "Yeah. Yeah. But the project at that time was not making use of them. We had our own, our own extension staff recruited from the project, who were coming from the villages and who had been trained in doing the work. So looking at it back it was not the best setup because you do not then leave the, you do not build up the capacity of the local authority. On the other hand you have built a bit of capacity in the villages for people who have stayed there. Not all of them have stayed there, also. Because just they've been used to having a, yeah... before that they were farmers, and then they have been used to have employed, to be employed by an organization that built up scales, so they could move on if necessary to other parts of the country."	Some CWRM systems are assisted by extension workers or house surveillance assistants who are permanently in the community.

10.2.1.6 AB2: On how to conceptualize the modeling and simulation tool

Table 50 AB2. Interviewee 1

Text Fragment	Resulting Statement
Vacant	Vacant

Table 51 AB2. Interviewee 2

Text Fragment	Resulting Statement
Vacant	Vacant

Table 52 AB2. Interviewee 3

Text Fragment	Resulting Statement
"And well, you can choose how much you want to simulate. We chose 20 because I read in the literature that more or less, a water point lasts 20 years. That should be good."	A simulation time of 20 years is sufficient to represent the life cycle of water points.
On whether a recently repaired pump failing is realistic: "No, I mean, I can gi-, to be honest no. And that's a bit... maybe that goes into your understanding of what a repair is. Because, you know, basically a water point, right? You can conceptualize it as two elements: there's a borehole and there is a pump. So when you say 20 years that's a typical count as civil engineering... counting thing. They just go look, it costs ten thousand dollars or whatever it is to develop a water point, it's a hole and it's a pump. And you might want to depreciate it over 20 years. I almost know that's where it comes from. Because I don't think it has any real... because actually the hole, if it's been properly developed, there's no reason why it should ever fail. A borehole, you know, I mean it can break down for complex hydrogeological reasons, but basically you can redevelop the hole indefinitely, you can replace the screens, if that's what's wrong and puff! The hand pumps probably fail about every 6 years. See you've actually got two different elements. And typically when we talk about a rural water point, maybe breaking down, they say: "Oh! The borehole is breaking down." But the borehole hasn't broken down. The pumps have broken down. So it's a classic CapManEx problem, actually. Because if you're not doing your CapManEx your ten thousand dollar investment is being destroyed because you didn't replace a ***."	Water points can be conceptualized as two components: borehole and pump. The borehole, if it's properly developed, should never fail. A hand pump might fail every 6 years. The costs of a water point can be depreciated over 20 years.
On whether a recently repaired pump failing is realistic: "So that might be... so the idea that because it's old is more likely to fail, what's basically a, I don't know exactly what you're doing in your code, but basically for me, I would almost treat it as indefinitely renewable. So, if you do the CapManEx on the	Hand pumps can be conceptualized as infinitely renewable.

borehole, you should then, I presume you're slope, saying that the probability of, your model breakdown probability. Once it's been CapManEx, you should put the probability back up as if it was new."	A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing.
On whether a recently repaired pump failing is realistic: "And then let it begin to… some people could model it like that, but I think that's a better way to model it than to just say, that there's an absolute, that, you know, as it gets older… So, you know, your probability, your breakdown is doing something like that. No, it's like as it gets older your probability of a breakdown does that, then you do CapManEx, and you reset the curve. And that's really what you're trying to do with your CapManEx. So that you never get to the probability for a breakdown being greater than…"	A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing.
On what is a bigger problem, insufficient hand pumps or high failure rates: "So. If you, if this is all a question of granularity of your model, I would be tempted, specially if it's at a proof of concept stage just to model the pumps. And assume, so basically make an assumptions and you could put it in there, the borehole is, basically it has indefinitely life. At least get it going in the pump. What you could then do, is that if you can get that working and you want to go to next, level of granularity, you could then put in, so you could have CapManEx per pumps, and you have CapManEx for redevelopment of the borehole. So redevelopment of boreholes is technically ***"	A properly developed borehole should never fail.
On the probability of failure of hand pumps: "Yeah, exactly, exactly. That's it. And I think given what you want to focus on, I would simplify. I'm looking at how pumps work, and I'm assuming, you know, basically, once the pump is about five or six years old, there's a high possibility that it's just gonna fail… - Ok. So, more or less they fail at 6 years, more or less… Yeah. - But would you say that a hand pump that is three years old is less likely to fail than a six years old? Yes. That's a good question. Because you can't… the examples of hand pumps are twenty years… if they're, if they're well maintained. […] You could make an argument that the main CapManEx, the water point where the hand pump, the main piece of CapManEx is to replace the hand pump. And that might be an easier to model, because then you can say: "look, there's a combined	A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing. A hand pump might fail every 6 years.

rehabilitation cost. Which is to replace the hand pump and if necessary… and if necessary redevelop the borehole. And it costs X.” And then you can just say that we, that you could then model, you could mod-, you could have the curve like this, representing the probability of breakdown, which at a certain point gets to like ninety or a hundred percent probability. If we haven’t done that within ten years, we just assume it fails. And the way that you reset that to cero is to do one CapManEx intervention which is to replace the hand pump, the blended cost. It’s a replacement plus if necessary redevelopment of the borehole, and the cost of the repairs in dollars or whatever. And then, and then you reset the clock to cero. Because you have replaced the hand pump. - Yeah. - Yeah. You have, and I think, you know, again it’s a granularity thing, if you at the policy implications, and I think this would probably be an easier way to model it, than getting into the details of is it borehole redevelopment, is it hand pump redevelopment, is it that I’m replacing a… I’m replacing a ring. Just assume that, that OpEx is happening, or not.”	
On the effect of OpEx on the probability of failure: “- I was planning on having a direct connection between OpEx and probability of failure. Yeah. - When more OpEx is received is more likely to fail. No! It’s- Unlikely. Less likely to fail. Yes, perfect. I would do it like that. - How… uhm… I know this is not- -scientific. -scientific it’s just maybe an educated guess… how much do you think it affects it? Let’s say that, let’s assume that some hand pump at a certain age is fifty percent likely to fail if it’s, even if it’s maintained. If it’s not maintained, how much would it drop? Or rise? Rise? I would say… assuming that you put a new hand pump, in the first three years, if it’s maintained you have no, you practically would say there’s very little chance that it’s gonna fail. If it’s not maintained this curve almost starts… assume the day you install it. In reality, if you go round and you look at hand pumps you find plenty that fail within a year or two. Because, you know, they were badly installed, or there’s some… I mean this is where… this is the difficulty of what you are trying to model. because what makes a hand pump fail, because a washer that costs fifty cents hasn’t been replaced, it’s gone. You know? - Yeah. And it can fail tomorrow because the washer failed, or should fail, if it was never put on. It was faulty installation and the washer is not there, then it won’t work.”	OpEx is inversely related to the probability of failure.

"- So, I'm distilling what are the key components that these systems of Community-based have. And one of them of course is the commitment of the community to take part in these activities of repair, or of having the meetings, or so on. So, what I'm arguing while modeling is that this high commitment can reflect in a high OpEx. Yes. - That can reflect in a low failure probability. Yes. - So that's part of what I'm linking. Yeah, great."	High community commitment can reflect in a high OpEx. High OpEx can reflect in low probability of failure of the water infrastructures.
On random numbers as a proxy on how people decide how many water points need to be built: "-and then what happens if they optimize quantity functional and non-functional. And then we said, let's test it randomly. Which is probably close to reality."	There is no certainty on how a district estimates how many new water points need to be built.
On hand pumps going out of water: "Let me put it this way. Hand pumps, if hand pumps are out of water, it's because either they were, they should never have been developed there, because there's just not enough resource, or because climate cycles or whatever mean, that they, or someone else is taking it. I think you're quite right not to model. You could put it in, but then you should put it in almost as a random thing… so it's fine. For what you're looking at, you don't need it. Because spending money in CapManEx isn't gonna do anything to where the water table is."	Boreholes running out of water are almost a random event.
On simulating hand pumps which boreholes run out of water: "What you could do, I mean you could do, what you could do is put in a cap, a catch. Or you know 10%, if I was using this as a didactic model, where I try to discuss with people at the district level, that well if you put your CapManEx, right, then you might want to put in a cap around the fact that after 10% of your boreholes can fail and then you want a time step, that has nothing to do with any of this, but it just makes it a bit more realistic, right? - Yeah. Well, in my method, I can easily include a function of water, water levels as a function of time, like seasonality. - Yeah. I could include the capacity of the pump, I could change it according to the season, assuming that it gives less water if it's a dry season. Not because it's the pump but because it's the well. But… But again, you know, what would be the point? You're… you've developed a model that allows you, you're trying to look at the balance between investment in CapEx and CapManEx. Right? - Yeah.	Boreholes running out of water are almost a random event.

And I think, you know, that isn't going, can't have an influence on whether it dries up or not, during the dry season. And that's a factor… yeah. Positioning, location, development, and use to some extent. So I think in a bigger, more complex model, what you're trying to understand all the things that can lead to system failure, you may want to put it in. But if you're trying to model CapEx and CapManEx, I'd leave it out, because it's just too complicated."	
On how to model the connection between Direct Support and functionality: "So, the question is to what extent you want to collapse all of this into a black box. And just say: Direct Support, if there's good Direct Support it will increase the ability of OpEx to be done properly by 10%. Or by 50%. Or by a 100%. If there's no Direct Support, there's a high probability that the, that OpEx won't be done properly."	Without Direct Support, there is a high probability that OpEx does not exercised.
On districts using Indirect Support funds: "Districts can use some, but… typically, to make your life easy think that Indirect Support comes from the district and Indirect Support comes from the national. And then if was you I'd leave Indirect Support out."	Indirect Support is rarely spent by districts.

10.2.1.7 AB3: additional sources of information suggested by the interviewees

Table 53 AB3. Interviewee 1

Text Fragment	Resulting Statement
Vacant	Vacant

Table 54 AB3. Interviewee 2

Text Fragment	Resulting Statement
"[…] there is also the work by the water point mappings, the AKVO and the, what is it called, Flow! F-L-O-W, and it is intended as an online crowd sourced GIS based monitoring of water point functionality in the whole world. But I know that they've got work active in Uganda. And I will look for the link there, because they also, so the organization involved is not only IRC but also AKVOFLOW, and organization in Amsterdam. And they might be an interesting group to go and speak to. Because they are very committed to modeling and application of the ICT, innovations and tools for understanding how are we performing in terms of providing access, and services. AKVOFLOW."	AKVOFLOW Akvo.org
"I can get the, some of the research reports to you. It's some of the stuff by Valerie Bey and Martin Watsisi. And, just ***. And he said, "So they have the evidence but they're still choosing to keep that as the predominant model because they can't think of what else it should be there, as the…""	

Table 55 AB3. Interviewee 3

Text Fragment	Resulting Statement
So… and I'm pretty sure that there has been work done on sort of hand pump failure rate things, so if you don't want to just, based on my rule of thumb, you could probably look some stuff up, particularly if you look at a website of an organization called SKAT… - How do you spell it? S-K… S-K-A-T - Ok. They've done quite a lot of work on this. But also, when you come on Tuesday, you could ask Stef… you could ask Stef, Stef knows about this… or possibly Catarina. Because when they did WASH costs they did look a lot… they did a lot of work on, you know, what are typical life spans of the different components. But yeah… I like your idea of doing…	SKAT www.skat.ch Stef Smits, IRC Catarina Fonseca, IRC

Table 56 AB2. Interviewee 4

Text Fragment	Resulting Statement
Vacant	Vacant

10.2.2 Synthesis of text fragments

1. B1: Building blocks of the CWRM paradigm
    a. How is the CWRM paradigm implemented?
        1. Interview 1
            1. The design of CWRM systems should consider the complete life cycle of water infrastructures.
            2. Stakeholders external to the community take part in the design and implementation some CWRM systems.
            3. Stakeholders external to the community take part in the funding of some CWRM projects.
        2. Interview 2
            1. The design of CWRM systems usually targets shared locations instead of individual properties.
            2. Stakeholders external to the community initiate the design of some CWRM systems.
            3. Users of infrastructure managed by CWRM systems are expected to pay and manage those infrastructures.
            4. In CWRM systems, authorities are responsible for supporting communities that are managing infrastructures.
            5. CWRM systems assume that a project can be managed by communities with little training.
            6. In CWRM systems, communities are expected to manage a water infrastructure technically, financially and equitably under extremely thriving circumstances.
            7. In CWRM systems, communities are expected to have the necessary funds to finance the life-cycle of the infrastructure.
            8. In CWRM systems, communities are expected to have the necessary funds to finance the life-cycle of the infrastructure.
            9. CWRM systems require Water User Committees.
            10. CWRM systems require users to pay for the services of a water infrastructure.
            11. CWRM systems require local managers to keep records of expenditure and maintenance.
            12. CWRM systems require caretakers for water infrastructures. These caretakers do not receive a salary but receive a small nominal amount of money.
            13. Stakeholders external to the community, such as development agencies and governmental bodies, take part in the design and implementation some CWRM systems.
            14. CWRM systems involve water infrastructures.
            15. CWRM systems’ water infrastructures are installed in communal locations.
            16. CWRM systems try to include gender perspective.
        3. Interview 3
            1. Indirect Support, or macro-level expenses, are typically spent at a national level, and not by communities.
        4. Interview 4

        1. In CWRM system, a water point committee, usually roughly representative of the community, is responsible for the management of the water infrastructure.
        2. In CWRM systems, members of the Water Point Committee managing the water infrastructure work on a volunteer basis.
  b. What is the philosophy behind the CWRM paradigm?
     1. Interview 1
        1. People who will be affected by a CWRM system should be involved in its conceptualization, planning, designing and implementation.
        2. People affected by a CWRM system should have decision-making power over the system.
        3. CWRM is close to the principles and practices of community-based natural resources management.
     2. Interview 2
        1. CWRM aims at having services delivered and managed at the level closest to their end users.
        2. CWRM aims at democratizing the provision of public services to citizens.
        3. CWRM aims at supporting citizens in attaining the highest attainable level of development.
        4. CWRM aims at including gender perspective by involving and empowering women.
        5. CWRM aims at including marginalized groups, such as those marginalized because of ethnicity, faith or physical ability.
     3. Interview 3
        1. Vacant
     4. Interview 4
        1. CWRM aims at decentralizing the provision of water services in rural areas.
        2. CWRM aims at promoting a sense of ownership of the infrastructure, in the community.
        3. In CWRM system, the community is responsible for the management of the water infrastructure.

2. B2: Enabling and restricting conditions of CWRM systems
  a. What are enabling conditions of CWRM systems?
     1. Interview 1
        1. Good-grounded ethnographic work in the communities affected by development projects can improve the outcome of those development projects.
        2. Fieldwork and research in communities affected by a development project should be based in well-grounded social science, such as anthropology.
        3. Collective benefits, such as using water for community sites (clinics or primary schools) motivate participants of CWRM systems to keep the system running.
     2. Interview 2
        1. CWRM projects have had functioning institutions and governance settings.

    2. Successful CWRM projects have had technical support, functioning relationships between multiple governance levels, reliable support for communities, or reliable and repeated investment from international aid and development.
3. Interview 3
    1. Direct Support can increase the functionality of a water point by facilitating training for the community and supporting regular repairs of the water infrastructure.
    2. Direct Support has an impact on communities by strengthening institutional arrangements and capacity building for repairing the water infrastructure.
4. Interview 4
    1. CWRM systems with users that are extended family are more likely to succeed than those CWRM systems with users who do not share family bonds.
    2. Regular visits from external stakeholders to CWRM systems can be a strong motivation factor for the committee members to continue their work.
    3. CWRM systems with users that are extended family are more likely to succeed than those CWRM systems with users who do not share family bonds.
    4. CWRM systems are more successful wen the end users are explicitly considered in the design of the system.
    5. Regular visits from external stakeholders to CWRM systems can be a strong motivation factor for the committee members to continue their work.
    6. Traditional leaderships, such as local chiefs, can exert a strong motivation on the community to take good care of the water infrastructure.
    7. Direct Support has an impact on communities by maintaining the Water Point Committee motivated to collect the fees from the users and to operate and maintain the water infrastructure.
    8. Local politicians can exert a strong motivation on the community to pay their contributions to maintain the water point.

b. What are restricting conditions of CWRM systems?
1. Interview 1
    1. From an anthropological perspective, the term community is problematic, because it assumes that certain formal and informal institutions exist, which is not necessarily the case.
    2. Development projects do not always include the most vulnerable groups.
    3. Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.
    4. Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.

    5. Some CWRM systems are implemented in settings where failed water-related projects exist.
    6. Some CWRM systems are implemented in settings where failed water-related projects exist.
    7. Development projects are not always based on good-grounded ethnographic work in the communities that are being affected.
2. Interview 2
    1. The design of CWRM systems includes assumptions that often do not hold.
    2. Stakeholders external to the community initiate the design and implementation of some CWRM systems without local support.
    3. Lack of good functioning governance and institutional structures drive CWRM systems to failure.
    4. CWRM systems set communities up for greater burdens that what they could realistically carry.
    5. The design of some CWRM systems do not consider the complete life cycle of water infrastructures.
    6. Some community members who are trained to be part of CWRM systems leave their volunteer positions in order to pursue remunerated jobs.
    7. The design of CWRM systems includes assumptions that often do not hold.
    8. The design of CWRM systems does not evaluate whether the initial assumptions held.
    9. Some CWRM systems are not self-sustained and depend on international aid and development.
    10. Some CWRM systems are not self-sustained and depend on international aid and development.
    11. The dependence of CWRM systems on international aid motivates relevant stakeholders to avoid taking responsibility for seeking the financial independence of those projects.
    12. Communities do not have enough money to maintain CWRM systems running.
    13. Communities do not have enough money to maintain CWRM systems running.
    14. The design of CWRM systems assumed that communities would develop a sense of ownership of water infrastructures.
    15. The design of CWRM systems assumed that communities with very little training would have all the necessary skills to maintain water infrastructures functional.
    16. Communities do not have enough resources to maintain CWRM systems running.
    17. Community members do not feel that they should be paying user fees because water infrastructures have high downtimes.

18. Community members do not feel that they should be paying user fees because they can and often do obtain water from alternative sources.
19. The training received by caretakers of water infrastructures is not sufficient to maintain CWRM systems running in the long term.
20. Some community members who are trained to be part of CWRM systems leave their volunteer positions.
21. Communities do not have enough tools to maintain CWRM systems running.
22. Governmental actors are not willing to change the CWRM paradigm as the status quo of the provision of rural water services.
23. Governmental actors do not have an alternative to the CWRM paradigm for the provision of rural water services.
24. Field evaluations do not always capture the actual state of CWRM systems.
25. In some CWRM systems, Water Point Committees do not meet nor manage the water infrastructure.
26. Field evaluations do not always capture the actual state of CWRM systems.
27. Field evaluations do not always capture the actual state of CWRM systems.
28. Some regulations to protect water sources are not enforced.
29. Field evaluations do not always capture the actual state of CWRM systems.

3. Interview 3
    1. Boreholes can dry, owing to the dry season in combination with poor borehole development and unauthorized water uses.
4. Interview 4
    1. From an anthropological perspective, the term community is problematic, because it assumes that certain formal and informal institutions exist, which is not necessarily the case.
    2. The design of CWRM systems includes assumptions that often do not hold.
    3. From an anthropological perspective, the term community is problematic, because it assumes that certain formal and informal institutions exist, which is not necessarily the case.
    4. The design of CWRM systems includes assumptions that often do not hold.
    5. The design of CWRM systems includes assumptions that often do not hold.
    6. Unanticipated population growth tends to have a negative influence on the management of CWRM systems.
    7. In CWRM systems whose communities lack cohesion, community members stop paying their fees, which in turn worsens the functionality of the water infrastructure.
    8. The design of CWRM does not always consider local realities.

9. CWRM systems are complex because they involve stakeholders with potentially diverging incentives and interests.
10. CWRM systems do not always have Water Point Committees that are representative of the community.
11. Water infrastructures are very often poorly built.
12. Water infrastructures are very often poorly built.
13. Often, Water Point Committees receive very little support from stakeholders external to the community after the water infrastructure is installed.
14. Often, Water Point Committees are not able to solve all issues related to a CWRM system.
15. In CWRM systems, communities do not have sufficient money to solve serious technical issues.
16. In CWRM systems, external stakeholders are needed to facilitate conflict resolution within the Water Point Committee or between the Water point Committee and the community.
17. CWRM systems which users are a collection of individuals from different backgrounds and different interests are likely to fail.
18. In CWRM systems in non-traditional settings, members of the community arrive and depart relatively often.
19. Bypassing non-cooperative traditional authorities in order to implement a CWRM systems is not effective in the long term.
20. Non-cooperative traditional authorities can deviate resources from the CWRM system.

3. B3: Looking beyond Community-based Water Resources Management
   a. What innovations have occurred in the water sector beyond the CWRM paradigm?
      1. Interview 1
         1. Vacant
      2. Interview 2
         1. The CWRM paradigm is the predominant model for the provision of rural water services in developing countries.
         2. Efforts to improve the provision of rural water services in developing countries focus on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes.
         3. Efforts to improve the provision of rural water services in developing countries are not innovating beyond the CWRM paradigm.
      3. Interview 3
         1. Vacant
      4. Interview 4
         1. Vacant
   b. What are foreseeable developments in the paradigms used for the provision of rural water services?
      1. Interview 1

1. Fieldwork and research in communities affected by a development project should be based in well-grounded social science, such as anthropology.

2. Interview 2
    1. The CWRM paradigm needs to be reconsidered as the predominant model for the provision of rural water services in developing countries.
    2. Efforts to improve the provision of rural water services in developing countries are not innovating beyond the CWRM paradigm.
    3. Future efforts to improve the provision of rural water services in developing countries should strengthen the position of governmental institutions as the leaders of those projects.
    4. Efforts to improve the provision of rural water services in developing countries focus on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes.
3. Interview 3
    1. Vacant
4. Interview 4
    1. CWRM systems need support from governmental institutions.
    2. CWRM will continue to be the paradigm for the provision or rural water services.
    3. CWRM will continue to be the paradigm for the provision or rural water services, because rural areas are remote and do not have district offices close by.
    4. Privatization of the provision of rural water services is not a likely alternative because areas are scattered and budget is limited.
    5. Privatization of the provision of rural water services is not a likely alternative, but its feasibility depends on each individual case.
    6. Privatization of the provision of rural water services would require a good business case, which would be difficult to produce.

4. B4: Modeling and simulation tools to study the problem

a. What modeling and simulation tools are usually used to study the provision of rural water services?

1. Interview 1
    1. System dynamics
    2. System dynamics, Spatial modeling (GIS modeling), Discrete-event modeling, Econometric modeling, Hydrological modeling
    3. Discrete-event modeling
2. Interview 2
    1. Spatial modeling (GIS modeling), Agent-based modeling
3. Interview 3

        1. Bayesian belief networks, Physically based ground water models
        2. Physically based ground water models, Hydrological modeling, Land-use models
        3. Agent-based modeling
    4. Interview 4
        1. Vacant

b. How can modeling and simulation tools be used to study enabling and restricting conditions of CWRM systems?
    1. Interview 1
        1. Models can be used as tools to create a facilitation environment that triggers processes to learn, discuss, build and foster collaborative action.
        2. In some cases, fostering participatory processes has priority over producing a technically advanced model.
        3. System dynamics is best suited to study problems at a strategic level, through small yet insightful models.
        4. In addition to system dynamics, agent-based modeling can also be used to foster collaborative processes, including combinations with serious gaming.
    2. Interview 2
        1. External facilitators should be clear on what is meant by modeling and simulation tools.
        2. External facilitators should be clear on what is the potential of modeling and simulation tools in aiding decision-making.
        3. External facilitators should explain to potential users that modeling and simulation tools do not necessarily have predictive power.
        4. Modeling and simulation tools can offer insights on the dynamics of complex and unpredictable scenarios.
        5. Stakeholders from governmental institutions are skeptical about the use of technical tools developed abroad if local stakeholders cannot manage them.
        6. Before modeling and simulation tools can be used with stakeholders from governmental institutions, stakeholders from governmental institutions need to receive exposure and build capacity to manage those tools.
        7. Stakeholders from governmental institutions can receive exposure and build capacity to manage modeling and simulation tools in collaborative processes and learning environments.
        8. Modeling and simulation tools can be used as didactic tools to explore plausible scenarios.
        9. Modeling and simulation tools should serve not only to explore a problem, but also to aid decision-making.
        10. Relevant stakeholders should be involved in the exploration of the potential of modeling and simulation tools in aiding decision-making.

11. External facilitators should be clear on what is the potential of modeling and simulation tools in aiding decision-making.
12. Modeling and simulation tools can help relevant stakeholders to build a more accurate idea of the problem that they aim at managing.
13. Conceptual modeling helps relevant stakeholders to build a common vision, or mental model, of a certain problem.
14. Modeling and simulation tools designed as experiential learning devices allow people to engage in processes for collective learning. Examples include spatial modeling (GIS), serious gaming, and potentially agent-based modeling.

3. Interview 3
    1. Models should be flexible enough to take inputs from experts opinion to hard data to produce representations of complex systems that can be used by people working in those systems.
    2. Modeling and simulation tools can be used to explore and explain the implications of policy alternatives.
    3. Modeling and simulation can make explicit the effect that uncertainty and policy decisions have on physical systems.
    4. Modeling and simulation tools can be physically based and policy oriented, depending on the objective of their use.
    5. Modeling and simulation tools can be used in a didactic way to understand complex systems.
    6. Modeling and simulation tools can be used as a sand box to experiment with a system without working in real time.
    7. Modeling and simulation tools can be used to justify an intervention logic.
    8. Modeling and simulation can make explicit the effect that policy decisions have on physical systems.
4. Interview 4
    1. Vacant

5. B5: The case of rural water service provision by water points in Uganda
    a. What is the role of the CWRM paradigm in the provision of water services by water points in rural Uganda?
        1.
    b. What levels of government are involved in the implementation of CWRM systems?
        1.
    c. How are funds allocated for the implementation of CWRM systems?
    d. How do communities file requests for new water points or for repair, renewal or rehabilitation of existing water points?
    e. What are plausible, and near changes in the provision rural water services in Uganda?
    f. What databases or statistics of these projects can be relevant for this research?
6. AB1: mentions of the problem addressed by the research that do not belong to other thematic blocks
    a. Unique category
        1. Interview 1

1. CWRM systems go wrong most of the time.
2. In some locations in Sub-Saharan Africa, water infrastructures have been installed but does not operate.
3. In some locations in Sub-Saharan Africa, vulnerable sources of water for human consumption are not protected. Instead, water uses such as irrigation have priority.
4. Some regulations to protect water sources are not enforced.
5. Impact assessment procedures and other planning instruments are not always executed.

2. Interview 2
   1. Communities are not managing to make CWRM systems succeed.
   2. Some field evaluations are conducted during long periods of time, in multiple communities, and assess multiple aspects, such as natural resources protection and rehabilitation schemes.
   3. The design of some CWRM systems include strong capacity building elements in their work with communities.
   4. The design of some CWRM systems include strong technical building aspects in their work with water infrastructures.
3. Interview 3
   1. Vacant
4. Interview 4
   1. Expenditures in Direct Support tend to be low.
   2. Some CWRM systems are designed from a top-down approach, leaded by district authorities.
   3. CWRM systems involve national, district and traditional authorities.
   4. Some CWRM systems are assisted by extension workers or house surveillance assistants who are permanently in the community.
   5. Some CWRM systems are assisted by extension workers or house surveillance assistants who are permanently in the community.

7. AB2: On how to conceptualize the modeling and simulation tool
   a. Unique category
      1. Interview 1
         1. Vacant
      2. Interview 2
         1. Vacant
      3. Interview 3
         1. A simulation time of 20 years is sufficient to represent the life cycle of water points.
         2. Water points can be conceptualized as two components: borehole and pump.
         3. The borehole, if it's properly developed, should never fail.
         4. A hand pump might fail every 6 years.
         5. The costs of a water point can be depreciated over 20 years.
         6. Hand pumps can be conceptualized as infinitely renewable.

7. A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing.
8. A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing.
9. A properly developed borehole should never fail.
10. A CapManEx event can be understood as a substitution of the hand pump, which would reset the probability of the hand pump failing.
11. A hand pump might fail every 6 years.
12. OpEx is inversely related to the probability of failure.
13. High community commitment can reflect in a high OpEx.
14. High OpEx can reflect in low probability of failure of the water infrastructures.
15. There is no certainty on how a district estimates how many new water points need to be built.
16. Boreholes running out of water are almost a random event.
17. Boreholes running out of water are almost a random event.
18. Without Direct Support, there is a high probability that OpEx does not exercised.
19. Indirect Support is rarely spent by districts.

4. Interview 4
   1. Vacant

8. AB3: additional sources of information suggested by the interviewees

a. Unique category
   1. Interview 1
      1. Vacant
   2. Interview 2
      1. AKVOFLOW: akvo.org
   3. Interview 3
      1. Vacant
   4. Interview 4
      1. SKAT: www.skat.ch
      2. Stef Smits, IRC
      3. Catarina Fonseca, IRC

10.3 Conclusions

The objective of the interviews reported in this document was to gather data that enabled the researcher to distill those functional requirements and evaluation criteria, and to conduct the initial exploration of the case study. To achieve this goal, the interviews were planned in five thematic blocks. These blocks, theoretically derived from Chapter 2 (Problem Definition), were decomposed into a set of questions. This section builds on the analysis of the data to provide answers of each set of questions.

To maintain the transparency of the research, answers to each question are provide in a table that indicates the statement of the interview from which it was derived.

10.3.1 B1: Building blocks of Community-based Water Resources Management

10.3.1.1 How is the CWRM paradigm implemented?

- In rural areas of Sub-Saharan Africa, the CWRM paradigm is implemented through CWRM systems. The design and implementation of these CWRM systems should fulfill the normative requirements:

Table 57 Normative requirements for the design and implementation of CWRM systems

Normative requirements	Statements derived from the interviews
Involve physical infrastructures for the provision of water.	1.a.2.14
Consider the complete life cycle of water infrastructures.	1.a.1.1, 1.a.2.7, 1.a.2.8
Target shared locations instead of individual properties.	1.a.2.1, 1.a.2.15
Be primarily funded by local users, who constitute a Water User Committee.	1.a.2.6, 1.a.2.7, 1.a.2.8, 1.a.2.9, 1.a.2.10
Be technically, financially, and equitably managed by communities –or local users, even under extremely thriving circumstances.	1.a.2.3, 1.a.2.6, 1.a.2.7, 1.a.2.8, 1.a.2.10
Have local managers (Water Point Committees) and caretakers keeping records of expenditures and maintenance, and who perform their duties without a salary (a small nominal amount of money is possible).	1.a.4.1, 1.a.4.2, 1.a.2.11, 1.a.2.12
Consider and provide initial training to the communities that will manage water infrastructures, and later support to continue with their work.	1.a.2.4, 1.a.2.5
Have technical support, functioning relationships between multiple governance levels, reliable support for communities, or reliable and repeated investment from international aid and development.	1.a.2.4, 1.a.4.1, 1.a.3.1
Have functioning institutions and governance settings.	1.a.2.4, 1.a.4.1

- Moreover, the design and implementation of CWRM systems might display other characteristics or supplementary requirements:

Table 58 Supplementary requirements for the design and implementation of CWRM systems

Supplementary requirements	Statements derived from the interviews
Involve stakeholders external to the community, such as development agencies and governmental bodies.	1.a.1.2, 1.a.1.3, 1.a.2.2, 1.a.2.13
Be initiated and funded by stakeholders external to the community.	1.a.1.3, 1.a.2.2
Assume that initial training for the communities will be sufficient for those communities to continue managing the system.	1.a.2.5
Include gender perspective.	1.a.2.16

10.3.1.2 What is the philosophy behind the CWRM paradigm?

- Table 59 presents the premises reflecting the philosophy of the CWRM paradigm, derived from the analysis of the data.

Table 59 Premises of the CWRM paradigm

Premise	Statements derived from the interviews
CWRM is close to the principles and practices of community-based natural resources management.	1.b.1.3
People involved in, or affected by, a CWRM system should be involved in its conceptualization, planning, design and implementation, and should have decision-making power over the system.	1.b.1.1, 1.b.1.2
Communities are responsible for the management of the water infrastructure, in order to deliver and manage water services at the level closest to their users.	1.b.2.1, 1.b.4.3
CWRM aims at democratizing and decentralizing the provision of water services in rural areas.	1.b.2.2, 1.b.4.1
CWRM aims at supporting citizens in attaining the highest possible level of development.	1.b.2.3
CWRM aims at including gender perspective by involving and empowering women.	1.b.2.4
CWRM aims at including marginalized groups, such as those marginalized because of ethnicity, faith, or physical ability.	1.b.2.5
CWRM aims at promoting a sense of ownership of the infrastructure in the community.	1.b.4.2

10.3.2 B2: Enabling and restricting conditions of CWRM systems

10.3.2.1 What are enabling conditions of CWRM systems?

- The conditions presented in Table 60, derived from the analysis of the data, are found by the interviewees to enable CWRM systems.

Table 60 Enabling conditions of CWRM systems

Enabling condition	Statements derived from the interviews
Including anthropological research in the communities with whom a CWRM system will be established can improve the outcomes of the system.	2.a.1.1, 2.a.1.2, 2.a.4.4
Collective benefits, such as using water for community sites (clinics or primary schools) motivate participants of CWRM systems to keep the system running.	2.a.1.3
CWRM systems with users that are extended family are more likely to succeed than those CWRM systems with users who do not share family bonds.	2.a.4.1, 2.a.4.3
Direct Support has a positive impact on functionality of the water point and on community involvement. It can be used to train the community to manage and repair the water infrastructure, support regular repairs of the water infrastructure, strengthen institutional arrangements and to facilitate regular visits from external stakeholders that keep the Water Point Committee motivated. A motivated Water Point Committee collects users' fees, maintains the water infrastructure, and continues to operate the CWRM system.	2.a.3.1, 2.a.3.2, 2.a.4.2, 2.a.4.3, 2.a.4.5, 2.a.4.7
Successful CWRM projects have had technical support, functioning relationships between multiple governance levels, reliable support for communities, or reliable and repeated investment from international aid and development.	2.a.2.1, 2.a.2.2
Traditional leaders and local politicians can exert strong motivation on the community to take good care of the water infrastructure and to pay their user fees.	2.a.4.6, 2.a.4.9

10.3.2.2 What are restricting conditions of CWRM systems?

- The CWRM paradigm and its implementation through CWRM systems involve assumptions that do not always hold in reality (2.b.1.1, 2.b.2.1, 2.b.2.7, 2.b.2.8, 2.b.4.1, 2.b.4.2, 2.b.4.3, 2.b.4.4, 2.b.4.5, 2.b.4.8). Table 61 presents the assumptions mentioned by the interviewees.

Table 61 Restricting conditions of CWRM systems: assumptions of the CWRM paradigm that do not always hold

Restricting condition explicitly related to an assumption of the CWRM paradigm	Statements derived from the interviews
The group of users taking part in a CWRM system are not necessarily a community. In other words, formal and informal institutions do not necessarily exist.	2.b.1.1, 2.b.4.1, 2.b.4.3, 2.b.4.17
Communities and their Water Point Committees do not have enough resources, such as money and skills, to maintain CWRM systems running.	2.b.2.4, 2.b.2.12, 2.b.2.13, 2.b.2.16, 2.b.2.21, 2.b.2.15, 2.b.2.19, 2.b.2.25, 2.b.4.14
Communities will not necessarily develop a sense of ownership of water infrastructures.	2.b.2.14

- Moreover, some restricting conditions of CWRM systems are linked to the planning of those systems, as presented in Table 62.

Table 62 Restricting conditions of CWRM systems that are related to the planning of those systems

Restricting condition related to the planning of a CWRM system	Statements derived from the interviews
Development projects do not always include the most vulnerable groups.	2.b.1.2
CWRM systems do not always have Water Point Committees that are representative of the community.	2.b.4.10
Development projects do not always include anthropological research in the communities with whom a CWRM system will be established. Therefore, they do not consider local realities.	2.b.1.3, 2.b.1.4, 2.b.1.7, 2.b.4.8
Some CWRM systems are implemented in settings where failed water-related projects exist.	2.b.1.5, 2.b.1.6
The complete life-cycle of water infrastructures is not always considered.	2.b.2.5
Stakeholders external to the community initiate the design and implementation of some CWRM systems without local support.	2.b.2.2
Often, Water Point Committees receive very little support from stakeholders external to the community after the water infrastructure is installed.	2.b.2.4, 2.b.4.13
Water infrastructures are very often poorly built.	2.b.3.1, 2.b.4.11, 2.b.4.12

- Table 63 presents additional conditions that restrict CWRM systems.

Table 63 Additional conditions that restrict CWRM systems

Additional conditions restricting CWRM systems	Statements derived from the interviews
Some CWRM systems are not self-sustained and depend on international aid and development.	2.b.2.9, 2.b.2.10
The dependence of CWRM systems on international aid motivates relevant stakeholders to avoid taking responsibility for seeking the financial independence of those projects.	2.b.2.11
Community members do not feel that they should be paying user fees because water infrastructures have high downtimes.	2.b.2.17
Community members do not feel that they should be paying user fees because they can and often do obtain water from alternative sources.	2.b.2.18
Some community members who are trained to be part of CWRM systems leave their volunteer positions in order to pursue remunerated jobs.	2.b.2.6, 2.b.2.20
Lack of good functioning governance and institutional structures drive CWRM systems to failure.	2.b.2.3
Field evaluations do not always capture the actual state of CWRM systems.	2.b.1.3, 2.b.1.4, 2.b.1.7, 2.b.2.24, 2.b.2.26, 2.b.2.27, 2.b.2.29, 2.b.4.8
Some regulations to protect water sources are not enforced.	2.b.2.28
Governmental actors are not willing to change the CWRM paradigm as the status quo of the provision of rural water services.	2.b.2.22
Governmental actors do not have an alternative to the CWRM paradigm for the provision of rural water services.	2.b.2.23
Unanticipated population growth tends to have a negative influence on the management of CWRM systems.	2.b.4.6
In CWRM systems whose communities lack cohesion, community members stop paying their fees, which in turn worsens the functionality of the water infrastructure.	2.b.4.7
CWRM systems are complex because they involve stakeholders with potentially diverging incentives and interests.	2.b.4.9
In CWRM systems in non-traditional settings, members of the community arrive and depart relatively often.	2.b.4.18
Bypassing non-cooperative traditional authorities in order to implement a CWRM systems is not effective in the long term.	2.b.4.19
Non-cooperative traditional authorities can deviate resources from the CWRM system.	2.b.4.20
Some regulations to protect water sources are not enforced.	2.b.2.28, 2.b.3.1

10.3.3 B3: Looking beyond Community-based Water Resources Management

10.3.3.1 What innovations have occurred in the water sector beyond CWRM?

Table 64 Innovations in the water sector beyond CWRM

Innovation	Statements derived from the interviews
Currently, CWRM is the predominant paradigm for the provision of rural water services in developing countries, and innovations beyond this paradigm are not common.	3.a.2.1, 3.a.2.3
Efforts to improve the provision of rural water services in developing countries focus on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes.	3.a.2.2
CWRM is likely to remain as the *status quo* because rural areas are remote and do not have district offices close by.	3.b.4.2, 3.b.4.3

10.3.3.2 What are foreseeable developments in the paradigms used for the provision or rural water services?

Table 65 Foreseeable developments in the paradigms used for the provision of rural water services

Foreseeable developments in the paradigms used for the provision of rural water services	Statements derived from the interviews
While CWRM needs to be reconsidered as the predominant paradigm for the provision of rural water services in developing countries, current efforts are not innovating beyond this paradigm.	3.b.2.1, 3.b.2.2
While privatization of the provision of rural water services is possible, in theory, factors such as scattered areas and limited budget limit the feasibility of a good business case.	3.b.4.4, 3.b.4.5, 3.b.4.6
Efforts to improve the provision of rural water services in developing countries are currently focused on the strengthening of institutions at national and district level to enable those institutions to take part of multi-actor, action research processes.	3.b.2.4
CWRM systems need support from governmental institutions.	3.b.4.1
Fieldwork and research in communities affected by a development project should be based in well-grounded social science, such as anthropology.	3.b.1.1

10.3.4 B4: Modeling and simulation tools to study the problem

10.3.4.1 What modeling and simulation tools are usually used to study this problem?

Table 66 Modeling and simulation tools used to study the provision of rural water services

Modeling and simulation tools used to study the provision of rural water services	Statements derived from the interviews
System dynamics	4.a.1.1, 4.a.1.2
Spatial modeling (GIS)	4.a.1.2, 4.a.2.1, 4.a.3.2
Discrete-event modeling	4.a.1.2, 4.a.1.3
Econometric modeling	4.a.1.2
Hydrological modeling	4.a.1.2, 4.a.3.2
Agent-based modeling	4.a.2.1, 4.a.3.3
Bayesian belief networks	4.a.3.1
Physically based ground water models	4.a.3.1, 4.a.3.2

10.3.4.2 How can modeling and simulation tools be used to study enabling and restricting conditions of CWRM systems?

- Three themes were identified in the answers to this question: selection of a modeling and simulation method, facilitation processes involving modeling and simulation tools, objective of using these tools, and features that these tools should exhibit. Hence, answers are presented in the following tables.

Table 67 On the selection of a modeling and simulation method to study the provision of rural water services

On the selection of a modeling and simulation method to study the provision of rural water services	Statements derived from the interviews
System dynamics is best suited to study problems at a strategic level, through small yet insightful models.	4.b.1.3
In addition to system dynamics, agent-based modeling can also be used to foster collaborative processes, including combinations with serious gaming.	4.b.1.4

Table 68 On the facilitation of processes that involve modeling and simulation tools to study the provision of rural water services

On the facilitation of processes that involve modeling and simulation tools to study the provision of rural water services	Statements derived from the interviews
Facilitation of processes to learn, discuss, build and foster collaborative action, where participatory processes have priority over technically advanced models.	4.b.1.1, 4.b.1.2, 4.b.2.14
Before engaging in a modeling and simulation exercise with stakeholders in the water sector, those stakeholders need to gain familiarity with to those tools and potentially build capacity to manage them. Familiarity and capacity building would help to reduce skepticism about technical tools developed abroad. Paradoxically, this can be achieved by engaging in collaborative processes and learning environments with modeling and simulation tools.	4.b.2.5, 4.b.2.6, 4.b.2.7
Relevant stakeholders should be involved in the exploration of modeling and simulation tools to aid decision-making. Their involvement can help those stakeholders to build a common vision, or mental model, of a certain problem.	4.b.2.10, 4.b.2.11
External facilitators should clearly explain to relevant stakeholders what are modeling and simulation tools, why they are not necessarily predictive tools, and what is their potential in aiding decision-making.	4.b.2.1, 4.b.2.2, 4.b.2.3, 4.b.2.11

Table 69 On the objective of using modeling and simulation tools to study the provision of rural water services

On the objective of using modeling and simulation tools to study the provision of rural water services	Statements derived from the interviews
To gain insights on the dynamics of complex problems and unpredictable scenarios, including the implications of policy alternatives.	4.b.2.4, 4.b.2.8, 4.b.2.12, 4.b.3.2, 4.b.3.5
To aid decision making.	4.b.2.9
To experiment with a system without working in real time.	4.b.3.6
To justify an intervention logic.	4.b.3.7
To make explicit the effect that policy decisions have on physical systems.	4.b.3.8

Table 70 On the features that modeling and simulation tools should exhibit to study the provision of rural water services

On the features that modeling and simulation tools should exhibit to study the provision of rural water services	Statements derived from the interviews
Flexible enough to take different inputs, such as experts' opinion and hard data.	4.b.3.1
Produce representations of complex systems that can be used by people working in those systems.	4.b.3.2
Make explicit the effect that uncertainty and policy decisions have on physical systems.	4.b.3.3
Physically based or policy oriented, depending on the objective of their use.	4.b.3.4

11 Appendix 2. Modeling methods

A diversity of modeling and simulation methods can be used for the analysis of complex problems, such as the conditions that enable and restrict CBM systems of domestic rural water points. The range of methods include system dynamics and agent-based modeling. Although the use of each of these methods facilitates the understanding of complex problems and the design of potential solutions, individual methods study complex systems from different angles and focus on different system features (Lättilä et al., 2010, Teose et al., 2011, Macal, 2010, Scholl, 2001).

In this appendix, the theories and building blocks of system dynamics and agent-based modeling are explained in the first and second section. Then, in the third section, the selection of system dynamics as the modeling method for this study is explained. Finally, in the fourth section, the main components of a quantitative system dynamics model are presented, and in the fifth section, the modeling cycle of system dynamics is described.

11.1 System dynamics

More than 50 years ago, Forrester (1958) founded SD around two notions from systems theory (Phelan, 1999): first, relevant variables affect each other and have information and material feedback; second, system's structure drives system's behavior. These notions imply that the behavior of non-linear complex systems (quasi-linear, nonlinear systems as opposed to highly non-linear chaotic systems (Phaff et al., 2006)) is determined by the interaction of negative and positive feedback between relevant variables (Forrester, 1958, Sterman, 2000). Thus, SD describes systems and their behavior by conceptualizing causal relations of relevant variables, which are then formalized into sets of differential equations (Macal, 2010, Parunak et al., 1998).

SD's representation of sets of differential equations uses two main components: stocks and flows (Sterman, 2000, Rahmandad and Sterman, 2008). Stocks represent accumulation of material and information. In mathematical terms, flows are the rates of change and stocks are the integrals over time. The solution of the sets of differential equations given by both components and auxiliary variables, describe the state of the system. This state changes continuously over time and depends on its own previous states. Specialized software for SD modeling solves these sets of differential equations deterministically, by applying numerical integration methods and discrete sufficiently small time steps to ensure numerical reliability.

Lättilä et al. (2010)'s literature review conceptualized eight aspects in which SD differs from other methods. First, it deals with a level of analysis and assumes homogeneity (Kim and Juhn, 1997, Parunak et al., 1998, Martinez-Moyano et al., 2007). Second, its unit of analysis is the structure of the system (Pourdehnad et al., 2002, Parunak et al., 1998). Third, its central mechanism is the feedback between system components (Kim and Juhn, 1997, Phelan, 1999, Pourdehnad et al., 2002, Parunak et al., 1998, Martinez-Moyano et al., 2007). Fourth, its main components are sets of differential equations, feedback loops, stocks and flows (Parunak et al., 1998, Pourdehnad et al., 2002, Phelan, 1999, Martinez-Moyano et al., 2007). Fifth, it fixes system structure during the simulation run (Kim and Juhn, 1997, Schieritz and Milling, 2003, Pourdehnad et al., 2002). Sixth, its strives for problem-solving (Pourdehnad et al., 2002, Phelan, 1999). Seventh, system structure determines system behavior (Schieritz and Milling, 2003, Parunak et al., 1998). Finally, it handles time in a continuous fashion (Borshchev and Filippov, 2004, Osgood, 2007).

11.2 Agent-based

Agent-based models focus on the study of individual agents that interact with each other and with their environment, giving rise to complex system behavior (Phelan, 1999, Bonabeau, 2002). AB does not assume system structure; on the contrary, it uses agents' internal decision rules or logic to modify the state of the system, which in turn modifies agents' behavior. Further, AB models have no central authority nor perfect information, which implies decentralized decisions to achieve individual objectives (Macal, 2010, Macal and North, 2006). Nevertheless, the agents individual decision rules allow collective intelligence to emerge when agents coordinate their decisions to achieve common goals that they could not reach through individual action alone. Such central notions, e.g. emergence, are described in the theory of complexity, from which AB departs (Phelan, 1999).

It follows that the four main components of the AB modeling are agents, actions, decision rules and the environment. To study the behavior of a system, these components are assembled in specialized software that enables the emergence of learning and adaptation beyond the reach of analytical mathematical methods (Bonabeau, 2002). This type of software resolves sets of equations by conducting calculations based on the current state of the system and the decision rules of the agents. As a maximum frequency, those calculations occur every time step, but the time unit can vary greatly depending on the model's conceptualization; however, the modeler can specify lower frequencies.

In addition to the study of SD's specificities, Lättilä et al's (2010) reported eight aspects that make AB unique. First, it studies individual agents and therefore, system heterogeneity (Kim and Juhn, 1997, Parunak et al., 1998, Martinez-Moyano et al., 2007). Second, its unit of analysis are agents' rules (Pourdehnad et al., 2002, Parunak et al., 1998). Third, its central mechanism is emergent behavior (Kim and Juhn, 1997, Phelan, 1999, Pourdehnad et al., 2002, Parunak et al., 1998, Martinez-Moyano et al., 2007). Fourth, its main components are agents, rules and interactions (Parunak et al., 1998, Pourdehnad et al., 2002, Phelan, 1999, Martinez-Moyano et al., 2007). Fifth, system structure can change during the simulation run (Kim and Juhn, 1997, Schieritz and Milling, 2003, Pourdehnad et al., 2002). Sixth, it aims for exploratory analysis (Pourdehnad et al., 2002, Phelan, 1999). Seventh, discrete events cause the system's dynamics (Schieritz and Milling, 2003, Parunak et al., 1998). Finally, AB models can handle both discrete and continuous time, the latter at the cost of high demand for computational capacity (Borshchev and Filippov, 2004, Osgood, 2007).

11.3 Method selection

The aim of this research is to explore how changes in the conditions that enable and restrict CBM systems influence the water service levels experienced by domestic users in rural Sub-Saharan Africa, as well as the financial costs of these interventions. The nature of the research is exploratory: on the one hand, it aims at capturing the structure and dynamic nature of CBM systems for domestic rural water supply; on the other hand, it aims at exploring how structural changes in the CBM paradigm can change the behavior of CBM systems.

Therefore, system dynamics was chosen as the modeling and simulation method for this research. This method allows the exploration of different structures and behaviors from a high-level perspective, while representing the complexity of the system. System dynamics also enables the identification of system components that can be studied in more detail with methods such as agent-based. Overall, the research problem exhibits the characteristics, identified by van Daalen and Thissen (2001), that make a problem situation suitable for analysis by system dynamics:

First, the problem analysis can benefit from the creation of a causal diagram, because different factors of CBM systems for domestic rural water points influence each other. Moreover, levels and flows are easily recognizable. An example is the sub-system of the physical infrastructure.

Second, to address the problem statement and the research objectives, system's behavior is more important than exact values. The research calls for gaining understanding about the overall system behavior, and its focus is not in the technical components on their own, but their interactions with social components.

Third, the system exhibits changes as a function of time. Examples include the ageing process of the physical infrastructure, the funding allocation and the participatory and managerial processes.

Fourth, the system can be considered as continuous, even if the system is not continuous in reality.

Fifth, the system can be described using levels and rates, such as the physical infrastructure, its ageing process, or the increase and decrease of community management and participation.

Sixth, the situation must be analyzed over a long period of years.

Seventh, feedbacks are expected because factors that reinforce each other have a strong effect on the system's behavior. Once modeled, the effect of feedbacks can lead to unexpected behavior.

Eight, relevant factors can be quantified, if not with mathematical accuracy, at least through sets of assumptions.

Finally, the problem situation is complex.

An additional argument for the selection of system dynamics as the modeling method is given by Clifford-Holmes et al.'s (2015) *Modeling in the muddled middle.* This approach argues that complexity-informed models and simulations can be used to explore the ambiguous space between policy design, implementation and adaptation in the field of water services. By engaging relevant stakeholders in the design and use of models, particularly system dynamics models, policy and decision making processes can be facilitated. Therefore, system dynamics is considered to be a suitable method to produce a model that can be used later by transition managers as a boundary object to explore and intervene in the problem situation (van Waas et al., 2015).

11.4 Main components of a quantitative system dynamics model

To specify the model conceptualization into a quantitative system dynamics model, three types of variables and two types of equations are used: levels, constant and auxiliary variables, and balance and rate equations. Based on Richardson and Pugh III (1981), Bankes (1993), Pruyt (2013) and van Daalen and Thissen (2001), in the following paragraphs, these types of variables and equations are detailed, as well as possible numerical methods to solve them.

Level variables are a representation of the accumulation of material (such as water points) or information (such as the management of Water Point Committees). They increase or decrease as a function of rate, and these changes are represented with differential equations. In the model, only variables that present considerable increases or decreases over time are represented as levels.

Constant variables are those that do not present considerable increases or decreases during the simulation time. While their real-world equivalent may not be constant, when changes are not large they can be modeled as such. In practice, the value of a constant is not always easy to determine. Therefore, it is important to determine how sensitive the model is to different values of constants.

Auxiliary variables are those that are not levels nor constants. They can be formulated as mathematical equations or as table functions (also known as lookup functions). Table functions are typically used when the relation between two variables is not easily represented by a mathematical equation.

Balance equations are mathematical expressions that indicate the cause, direction and magnitude of changes in a level variable. These changes can represent flows of material or information, according to the type of level variable. For instance, changes in the total number of water points represent a flow of material, and changes in the management of Water Point Committees represent a flow of information. In the model, every level variable has a balance equation, which integrate the model's system of equations. The behavior of the system can be analyzed when this system is solved.

Rate equations are the differential equations that represent changes in a level variable. They are components of balance equations.

After the model has been quantified and all equations have been specified, the system of equations can be solved numerically in software such as Vensim® (www.vensim.com), Stella® (www.stella.com), PowerSim® (www.powersim.com)or AnyLogic® (www.anylogic.com). The user enters the model in the software and specifies the numerical method of choice, being Euler and Runge-Kutta the most common ones, and the time step. On the one hand, Euler method is recommended for models that contain discrete variables or functions that generate integer values. On the other hand, Runge-Kutta (2 and 4) is suitable for models containing continuous variables. While this method does not cope with integer values appropriately, it is ideal for continuous models with oscillatory behavior. Nonetheless, Euler method with small time steps can yield similar results than its counterpart. The selection of a time step depends on the accuracy desired for the result and the computation capacity to solve the equations. A general recommendation is to select a time step that is from 50% to 10% of the smallest time constant in the model. This research used the software Vensim DSS® to solve the equation, using Euler as the method of choice, with a time step of 0.001.

11.5 System dynamics modeling cycle

The system dynamics modeling cycle can be conceptualized in four stages (van Daalen and Thissen, 2001, Sterman, 2000): conceptualization, specification, verification and validation, and model use. Each of these stages is introduced below.

Conceptualization or qualitative System Dynamics. In this phase, cause-effect diagrams are created, also known as causal loop diagrams. These diagrams aim at representing feedbacks and interactions between the system variables. The qualitative analysis of these diagrams enables learning processes and assists in defining the boundaries of the system to be modeled.

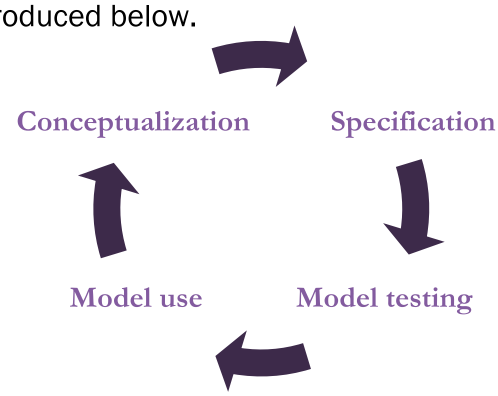


Figure 40 Modeling cycle

Specification or quantitative System Dynamics. During this phase, quantitative data is entered into the qualitative model: the form of the causal relations is made explicit, parameters are determined and tests are designed. This research uses the software Vensim DSS®.

Verification and validation. These activities are undertaken by carrying out different tests. On the one hand, verification checks that the model was coded correctly, that it is dimensionally consistent and that an appropriate numerical integration method with a correct time step has been chosen. On the other hand, the objective of validation is to build confidence in the model. It can include analyzing whether the model produces data or trends that represent the real system, as well as validation of the model structure.

From knowledge to design. After a system dynamics method has been verified and validated, it can be used to gain knowledge on how to improve system behavior. Through the design and implementation of experiments, users can learn how to re-design system structures or strategies.

12 Appendix 3. Validation Interviews and Model Implementation

This appendix presents an overview of the conceptualization process of the systems model built as part of this study. First, Section 1.1 describes the conceptualization process. Then, Section 1.2 to 1.4 presents the results of the model conceptualization.

12.1 Conceptualization process

Based on a literature review on modeling and simulation methods, system dynamics was the chosen method for the design of the tool. Once that the method was chosen, the conceptualization process departed from the systems diagram below (Figure 9), which is described in detail in Chapter 4. In this diagram, important variables are coded by color:

Criteria, in light blue, represent the indicators of the state of the problem.

External factors, in grey, cannot be influenced by the actors in the system, but influence the system variables or the criteria.
Policy actions, in purple, are variables that actors can affect to influence the criteria.

The remaining variables are system variables, and they are coded by color to differentiate five sub-systems:

Physical infrastructure, depicted in red.

Demand and need, depicted in black.

Management and participation, depicted in green.

Available budget, depicted in dark blue.

Allocation and execution, depicted in yellow.

Based on the systems diagram, the first step in the conceptualization process was to build causal loop diagrams that represent the sub-systems further. List Extension Method was the method of choice to build the causal loop diagrams (Coyle, 1996). This systematic method begins with a *model list* that contains the most important variable, according to what the model aims to represent. The list is expanded by adding a new column to the left of the model list, called *first extension.* This addition contains variables that directly influence the model list. The procedure is repeated until endogenous variables, or variables that do not belong to the sub-system, are found.

Based on the results of the List Extension Method, a causal loop diagram is built. This diagram aims at representing the causal relations between the variables in the sub-system. Afterwards, stock and flow diagrams are built. They consist in the transfer of causal loop diagrams into the software where the model will be built: Vensim DSS®. In stock and flow diagrams, variables in boxes represent accumulation of material or information, and are known as stocks or levels. Variables located in double-lined arrows represent rates or flows, which are differential equations that indicate changes in the value of levels. Finally, variables with no boxes nor double-lined arrows represent auxiliaries.

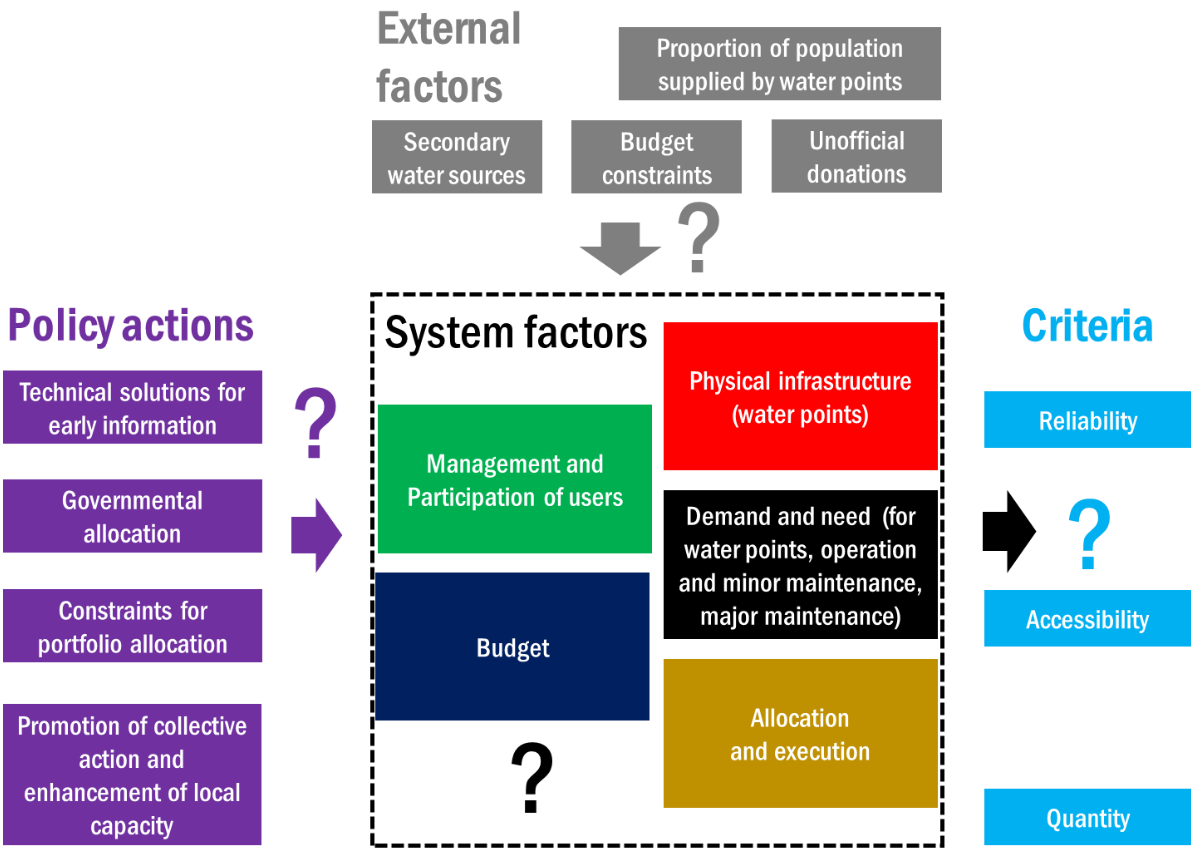


Figure 41 Systems diagram of CBM systems for domestic rural water supply in Sub-Saharan Africa

After completing the causal loop diagrams for each sub-system, based on the results of the List Extension Method, three experts on CBM of domestic rural water points were interviewed. Through a structured interview, they were asked questions to determine whether the causal loop diagrams were an accurate representation of the system. Their input was used to adapt the initial causal loop diagrams into the versions that are presented in this Appendix. In the same meeting, interviewees were asked about other two topics: plausible values of relevant parameters in the model, and plausible modes of behavior of the system in reality.

Section 1.2 describes the conceptualization interviews and present a summary of the insights obtained. Then, Sections 1.3 to 1.6 address one sub-system, respectively, and section 1.7 addresses the key performance indicators. Sections 1.3 to 1.7 are organized in three items: the results of the List Extension Method, an extended causal loop diagram and a stock-flow diagram of the sub-system.

12.2 Validation interviews

The implementation of the List Extension Method and the realization of the causal loop diagrams were iterative processes in which the diagrams gradually became those that are presented in this Appendix. During these iterative processes, three experts in CBM systems were interviewed. The objective of these interviews was to gain insight on whether relevant variables and accurate relations between those variables were represented in the model conceptualization. Nonetheless, the meetings were seized to achieve other two objectives: to obtain educated guesses on plausible values of relevant parameters in the model, and on plausible modes of behavior of the system in reality. Insight from these last two objectives were used in the following step of the modeling process (model implementation).

The realization of the conceptualization interviews was divided in five key steps (Figure 42): (1) Method selection; (2) Interview design; (3) Implementation; (4) Data processing; and (5) Data analysis. The methods applied to each of these key steps are explained in the sub-sections below.

Figure 42 Key steps in the realization of the interview process for the validation interviews

12.2.1 Method selection

First, interviews were the preferred data collection method for five main reasons. They enable a discussion beyond secondary sources. The interviewer can request clarification of concepts. They make possible a more direct rapport between interviewee and interviewer. The interviewer can observe features that would remain unseen with any other means of communication. Finally, from the three main types of interviews, the structured type was selected. Having a rigid set of questions and possible answers provides a strong guide for the discussion, and allows the interviewer to gather the necessary data to review the causal loop diagrams. Nonetheless, when judged necessary by the interviewer or when requested by the interviewee, the conversation diverged from the questions to discuss other ideas.

12.2.2 Interview design

The second key step was interview design. Each interview consisted in three main parts. In the first part, the interviewer welcomed the interviewee, explained the objective of the interview, asked for permission to record the audio of the meeting, and explained the structure of the interview.

In the second part, the interviewer introduced her research, including problem description, expected research contribution, process and methods, and an overview of the systems diagram (Figure 9).

In the third part, a discussion took place regarding three topics.

Interviewees were asked closed questions regarding the causal relations in the model conceptualization. They were presented with a set of statements, and were invited to use a Likert scale to define the extent at which they agreed with those statements (strongly agree, agree, neutral, disagree and strongly disagree). The interview provided room for additional comments, and interviewees were allowed to either answer with the scale without adding any comment, or provide comments without using the scale when they were unsure.

Interviews were required to provide educated guesses for the value of parameters that may be required for the model formulation. They were asked to answer with a common value that they have observed, and with maximum and minimum plausible values. Interviewees were free to omit any or all of these values when they were unsure, and to add comments to their answers.

Interviews were asked about plausible modes of behavior of the system. Again, they were presented with a set of statements, and were invited to use a Likert scale to define the extent at which they agreed with those statements (strongly agree, agree, neutral, disagree and strongly disagree). The interview provided room for additional comments, and interviewees were allowed to either answer with the scale without adding any comment, or provide comments without using the scale when they were unsure.

Questions, summary of answers and estimation of parameters, are detailed in sub-section 1.2.5.

12.2.3 Implementation

Because the objective of the interviews was discuss the causal relations between relevant variables in CBM systems for domestic rural water points, potential interviewees should have knowledge on these systems. Therefore, the three interviewees that participated in the initial interviews (Appendix 1), and who are experts in CBM systems of domestic rural water points, were invited to participate in the conceptualization interviews. Inviting the same interviewees would also serve as follow-up from the last meeting, to discuss how the first set of interviews was process and how the research had evolved.

Each candidate was contacted individually, via email, to request a one-hour appointment. All appointments were scheduled at quiet locations that allowed to record of the audio of the interview.

Table 8 presents a brief professional biography of the potential interviewees and Table 11 specifies the date, place and duration of each interview.

Table 71 Selection of potential interviewees for the Conceptualization interviews

Interviewee	Brief professional biography
Deirdre	Programme manager, trainer, researcher and PhD candidate with more than 17 years of experience in domestic water, sanitation and hygiene services in Africa and Asia. Her research focuses on governance of WASH services, organizational and individual capacity development and sector change processes with the aim of achieving universal coverage.
Patrick	Manager at a water, sanitation and hygiene services NGO with headquarters in The Hague, The Netherlands. He has over twenty years of experience in a broad range of issues around water, its management and its use in improving human well-being, mainly in Africa and South Asia. His main area of interested is how to ignite and support sector wide change to achieve more sustainable water use and improved services for all.
Valérie	Water and sanitation engineer and social anthropologist with more than ten years of experience in the water, sanitation and hygiene sector in Africa and Latin America. Her work has centered on research, facilitation of learning processes, monitoring and capacity building of NGO's and local governments. Currently, she is taking steps to widen her work to other non-profit sectors domains, such as human rights, education, renewable energies, environmental protection or immigration and integration.

Table 72 Date, place and duration of the interviews for the Conceptualization interviews

Interviewee	Date and time	Place	Duration
Deirdre	2016. June 2 10:00h	Delft, The Netherlands	1 hour
Patrick	2016. May 27 13:30h	The Hague, The Netherlands	1 hour
Valérie	2016. June 4 14:00h	The Hague, The Netherlands.	1 hour 20 minutes

12.2.4 Data processing

In order to process the data of each interview, the interviewees' answers were summarized in tables, according to the sub-system under discussing.

12.2.5 Data analysis

The summaries resulting from the data processing were used as inputs to redesign the results of the List Extension Method, the causal loop diagrams and the stock and flow diagrams for each sub-system. Table 73, Table 76, Table 79, Table 82 and Table 85 below present the summaries of the interviews. Under each table, the main changes in the model conceptualization derived from those summaries are specified. Table 74, Table 77, Table 80, Table 83 and
Table 86 detail the educated guesses from the experts. The remaining tables summarize the answers regarding plausible model behavior. To answer these questions, interviewees

were require to consider the 2013 current situation of Kabarole District, in Uganda (see Chapter 7), and to imagine plausible developments under the current policies and trends. The main insights derived from these questions are presented under each table.

Sub-system 1: physical infrastructure

Table 73 Interviews summary for structure of Sub-system 1: physical infrastructure

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
Charities donate water points, which are not included in the district conditional grant.	X					1	
	X					2	
		X				3	
OpEx events increase the lifespan of a water point.		X				1	
	X					2	However, it only delays ageing and failure.
		X				3	

Main changes:

- No major changes were made based on these findings.

Table 74 Educated guesses for parameters of Sub-system 1: physical infrastructure

Parameter	Common value	Minimum Plausible	Maximum Plausible	Interviewee	Comments
average lifespan of a water point	10 years	0 years	NA	1	
			6 years	2	
	10 years			3	
effect of OpEx in the life of a water point	0 to 100%			1	"There is the killer question." A water point can break immediately.
	50%			2	Could increase lifespan by half.
	50%			3	Reduced at least by half.
ratio of new water points donated by charities to new water points installed through CapEx execution	30 to 50%			1	Varies every year.
				2	Unsure.
				3	Unsure.

Table 75 Interviews summary for behavior of Sub-system 1: physical infrastructure

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
The total number of water points increases over time.	X					1	Assuming that someone is paying.
		X				2	
	X					3	
A rapid increase in the total number of water points is followed by a slower increase.			X			1	Idealized scenario in which the gap is closed.
		X				2	If they turn to piped schemes.
		X				3	
The fraction of failed water points is approximately one third of the total number of water points.		X				1	
			X			2	Might be too high for Kabarole.
				X		3	
The majority of the water points are older or aged.		X				1	
		X				2	
		X				3	

Main insights:

- In the initial conceptualization of the model, failed water points were only repaired through the action of the public sector. Nonetheless, after this set of interviews, the model was modified to represent local managers who may also be able to repair failed water points. This change addresses the third statement as well.

Sub-system 2: Demand and need

Table 76 Interviews summary for structure of Sub-system 2: Demand and need

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
All water points, functional or failed, require OpEx.			X			1	Depends on how OpEx and CapManEx are defined.
	X					2	
		X				3	Depends on how OpEx and CapManEx are defined.
IT solutions decrease the time to file a CapManEx request.		X				1	
	X					2	
	X					3	
Communities' involvement in the management of water points increases the number of CapManEx requests.			X			1	Depends on how OpEx and CapManEx are defined.
	X					2	
				X		3	Local managers may be self-sufficient and solve the issue.
Communities' participation increases the number of CapEx requests.				X		1	Installation of new water points is not driven by demand, as the demand already exists but the execution is constrained by resources. Usually, there will be a needs assessment by public sector.
		X				2	People come to know their rights and ways to express their demand.
		X				3	

Main changes:

- The definitions of operation and maintenance (Op), and capital maintenance (CapMan) were further detailed. A water point requires CapMan when its water flow has considerably decreased and although it may still deliver a flow, it can be considered to be non-functional.
- In the initial conceptualization, the CapManEx demand could only decrease by the action of the public sector. In the most updated conceptualization, it can also decrease through the action of local managers, who may resolve the issue without intervention of the public sector.

Table 77 Educated guesses for parameters in Sub-system 2: Demand and need

Parameter	Common value	Minimum Plausible	Maximum Plausible	Interviewee	Comments
average time to execute a CapEx event	6 months	3 months	1 year	1	
	9 months	6 months	2-3 years	2	
	1 year	6 months	2-3 years	3	Luck, political moment, location.
average time to execute a CapManEx event	3 days		3 months	1	3 days is a benchmark.
	1 month	2 weeks	1 year	2	
	2-3 months	1 month	1 year	3	It should not be more than 2 weeks.
standard time to file a CapManEx request	days			1	Highly variable.
		1 day	2 weeks	2	Depends on the management.
		1 day	Abandoned	3	Particularly when there are secondary sources.
time to file a CapEx request	NA			1	The system is not driven by demand for CapEx.
				2	Unsure.
		2 weeks	Never	3	Usually very fast.
time to file a CapManEx request when technical solutions are in place	Immediate			1	
	1 day			2	If users are willing to spend their own money on sending a message.
	Immediate			3	In theory, because they send an SMS.

Table 78 Interviews summary for behavior of Sub-system 2: Demand and need

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
The demand of CapEx and CapManEx does not always equal the actual need.						1	
		X				2	
	X					3	
The demand of CapEx is typically lower than the actual need.						1	
	X					2	
				X		3	People usually ask for more water points than the standard.
The demand of CapManEx is typically lower than the actual need.						1	
	X					2	People are afraid that they might have to pay, that no one will come, or don't know who to ask.
		X				3	Because it should address not only failure, but expensive repairs. But users don't know about it.
More demands for CapManEx are filed than demands for CapEx.						1	
			X			2	Not sure, they might be afraid that they have to pay.
			X			3	Not sure.

Main insights:

- In the initial conceptualization of the model, the construction of new water points was driven by the demand for CapEx, expressed by local users. Nonetheless, after this set of interviews, the model was modified to reflect that the demand for CapEx already exists and reality is not driven by this phenomena. Therefore, the comparison between CapManEx and CapEx is no longer relevant.

Sub-system 3: management and participation

Table 79 Interviews summary for structure of Sub-system 3: management and participation

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
The amount of OpEx collected is higher when communities participate in the management.			X			1	Depends on how OpEx and CapManEx are defined.
			X			2	Complicated statement that might not be as straight forward.
		X				3	Depends on how OpEx and CapManEx are defined.
The amount of OpEx collected is decreased by other needs that users have. The financial value of these needs is unpredictable.		X				1	
	X					2	
		X				3	
The number of OpEx executed increases when communities are involved in the management of the water point.			X			1	Depends on how OpEx and CapManEx are defined.
		X				2	
		X				3	
Involvement in participation increases with satisfaction of users.		X				1	
			X			2	Many matters demand their attention.
		X				3	
Involvement in participation decreases with access to a secondary water source.			X			1	
				X		2	Users may be committed to the water point, in spite of having a secondary source.
				X		3	
Involvement in the management increases with the availability of funding for OpEx.		X				1	
			X			2	
		X				3	
Involvement in the management increases with the execution of DS events.		X				1	
		X				2	Nonetheless, depends on many factors.
		X				3	

Main changes:

- The definitions of operation and maintenance (Op), and capital maintenance (CapMan) were further detailed. A water point requires CapMan when its water flow has considerably decreased and although it may still deliver a flow, it can be considered to be non-functional.

Table 80 Educated guesses for parameters in Sub-system 3: management and participation

Parameter	Common value	Minimum Plausible	Maximum Plausible	Interviewee	Comments
time that a DS event remains effective	3 months	1 month	1 year	1	Ideal visits would occur every month, but are likely to occur every year.
				2	Unsure.
	3 months.			3	Should be conducted every 3 months.

Table 81 Interviews summary for behavior of Sub-system 3: management and participation

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
More OpEx is executed than DS.						1	
	X					2	
				X		3	Not sure. Maybe in the average of the district.
Not all the OpEx that is collected is spent.						1	
		X				2	Troubles to even collect a little bit, while they should even have a reserve.
		X				3	Depends on whether collection is continuous.
About 50% or less of the total water points have active water users committees.						1	
		X				2	In theory, they do.
	X					3	Way less than half. Is this even in place? It may be dissolved.
About 50% or less of the total water points have active water point committees.						1	
		X				2	
	X					3	Way less than half.

Sub-system 4: budget

Table 82 Interviews summary for structure of Sub-system 4: budget

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
Budget for CapEx is authorized only at the beginning of a year.		X				1	
	X					2	
		X				3	Although unsure, might be particularly influenced by political moment, such as elections.
When available, budget for CapManEx can be authorized during the year.		X				1	
		X				2	Unsure.
				X		3	
When available, budget for DS can be authorized during the year.		X				1	
		X				2	Unsure.
				X		3	

Main changes:

- The CBM system has certain absorption capacity. This means that budget being available does not translate in budget being spent. Therefore, three variables were added to the model conceptualization: *CapEx capacity, CapManEx capacity* and *DS capacity.* These variables represent the resources, in addition to funding, that the system allocates to work in a certain activity.

Table 83 Educated guesses for parameters in Sub-system 4: budget

Parameter	Common value	Minimum Plausible	Maximum Plausible	Interviewee	Comments
average cost of a CapEx event			10000 USD	1	
				2	
				3	
average cost of a CapManEx event			1000 USD	1	Depends on how OpEx and CapManEx are defined.
				2	
				3	
average time to execute a DS event				1	There is a definition, possibly 1USD per person per year?
				2	
				3	
average time to execute a DS event	immediate			1	
				2	
				3	
ratio of funding received from development partners to funding received from the public sector.				1	Unsure.
				2	Unsure.
				3	Unsure.

Table 84 Interviews summary for behavior of Sub-system 4: budget

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
A somewhat constant expenditure in CapEx is followed by lower CapEx and higher CapManEx.						1	
			X			2	Don't know.
		X				3	
DS is the lowest expenditure.						1	
		X				2	
	X					3	
Please elaborate on the graph of ratio of expenditures (below the table).						1	
			X			2	Seems like something we would like to see. Something is underlying in the assumptions.
			X			3	Not sure.
By the end of a year, not all the budget has been spent.						1	
			X			2	There are problems dispersing the money, inability to allocate funds, and not enough capacity as technicians. The budget remains approved but not necessarily spent.
		X				3	Often there is late disbursement, and if they send the money back, they get less money next year.

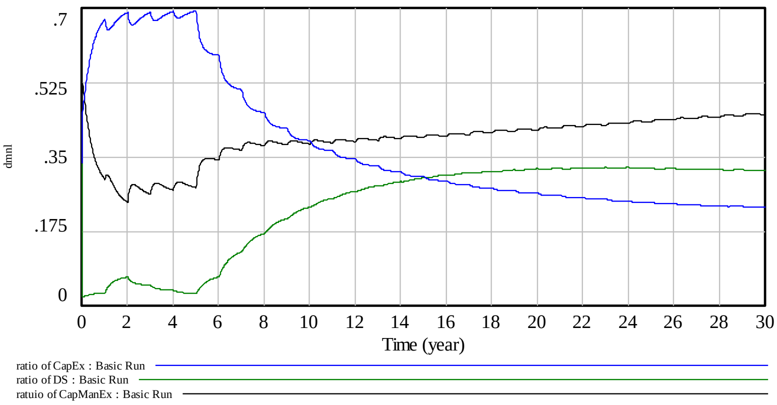


Figure 43 Ratio of expenditures in Kabarole district, starting from 2013

Main insights:

- The patterns of behavior in the graph with the ratio of expenditures (Figure 43) are produced by the rules implicit in the model to allocate funding: a maximum of 70% of the public budget can be spent in CapEx at the beginning of the year. When that maximum is allocated, another share can be allocated to CapManEx, until all water points have been repaired. Only when most water points have been repaired, money can flow towards DS. In reality, however, funding is not necessarily allocated to DS.
- Before the interviews, the budget spend on CapEx, CapManEx and DS depending mostly on what had been approved and on the cost of each event. After these interviews, the model was modified to integrate the capacity to conduct this activities, as an additional constraint to spend the budget.

Sub-system 5: allocation and execution

Table 85 Interviews summary for Sub-system 5: allocation and execution

Statement	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Interviewee	Comments
The priorities for expenditures are: CapEx, CapManEx, DS.			X			1	
			X			2	Unsure. Allocation might occur with percentages, not hierarchy.
			X			3	
Usually, public water regulations state that there is a target percentage of the allocation that should be spent in CapEx.		X				1	
		X				2	
			X			3	

Main changes:

- The model conceptualization used to have a set of conditions: if all the demands for new water points had been satisfied, then demands for CapManEx could be addressed. If all the demands for CapManEx had been satisfied, then DS could be provided. Now, the model conceptualization considers allocation ratios for the three expenditures, instead of a set of priorities.

Table 86 Educated guesses for parameters in Sub-system 5: allocation and execution

Parameter	Common value	Minimum Plausible	Maximum Plausible	Interviewee	Comments
maximum ratio of the available budget that can be spent in CapEx		30%	70%	1	
			70%	2	
				3	

12.3 Sub-system 1: Physical Infrastructure

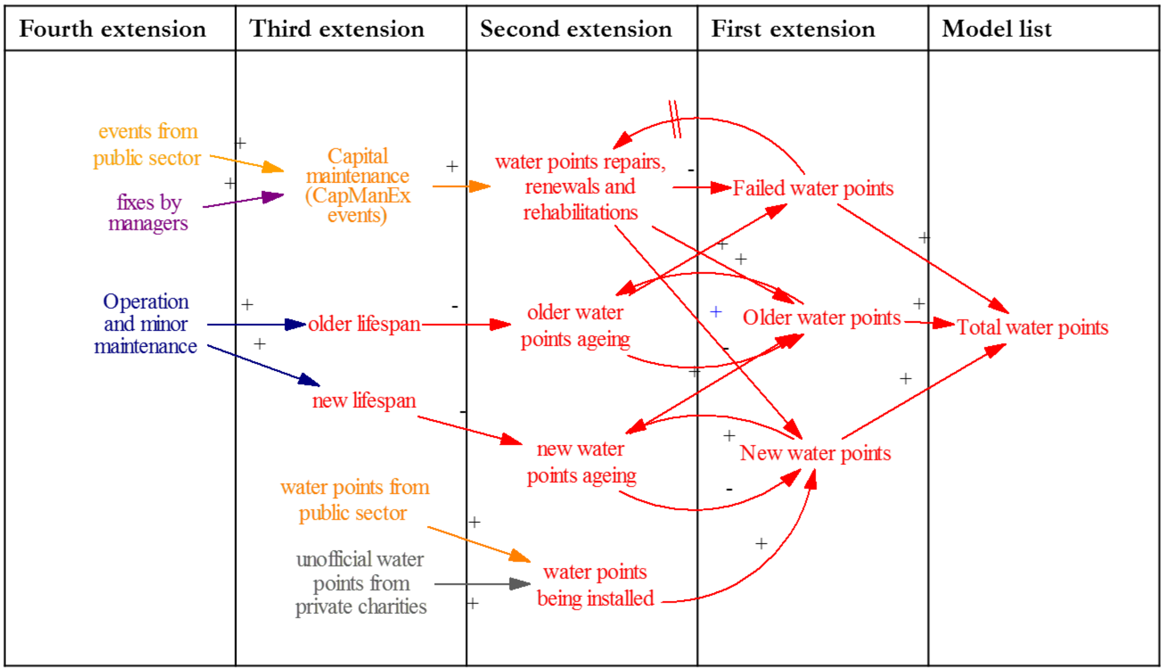


Figure 44 List extension method for Sub-system 1: physical infrastructure

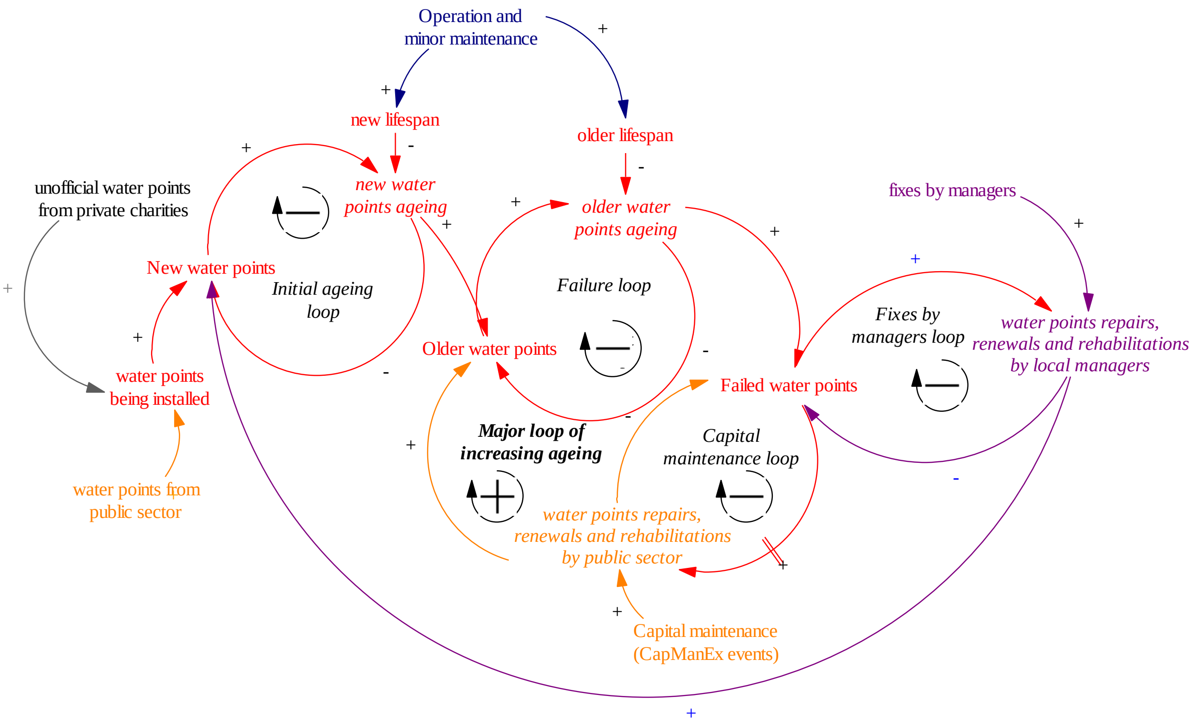


Figure 45 Extended causal loop diagram for Sub-system 1: physical infrastructure

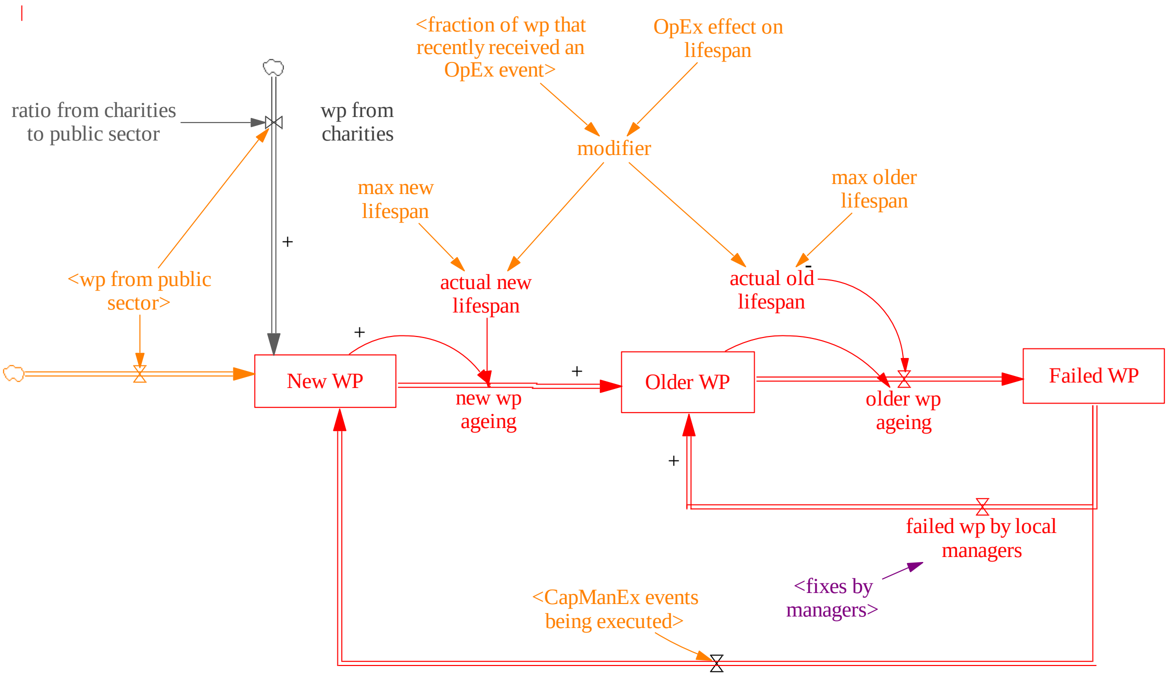


Figure 46 Stock and flow diagram for Sub-system 1: physical infrastructure

12.4 Sub-system 2: Demand and Need

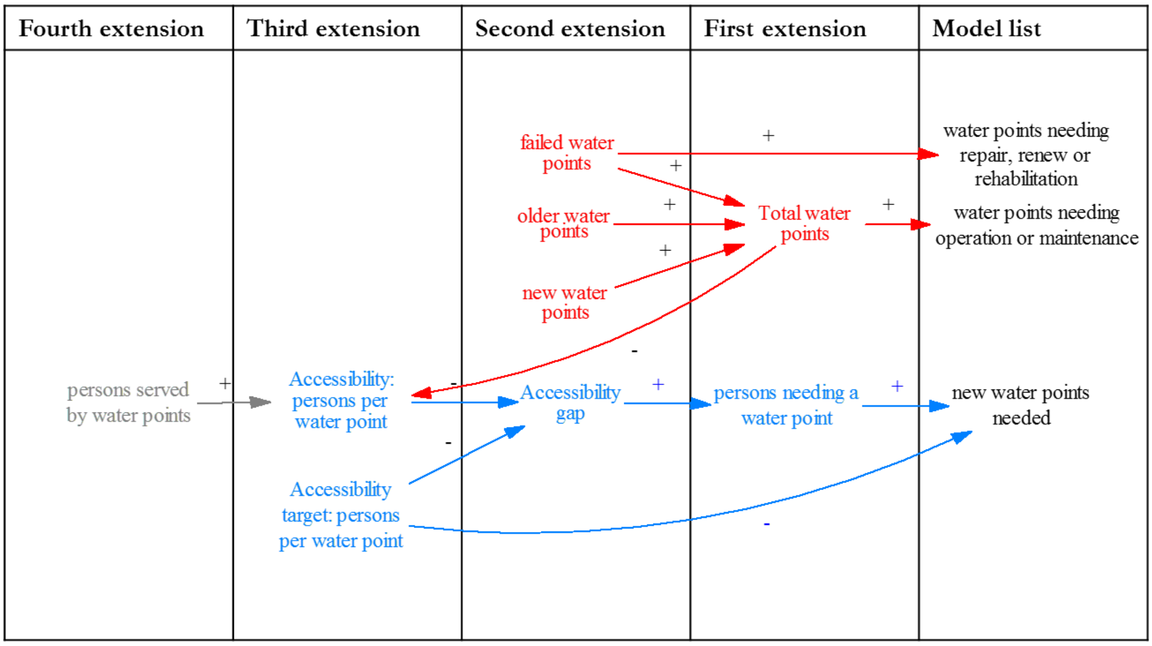


Figure 47 List extension method for Sub-system 2: CapEx, CapManEx and OpEx need

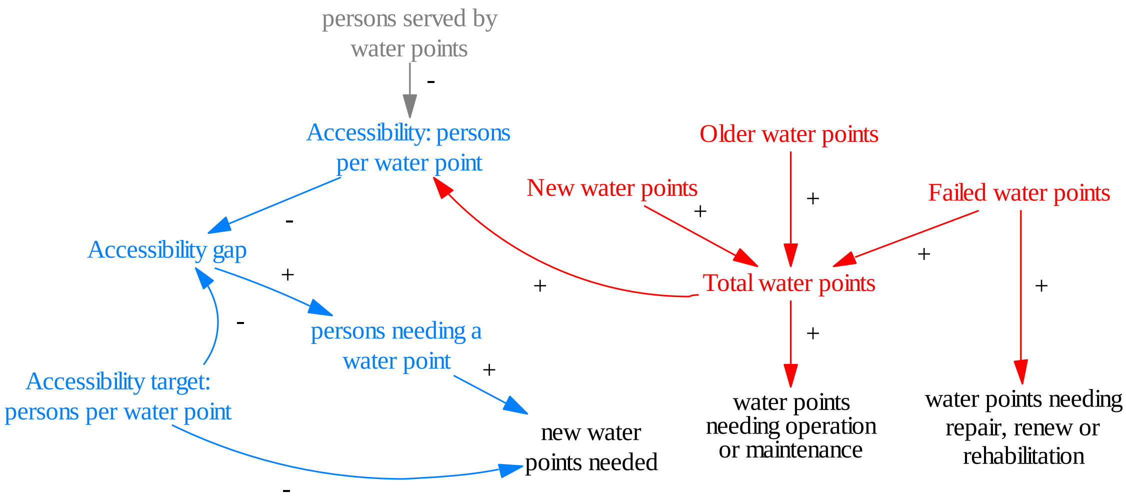


Figure 48 Extended causal loop diagram for Sub-system 2: CapEx, CapManEx and OpEx need

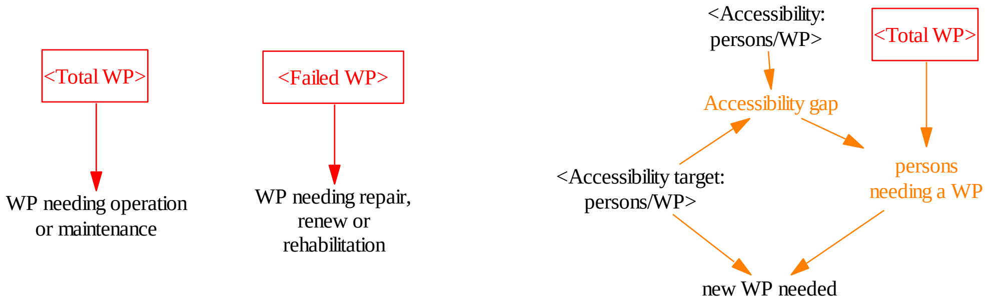


Figure 49 Stock and flow diagram for Sub-system 2: CapEx, CapManEx and OpEx need

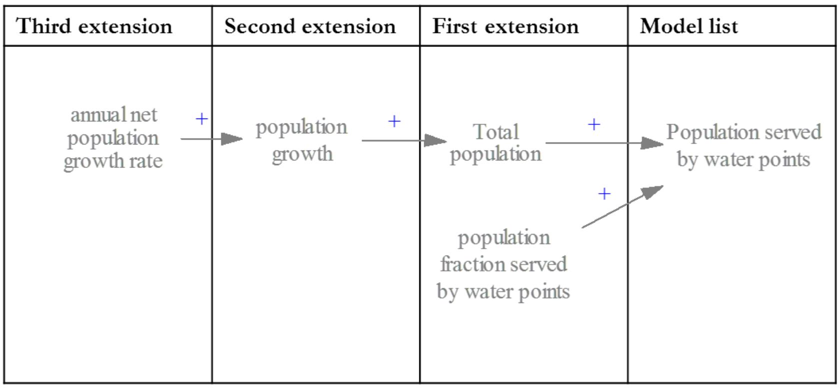


Figure 50 List extension method for Sub-system 2: population served by water points

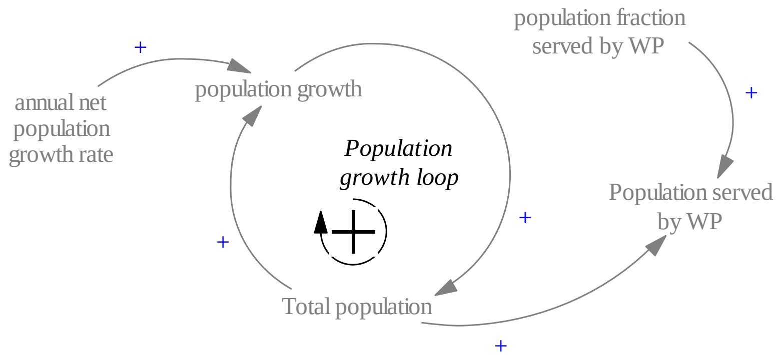


Figure 51 Extended causal loop diagram for Sub-system 2: population served by WP

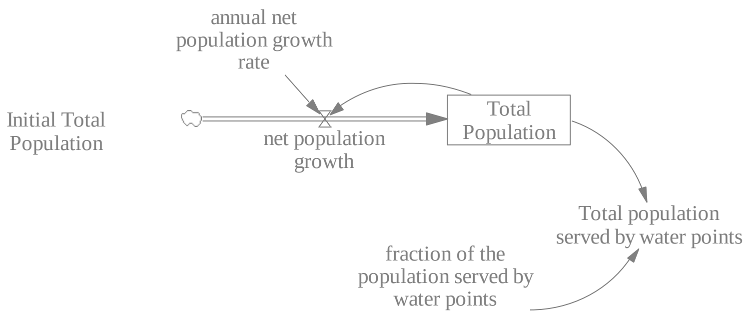


Figure 52 Stock and flow diagram for Sub-system 2: total population served by water points

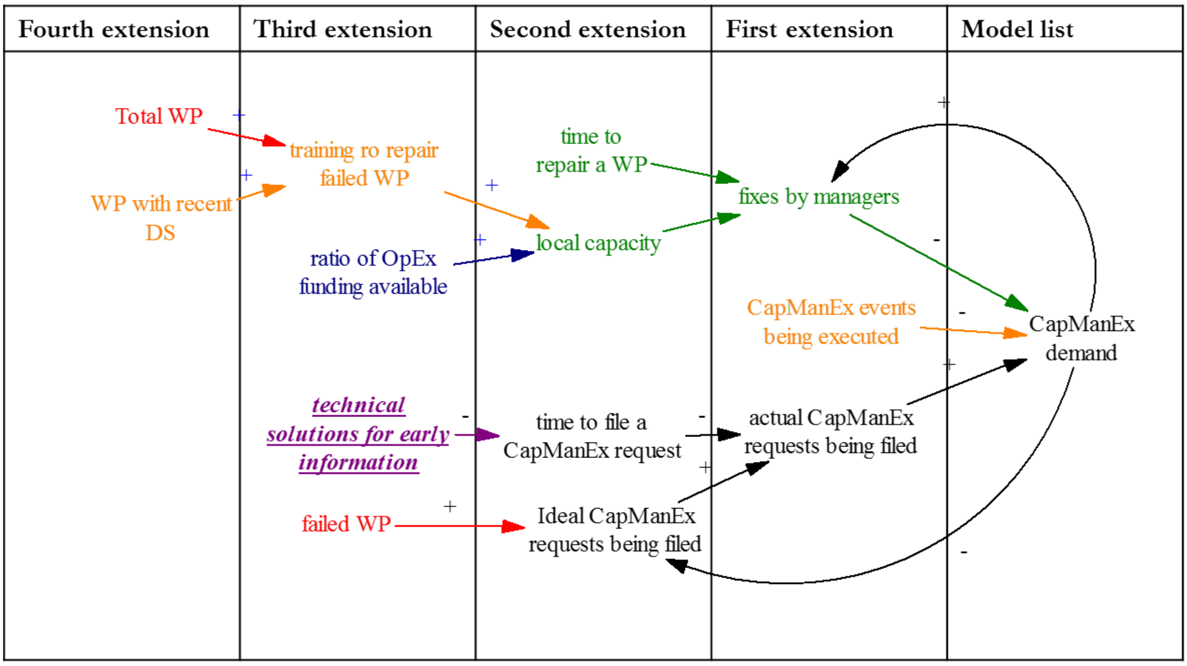


Figure 53 List extension method for Sub-system 2: CapManEx demand

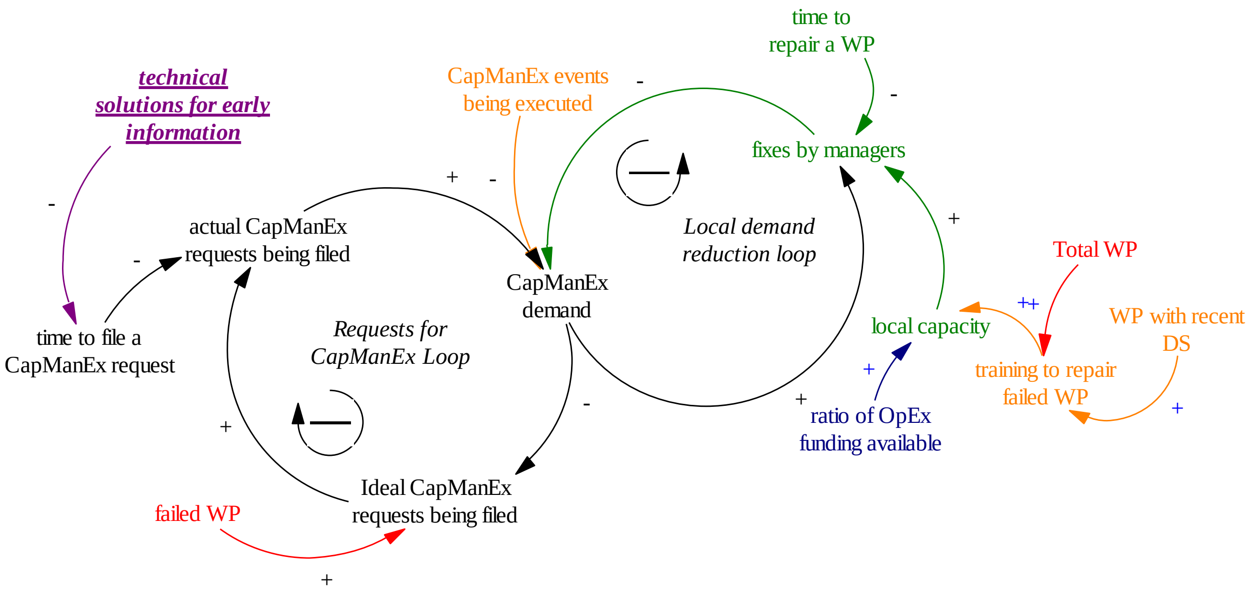


Figure 54 Extended causal loop diagram for Sub-system 2: CapManEx demand

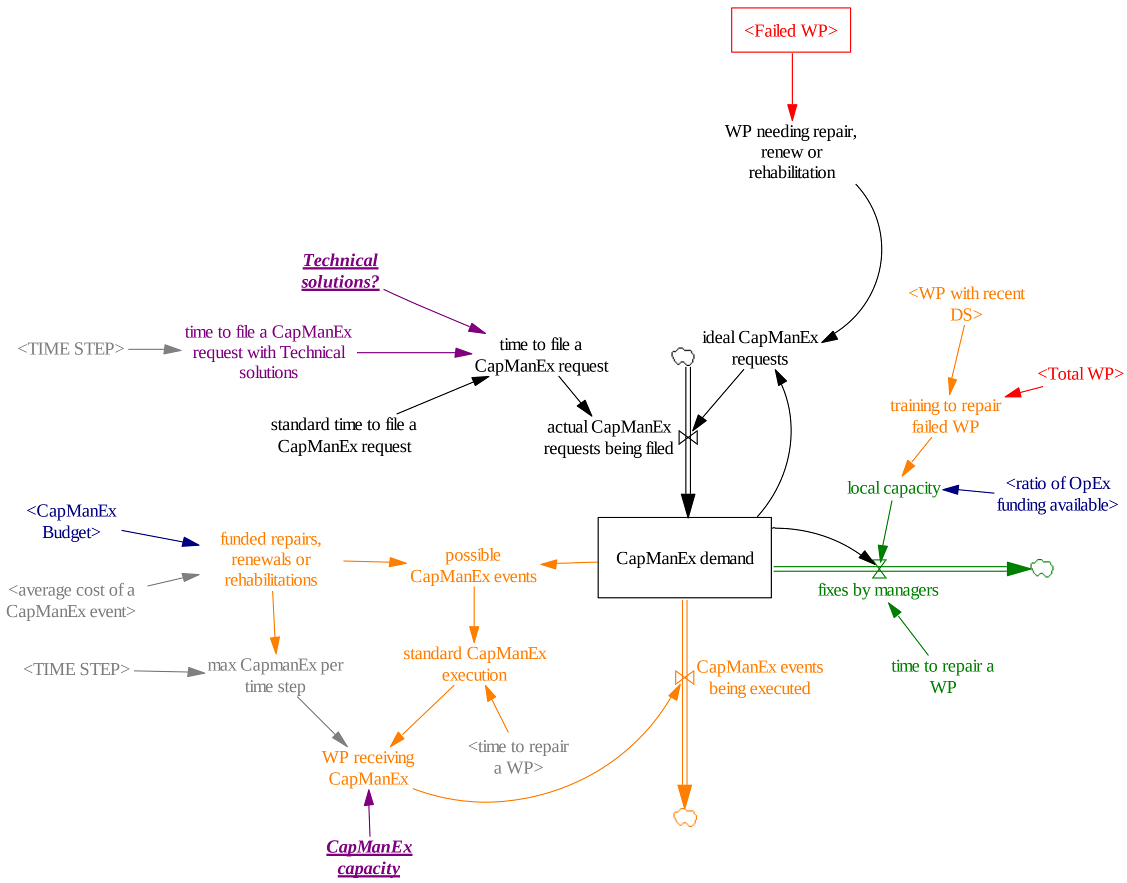


Figure 55 Stock and flow diagram for Sub-system 2: CapManEx demand

12.5 Sub-system 3: Management and Participation

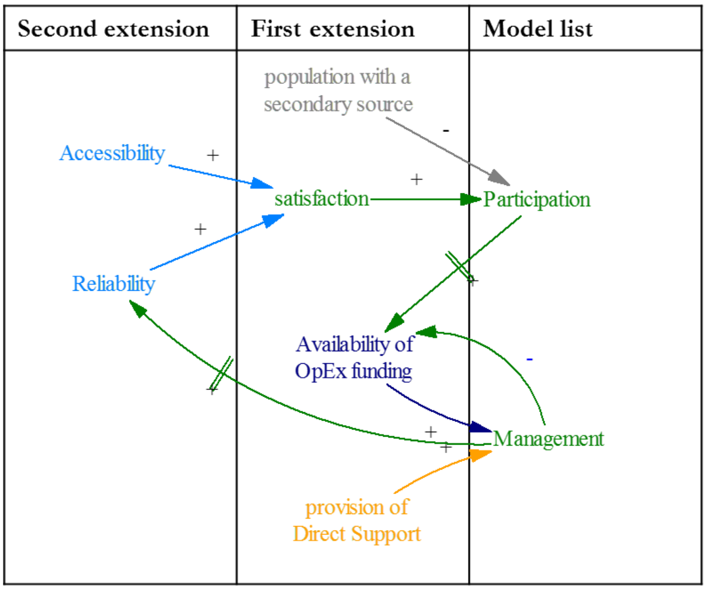


Figure 56 List extension method for Sub-system 3: management and participation

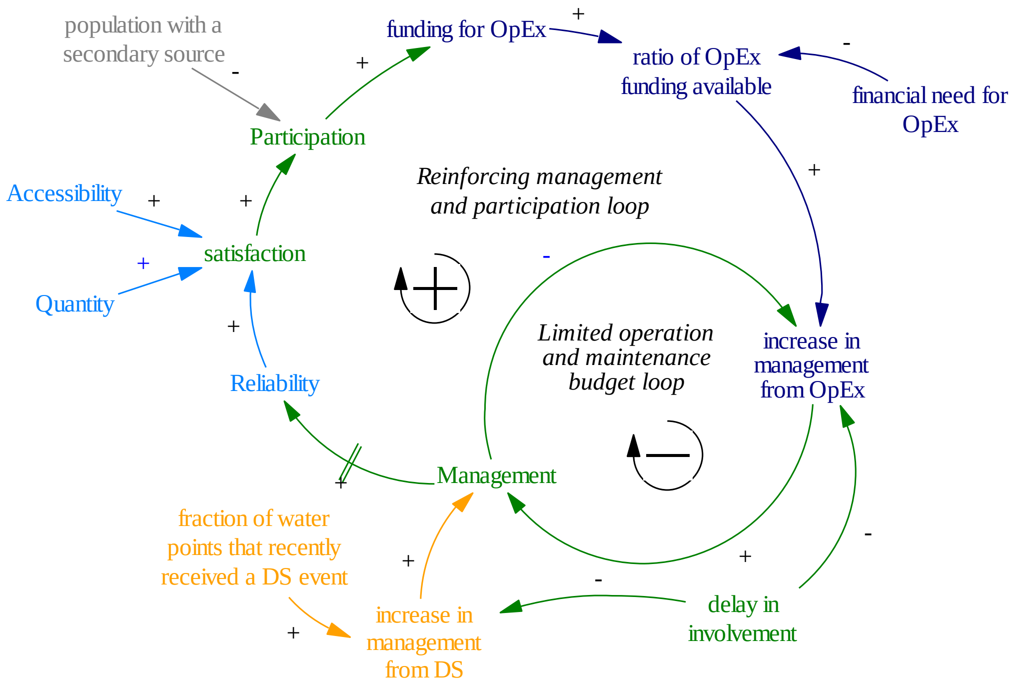


Figure 57 Extended causal loop diagram for Sub-system 3: management and participation

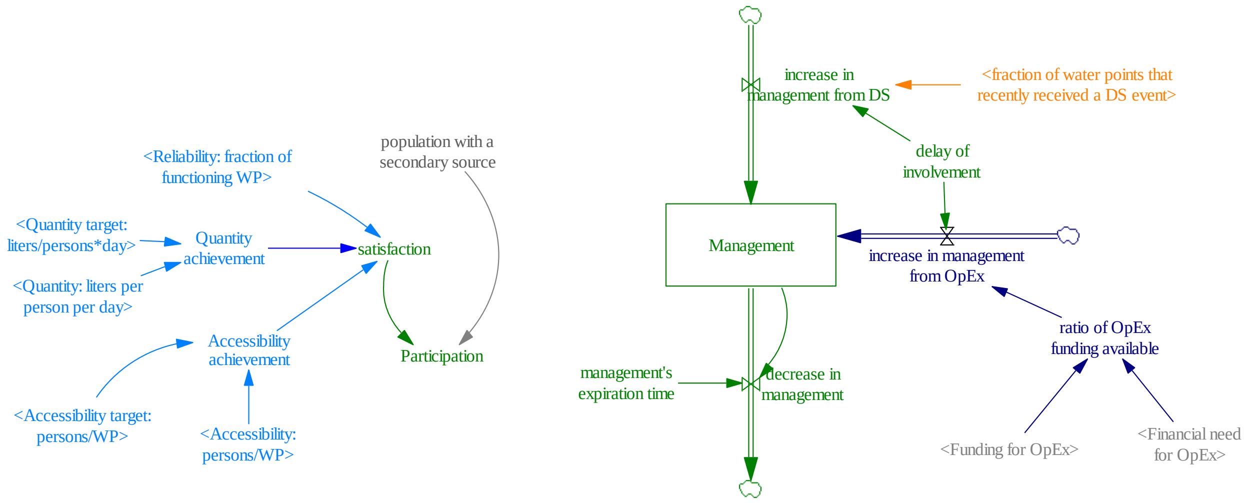


Figure 58 Stock and flow diagram for Sub-system 3: management and participation

12.6 Sub-system 4 and 5: Budget and Allocation

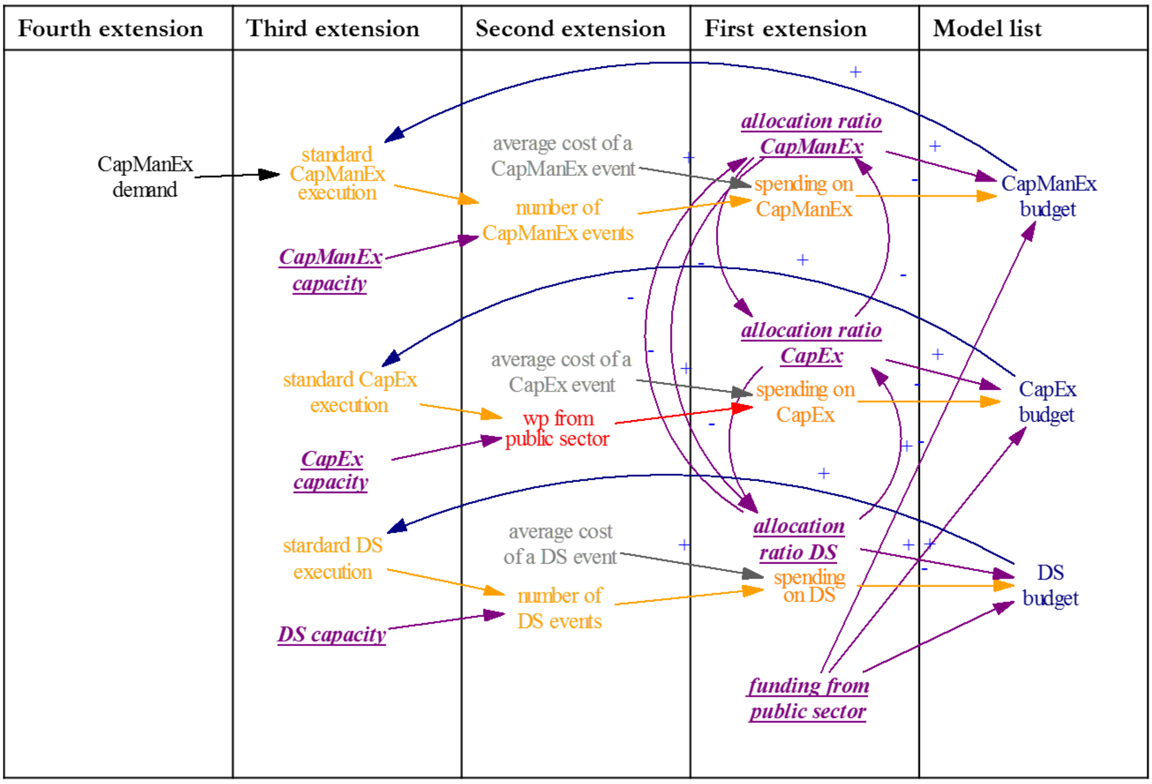


Figure 59 List extension method for Sub-system 4 and 5: Budget and Allocation and execution

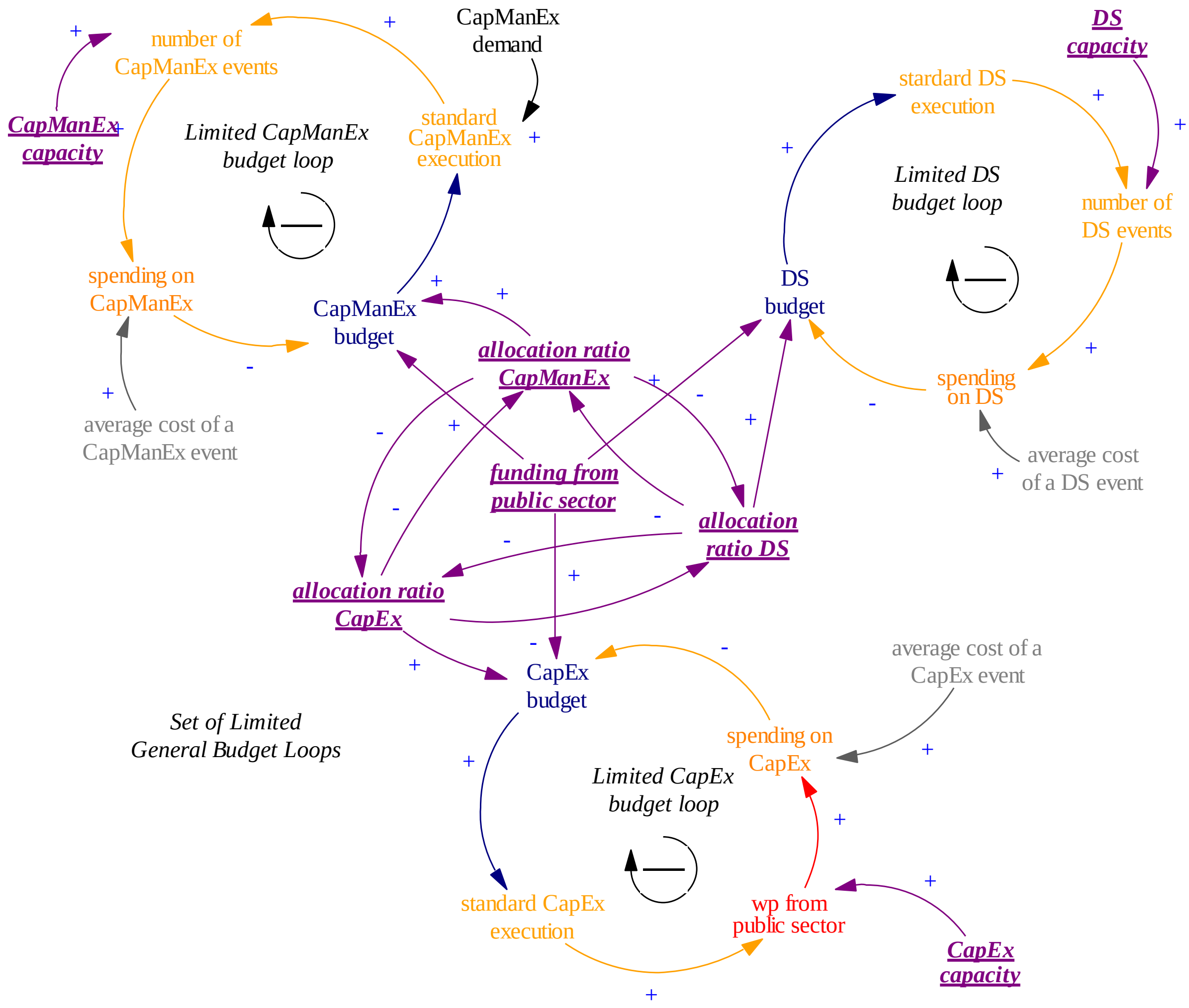


Figure 60 Extended causal loop diagram for Sub-system 4 and 5: Budget and Allocation and execution

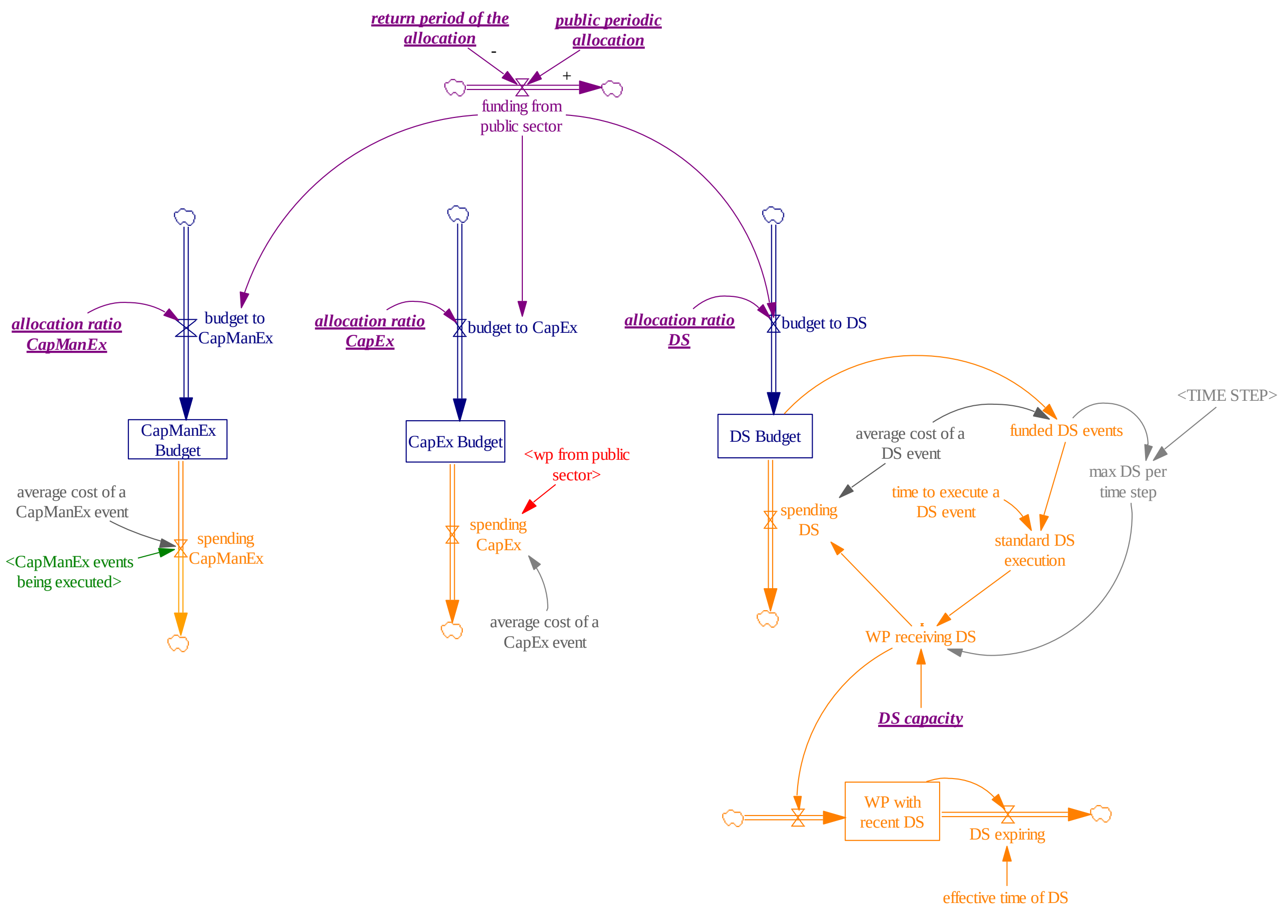


Figure 61 Stock and flow diagram for Sub-system 4 and 5: Budget and Allocation and execution

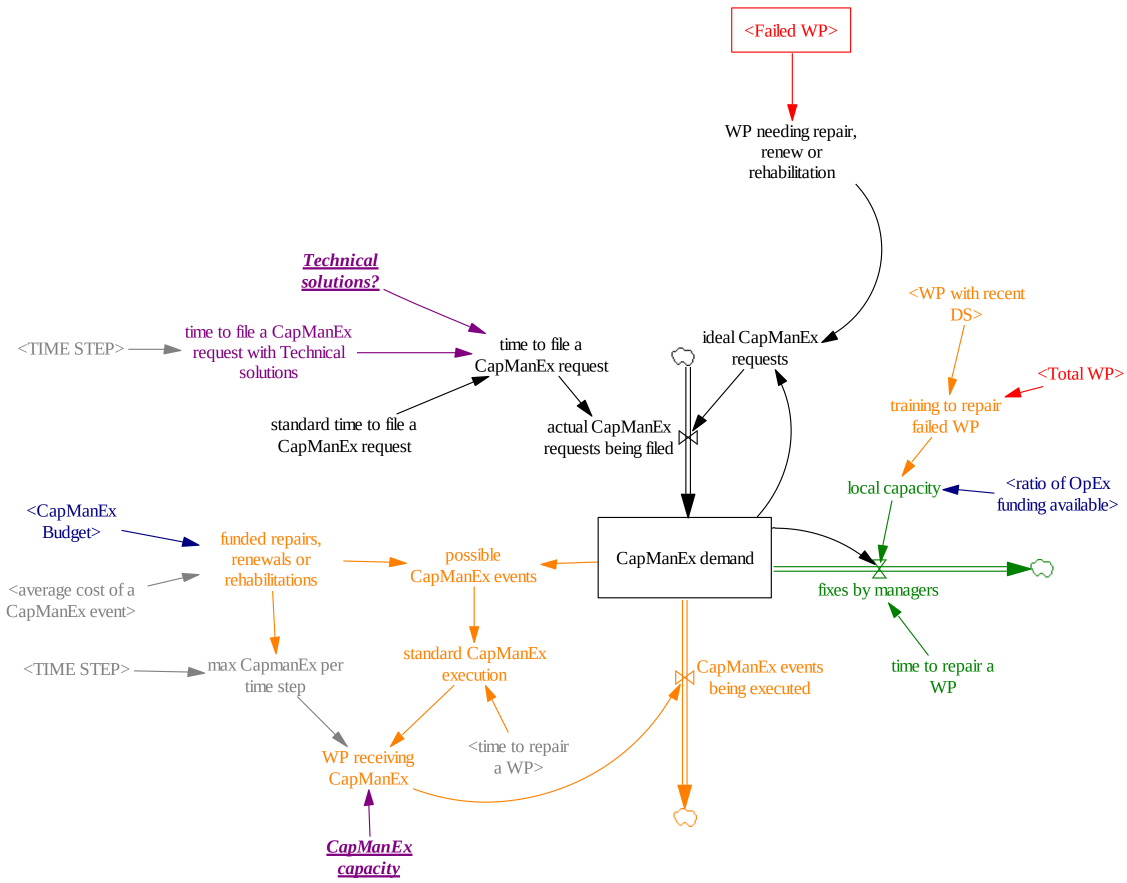


Figure 62 Stock and flow diagram for Sub-system 4 and 5: execution of CapManEx

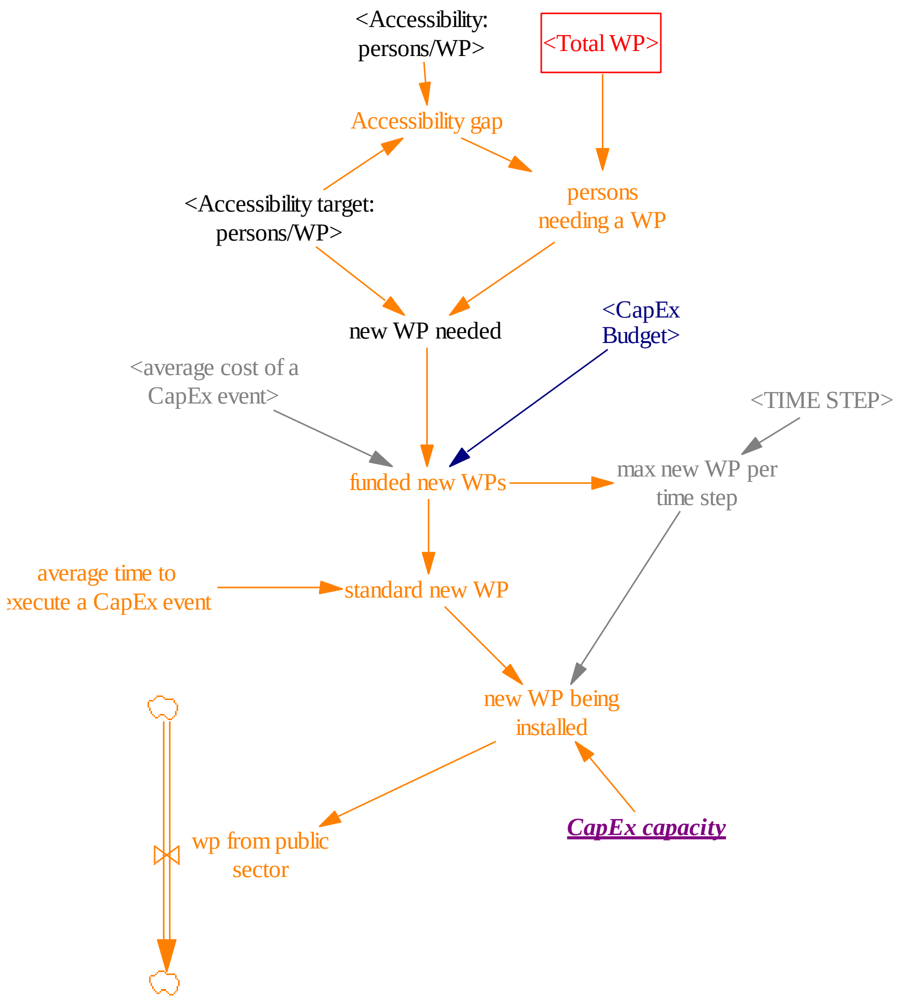


Figure 63 Stock and flow diagram for Sub-system 4 and 5: execution of CapEx

12.7 Key Performance Indicators

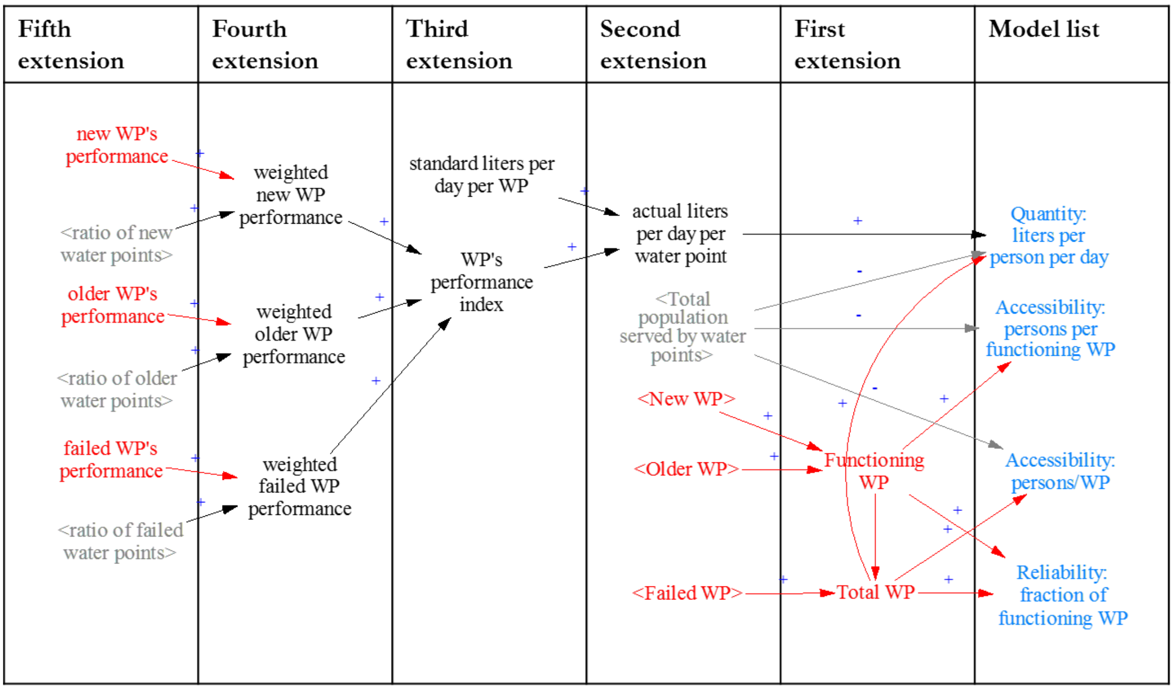


Figure 64 List extension method for the key performance indicators: water service levels

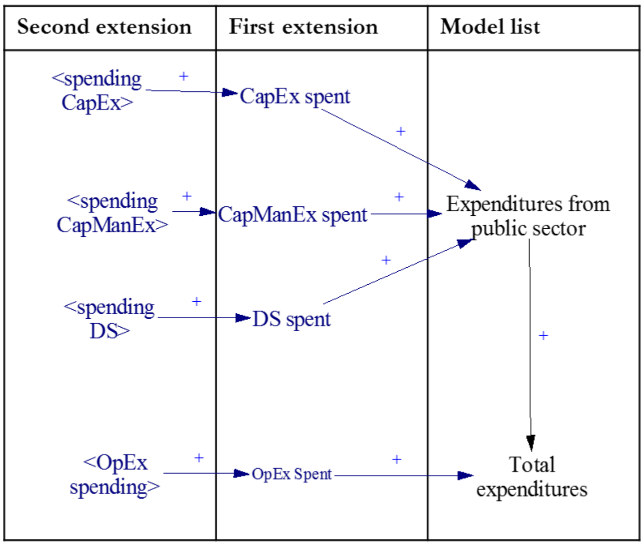


Figure 65 List extension method for the key performance indicators: financial costs

13 Appendix 4. Verification interview

Model testing consists in verifying and validating a model by undertaking different tests. Verification checks that the model was coded correctly, that it is dimensionally consistent and that an appropriate numerical integration method with a correct time step has been chosen. Validation aims at building confidence in the model. As part of the verification process, an interview an interview was conducted with a system dynamics expert. The objective of this interview was to identify areas of improvement in the model, including choice of numerical method and time step. Feedback from this interview was incorporated into the final model.

The appendix motivates the use of an interview to verify the model, describes the interview's design and implementation, as well as the data process and analysis.

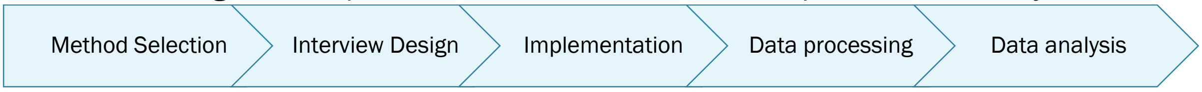


Figure 66 Key steps in the realization of the interview process for the verification interview

13.1 Selecting a type of interview

An interview was the preferred data collection method for four main reasons. First, interviews enable a discussion on the model. Second, interview and interviewer can request clarification of concepts. Third, interviews make possible a more direct rapport between interviewee and interviewer.

Finally, from the three main types of interviews (structured, semi-structured and open), an open interview was selected. In an open interview, the conversation between the interviewer and interviewee is free and does not have to obey guidelines. Thus, unexpected yet relevant details can be discussed freely.

13.2 Designing the interview

The interview consisted in three main parts. In the first part, the interviewer welcomed the interviewee, explained the objective of the interview, asked for permission to record the audio of the meeting, and explained the structure of the interview.

In the second part, the interviewer introduced her research and explained the role of the interview in the process. Moreover, the interviewee was provided with the complete documentation of the quantitative system dynamics model. She was asked to identify warning signs that may suggest flaws in the model formulation, and to make any additional comments that might be useful for the verification process.

Finally, the interviewee provided feedback on the model and made suggestions for its improvement.

13.3 Conducting the interview

A system dynamic expert from TU Delft's faculty of Technology, Policy and Management was selected as interviewee. She was contacted via e-mail to to request a one-hour appointment. The appointment was scheduled at her office, a quiet location that allowed to record of the audio of the interview. Table 8 presents a brief professional biography of the interviewee, while Table 11 specifies the date, place and duration of each interview.

Table 87 Interviewee's brief professional biography

Interviewee	Brief professional biography
C. Els van Daalen	"Associate Professor at the Policy Analysis section of the Faculty of Technology, Policy and Management of Delft University of Technology (TU Delft) in the Netherlands. After obtaining her PhD in mechanical engineering on the topic of validation of knowledge based systems, she joined the faculty of Technology, Policy and Management in 1994. She is involved in both teaching and research in the area of methods for systems analysis and systems engineering. Specific methods of interest are System Dynamics and serious gaming. She has published on methodological issues as well as on applications of these methods." (Delft University of Technology, 2016)

Table 88 Date, place and duration of the verification interview

Interviewee	Date and time	Place	Duration
C. Els van Daalen	2016. June 3 10:00h	Room B2.230. Faculty of Technology, Policy and Management. Delft University of Technology. Delft, The Netherlands	50 minutes

13.4 Processing the data

In order to process the data of the interview, the interviewers played the recording of the interview and made a summary of the relevant discussion points.

13.5 Analyzing the Data

Based on the summary of the relevant discussion points, necessary actions to modify the model were identified. Both, discussion points and necessary action, are summarized in Table 89.

Table 89 Date, place and duration of the initial interviews (Part A)

Discussion point	Explanation	Necessary action
Units with dimensionless variables are 25% of the model. Is this necessary?	Sub-system 3 represents social information, which is conceptualized as percentages that are dimensionless.	Check that dimensionless variables represent a real situation and can be explained.
Is the time step appropriate?	An inappropriate choice of time step can change the behavior of the model.	Check the choice of time step by simulating the model with smaller time steps.
Variables with embedded data	Variables with embedded data indicate that some numbers are introduced in an equations, which could be entered as variables instead. There is a tension between transparency of the model (no embedded data) and level of detail that the model should display.	Check variables with embedded data and decide whether those numbers will transformed into variables.

Table 90 Date, place and duration of the initial interviews (Part B)

Discussion point	Explanation	Necessary action
Lookup functions ending in slope	It is unusual for lookup functions to end in a slope.	Verify whether there is a real situation in which this lookup holds.
IF THEN ELSE formulations.	In a continuous model, it is convenient to avoid discrete shocks, such as IF THEN ELSE functions.	Identify opportunities to model the same phenomena from a continuous perspective.
Complex variables	Equations with more than 3 variables in their expression can be difficult to understand.	Check the convenience of splitting these equations through the use of additional intermediate variables.
Annual allocation is entered at the beginning of the year.	A discrete shock can complicate the solving and interpretation of a continuous model.	Check whether it is possible to model this phenomena from a discrete perspective.
Model integrates phenomena with very different time frames.	Is it necessary to include phenomena that have a small time frame? Perhaps their actual effect is not significant.	Elements with different time frames were intentionally included to test their actual effects and discuss issues of scale.
Is the use of noise necessary for the model?	In a continuous model, noise may not have a significant effect in the long term, but it is worth testing.	Again, noise was included for communication purposes.

14 Appendix 5. Model Testing

Model testing consists in verifying and validating a model by undertaking different tests. Verification checks that the model was coded correctly, that it is dimensionally consistent and that an appropriate numerical integration method with a correct time step has been chosen. Validation aims at building confidence in the model. Within the two types of validation (direct structure tests and structure-oriented behavior tests), this chapter addresses sensitivity analysis.

Sensitivity analysis is a test that identifies the elements in the model to which the model itself is sensitive. The results of this test are then used to gain insights on the parameters in the model that require higher levels of accuracy, and on the parameters that can be used to design interventions in the system.

To conduct sensitivity analysis, the model was parameterized with the values from . was conducted in a semi-automated manner in the software Vensim DSS®, using the tool for Monte Carlo simulation with Latin Hypercube, with a random uniform distribution. For each relevant parameter in the model, the model was resolved 100 times, in other words, 100 simulation runs were conducted for each parameter. During each of this different runs, the parameter under study was given a different value, within a range of plausible values. To measure the effect that each of these changes had on the model behavior, the values of the key performance indicators were recorded (KPI). Then, the values of the 100 simulation runs were plotted in seven graphs: one for each KPI. The graphs present the sensitivities as confidence bounds or areas in the plot indicating the values that the KPI of a certain percentage of the simulation runs had. In the graphs, the yellow area indicates that 50% of the simulation runs produced values in that area, for a given time; green indicates 75%; blue 95% and grey 100%.

The first section in this Appendix presents the plots with results of the sensitivity analysis for each sub-system. Then, the second section analyzes these results.

14.1 Sensitivity plots

14.1.1 Sub-system 1: physical infrastructure

Table 91 Testing of Sub-system 1 (Part A)

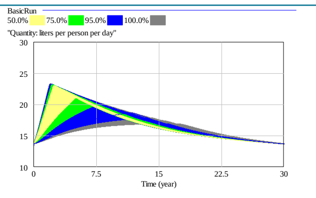
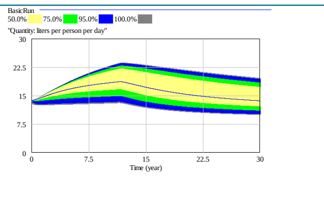
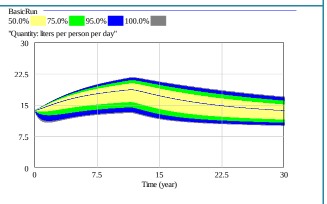
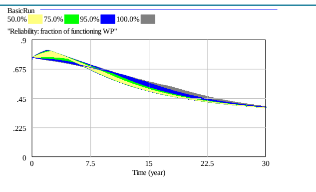
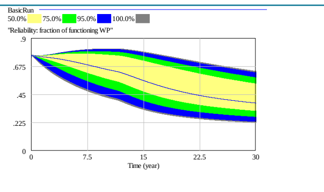
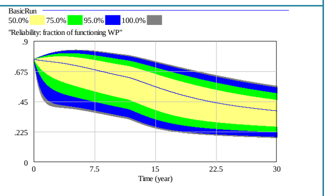
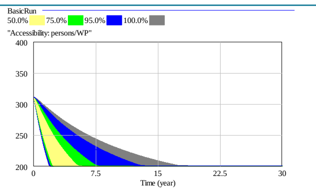
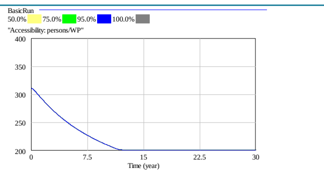
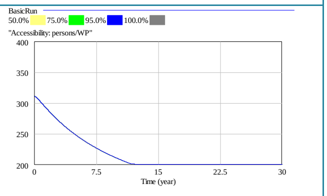
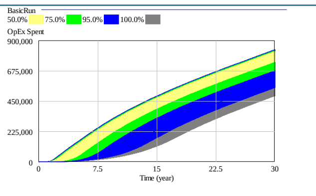
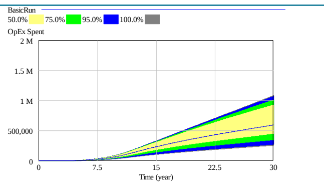
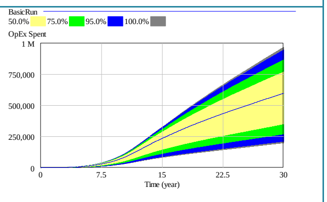
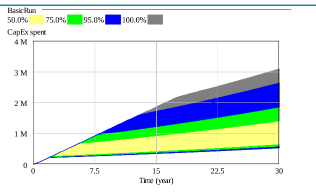
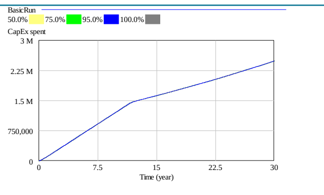
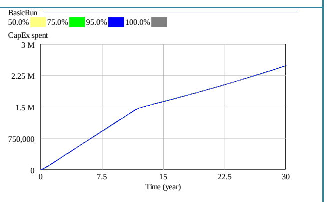
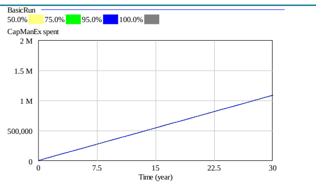
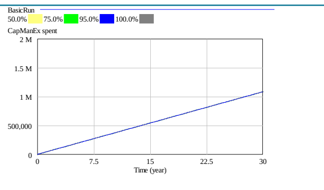
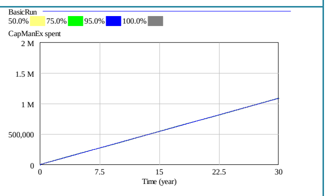
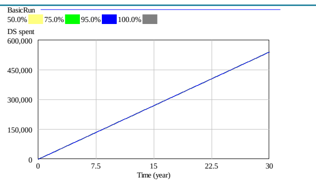
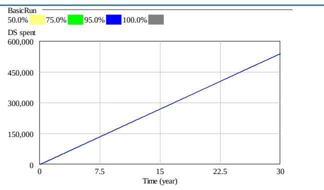
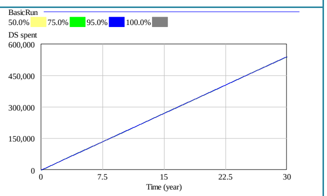
Parameter	ratio from charities to public sector	max new lifespan	max older lifespan
Units	dimensionless	years	years
Minimum plausible	0	0.1	1
Maximum plausible	5	10	10
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 92 Testing of Sub-system 1 (Part B)

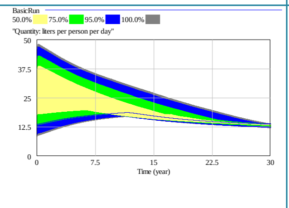
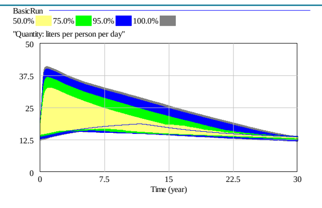
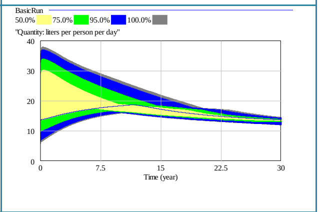
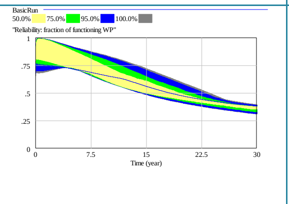
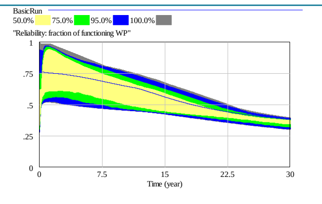
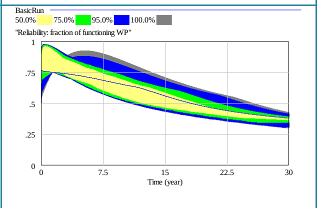
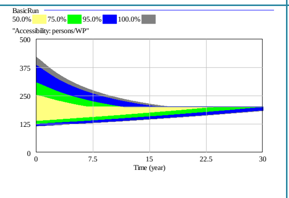
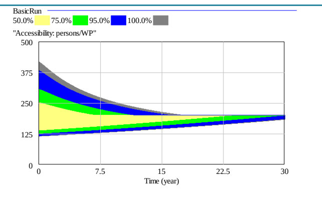
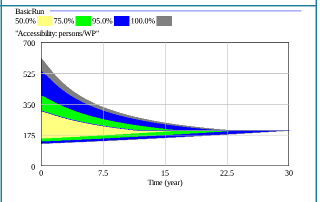
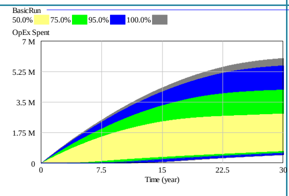
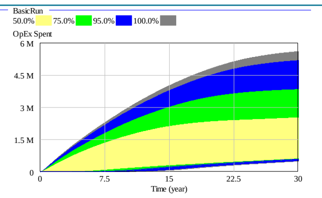
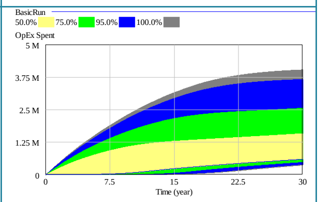
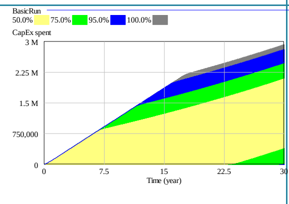
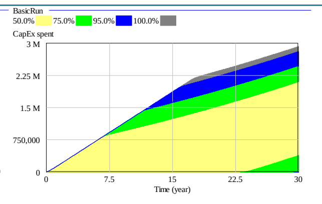
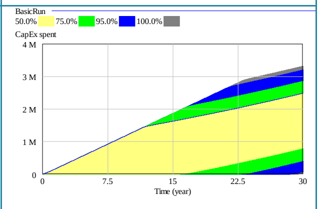
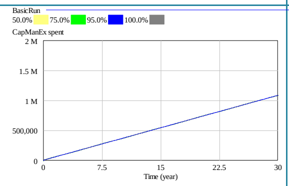
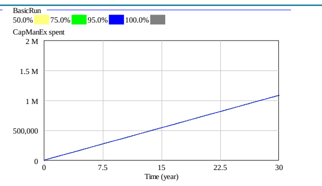
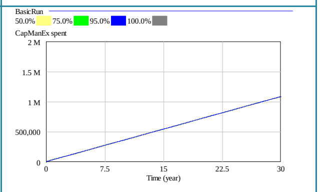
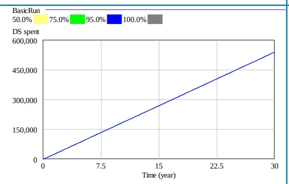
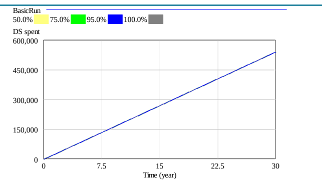
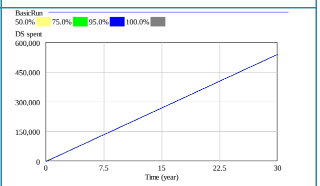
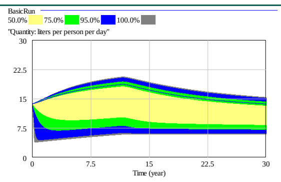
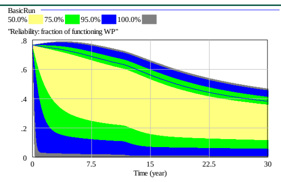
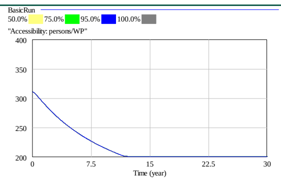
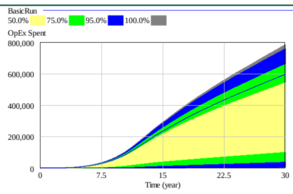
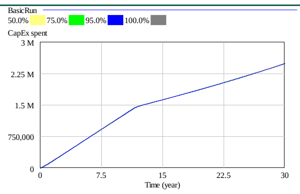
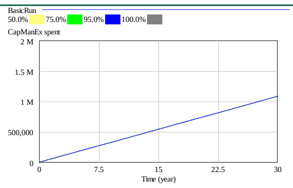
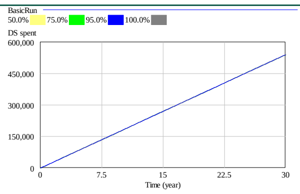
Parameter	Initial new WP	Initial failed WP	Initial older WP
Units	Water points	Water points	Water points
Minimum plausible	0	0	0
Maximum plausible	2000	2000	2000
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 93 Testing of Sub-system 1 (Part C)

Parameter	OpEx effect on lifespan
Units	dimensionless
Minimum plausible	0
Maximum plausible	1
Sensitivity plot: Quantity	
Sensitivity plot: Reliability	
Sensitivity plot: Accessibility (persons per water point)	
Sensitivity plot: OpEx Spent	
Sensitivity plot: CapEx Spent	
Sensitivity plot: CapManEx Spent	
Sensitivity plot: DS Spent	

14.1.2 Sub-system 2: Demand and need

Table 94 Testing of Sub-system 2 (Part A)

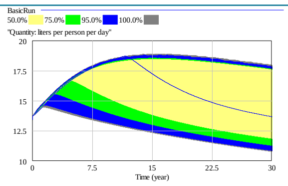
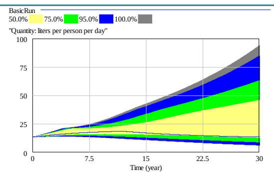
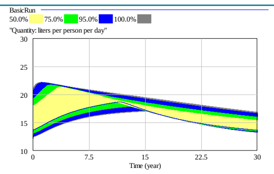
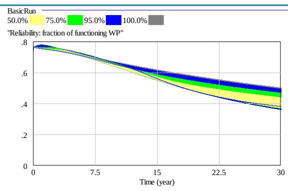
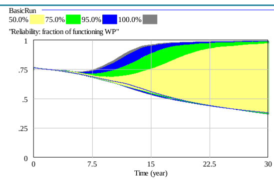
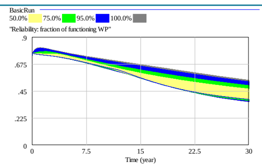
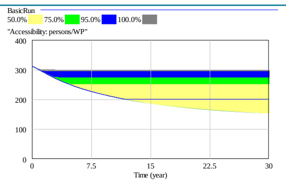
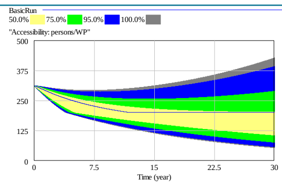
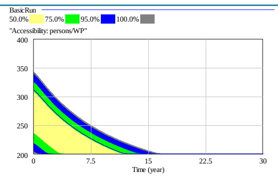
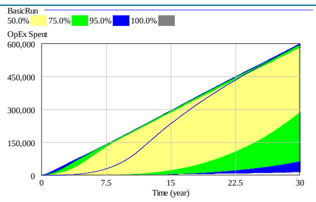
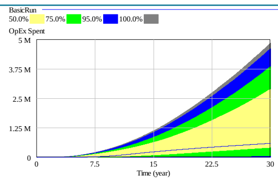
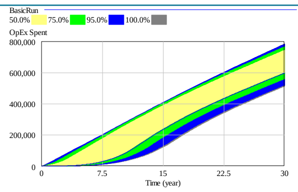
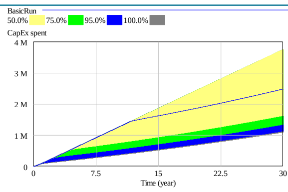
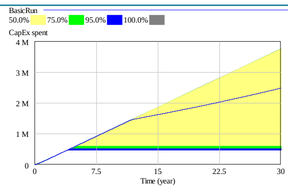
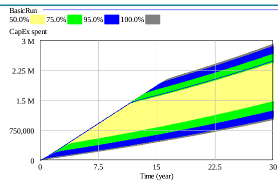
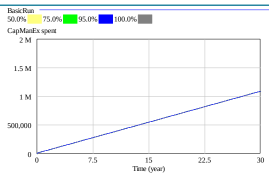
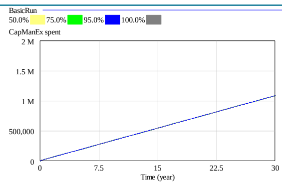
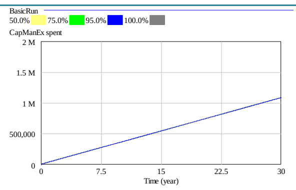
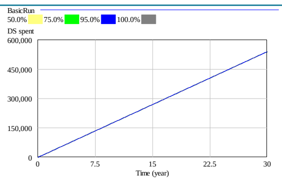
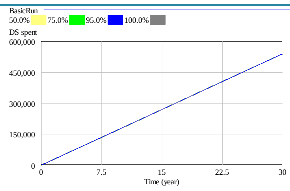
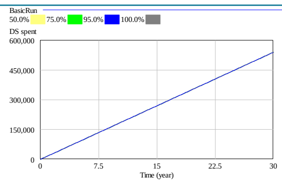
Parameter	Accessibility target: persons/water point	annual net population growth rate	fraction of the population served by water points
Units	Persons/water point	Dimensionless/year	Dimensionless
Minimum plausible	100	-5%	0.5
Maximum plausible	300	5%	0.85
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 95 Testing of Sub-system 2 (Part B)

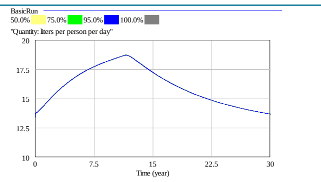
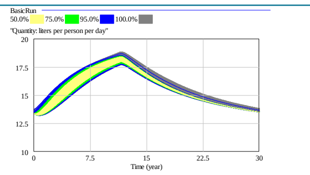
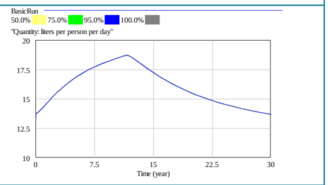
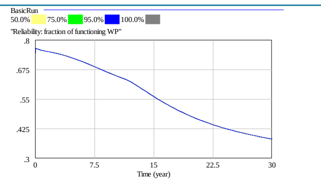
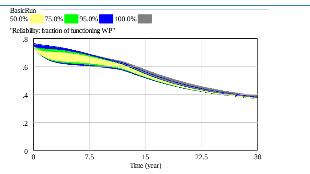
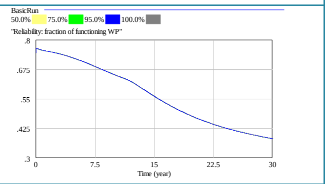
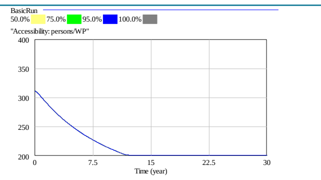
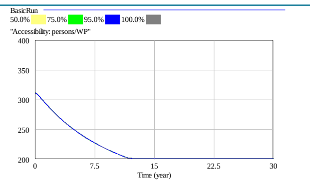
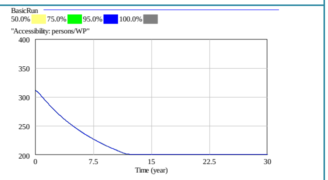
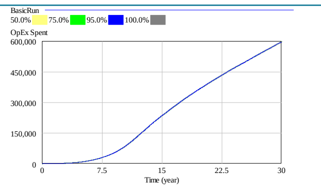
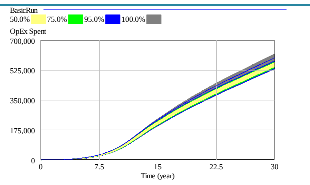
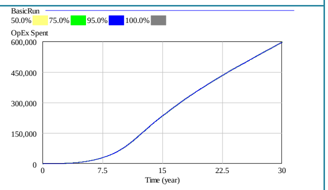
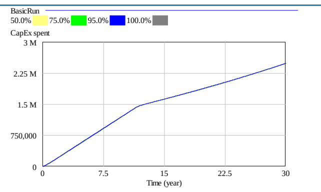
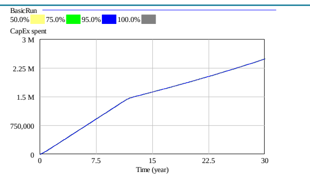
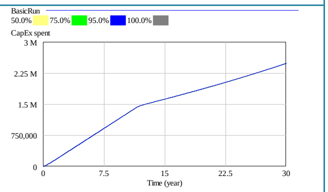
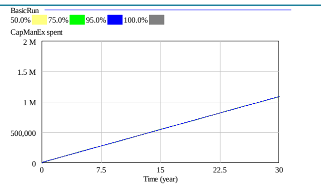
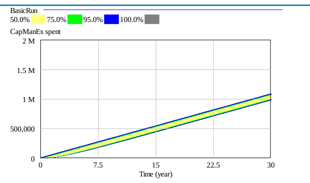
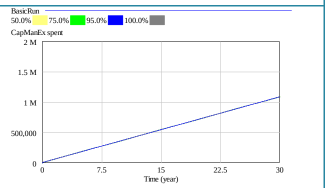
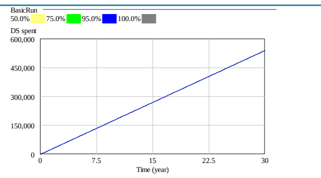
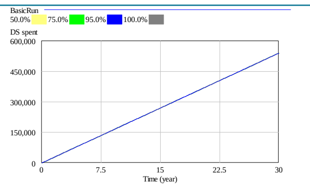
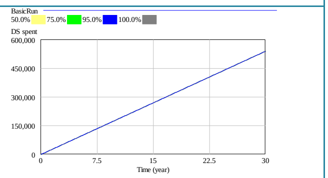
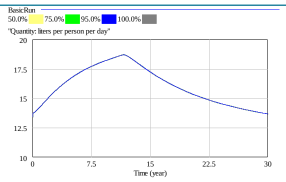
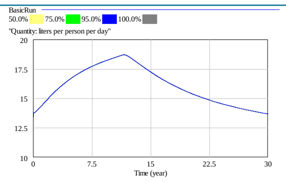
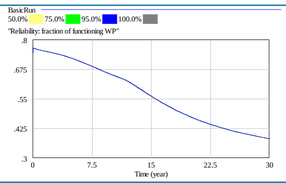
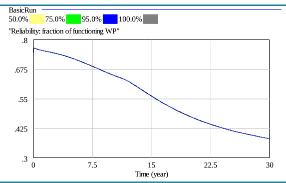
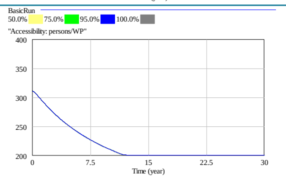
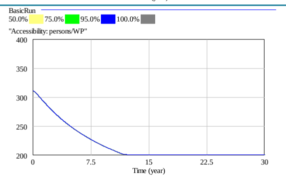
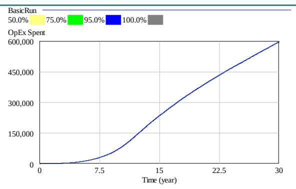
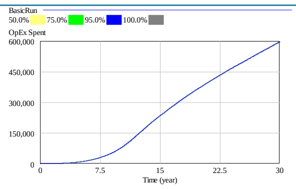
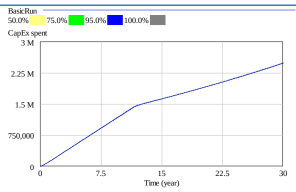
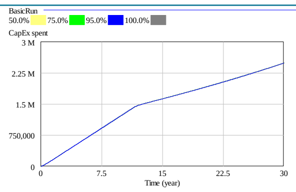
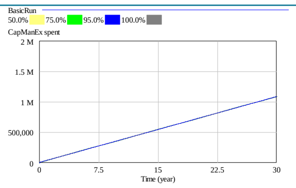
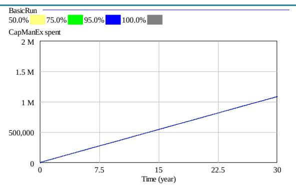
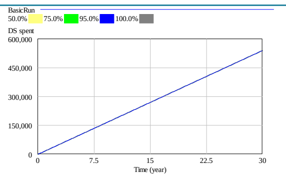
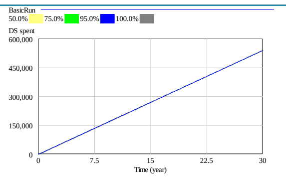
Parameter	standard time to file a CapManEx request	time to repair a WP	CapManEx capacity
Units	Years	Years	Dimensionless
Minimum plausible	0.01	0.01	1
Maximum plausible	0.5	3	100
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 96 Testing of Sub-system 2 (Part C)

Parameter	Technical solutions?	Initial CapManEx demand (ratio)
Units	Years	Dimensionless
Minimum plausible	0	0
Maximum plausible	1	1
Sensitivity plot: Quantity		
Sensitivity plot: Reliability		
Sensitivity plot: Accessibility (persons per water point)		
Sensitivity plot: OpEx Spent		
Sensitivity plot: CapEx Spent		
Sensitivity plot: CapManEx Spent		
Sensitivity plot: DS Spent		

14.1.3 Sub-system 3: management and participation

Table 97 Testing of Sub-system 3 (Part A)

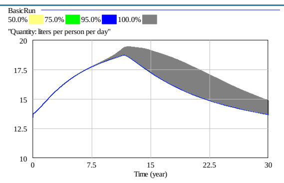
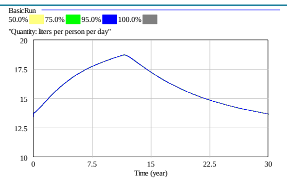
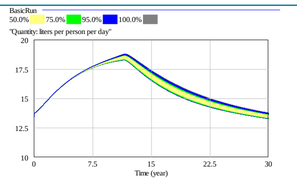
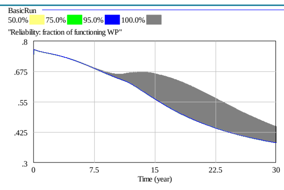
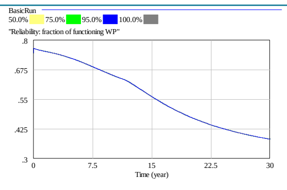
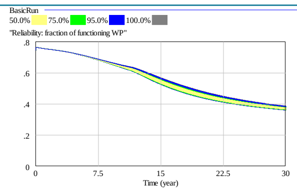
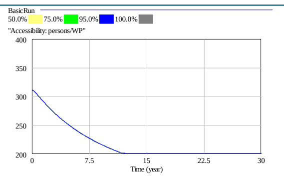
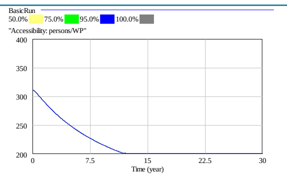
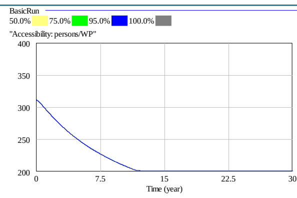
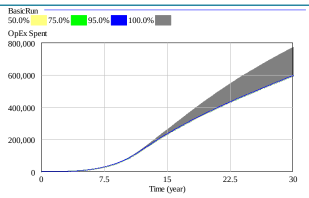
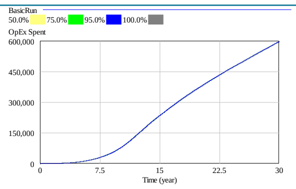
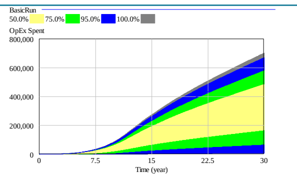
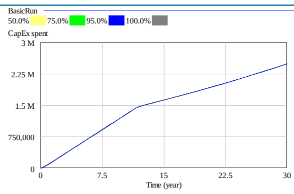
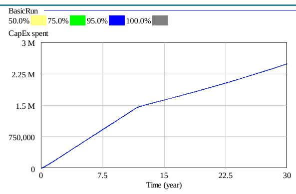
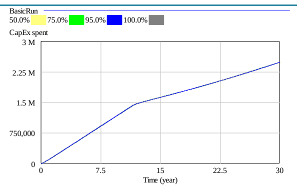
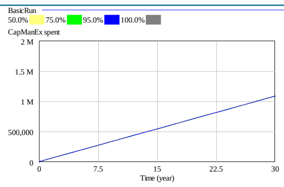
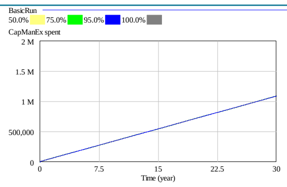
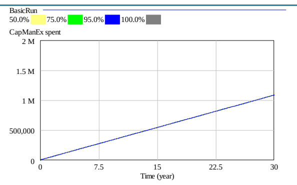
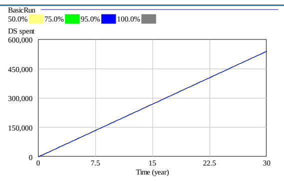
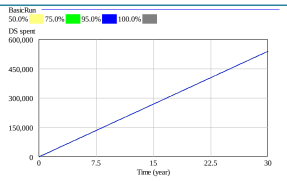
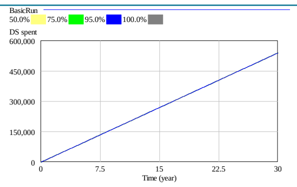
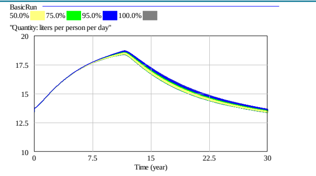
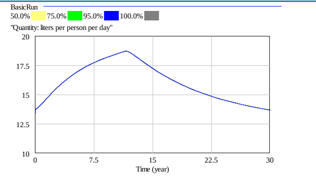
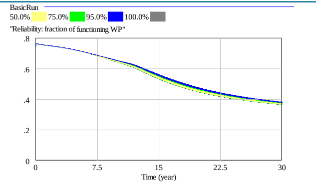
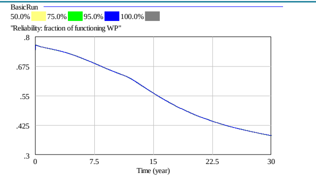
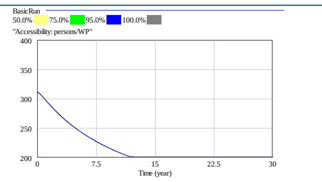
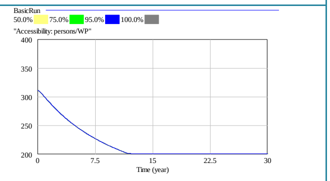
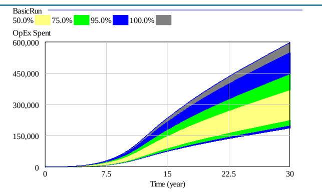
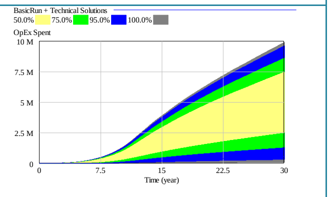
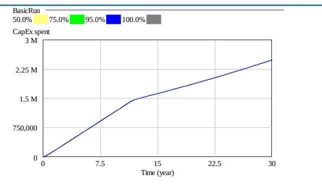
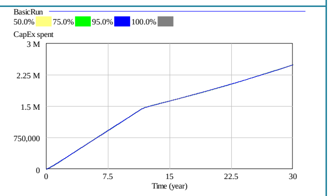
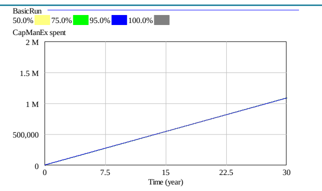
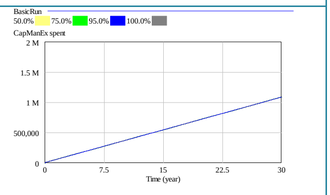
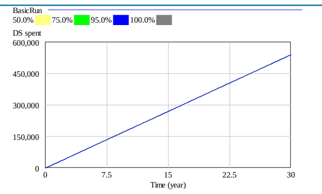
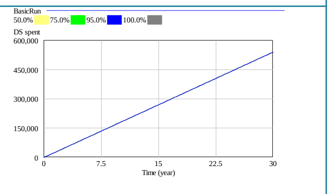
Parameter	delay of involvement	management's expiration time	population with a secondary source
Units	years	years	Dimensionless
Minimum plausible	0.01	0.25	0
Maximum plausible	3/12	2	1
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 98 Testing of Sub-system 3 (Part B)

Parameter	quantity target	cost of operation and minor maintenance
Units	Liters/person*water point	USD/water point (each operation)
Minimum plausible	20	0
Maximum plausible	60	100
Sensitivity plot: Quantity		
Sensitivity plot: Reliability		
Sensitivity plot: Accessibility (persons per water point)		
Sensitivity plot: OpEx Spent		
Sensitivity plot: CapEx Spent		
Sensitivity plot: CapManEx Spent		
Sensitivity plot: DS Spent		

14.1.4 Sub-system 4 and 5: budget and allocation and execution

Table 99 Testing of Sub-system 4 and 5 (Part A)

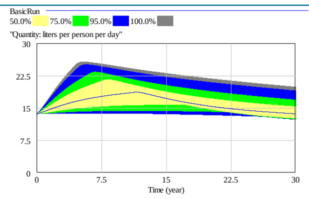
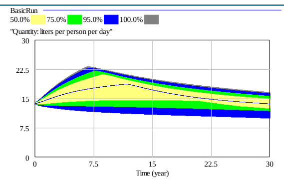
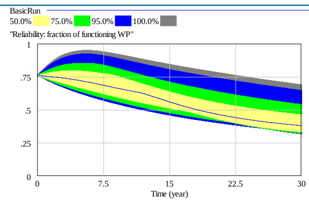
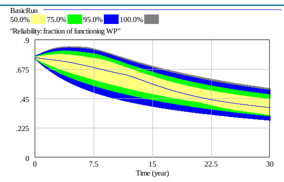
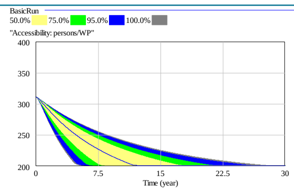
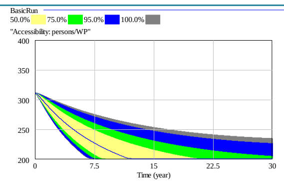
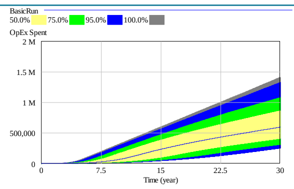
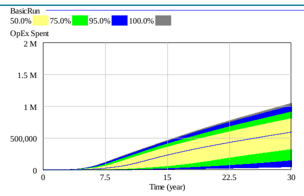
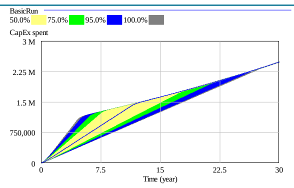
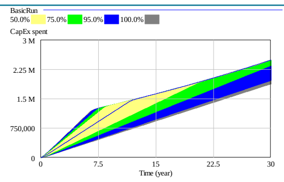
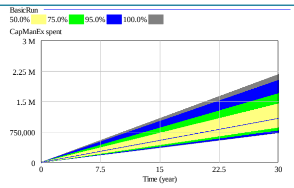
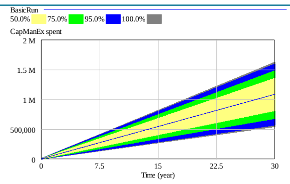
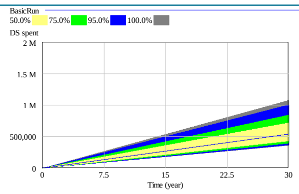
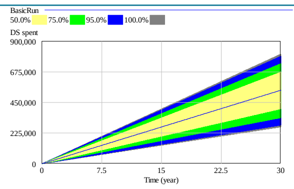
Parameter	return period of the allocation	public periodic allocation
Units	years	USD
Minimum plausible	0.5	90,000
Maximum plausible	1.5	270,000
Sensitivity plot: Quantity		
Sensitivity plot: Reliability		
Sensitivity plot: Accessibility (persons per water point)		
Sensitivity plot: OpEx Spent		
Sensitivity plot: CapEx Spent		
Sensitivity plot: CapManEx Spent		
Sensitivity plot: DS spent		

Table 100 Testing of Sub-system 4 and 5 (Part B)

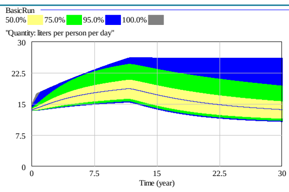
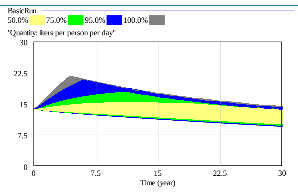
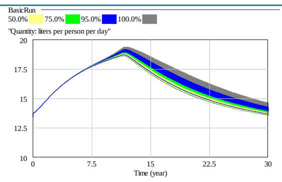
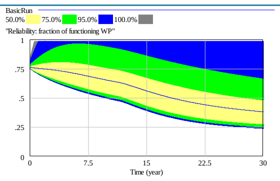
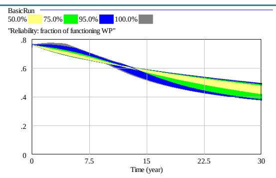
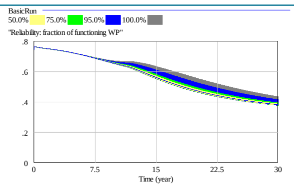
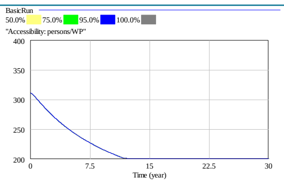
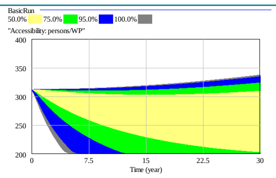
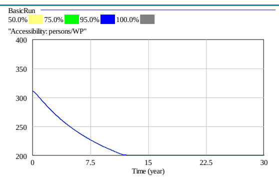
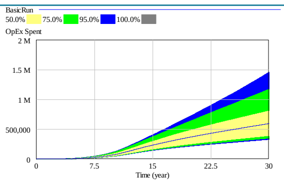
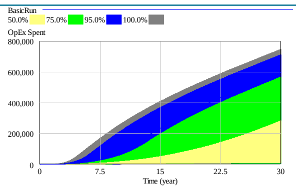
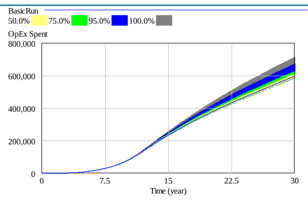
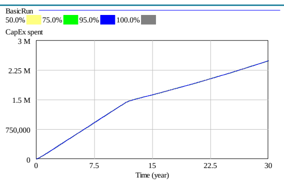
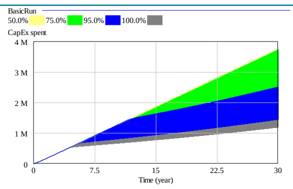
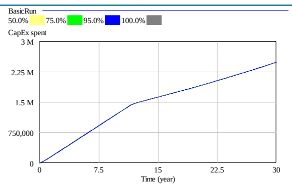
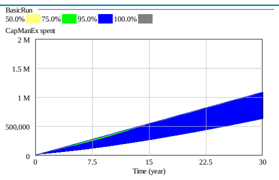
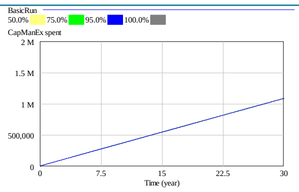
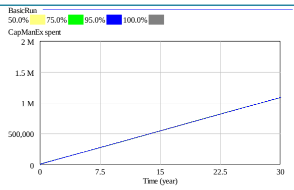
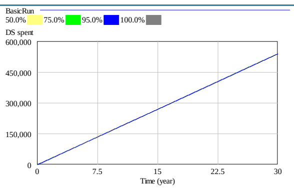
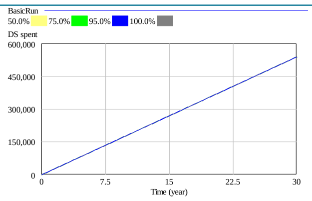
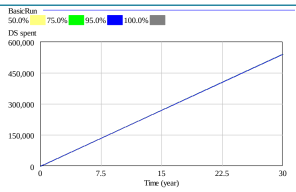
Parameter	average cost of a CapManEx event	average cost of a CapEx event	average cost of a DS event
Units	USD	USD	USD
Minimum plausible	100	1000	100
Maximum plausible	1000	10000	1000
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 101 Testing of Sub-system 4 and 5 (Part C)

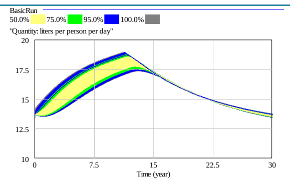
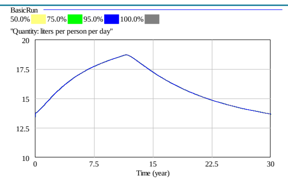
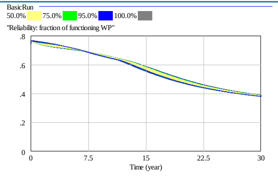
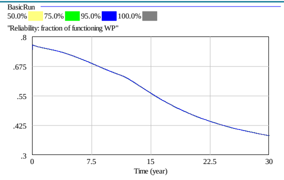
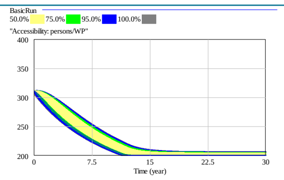
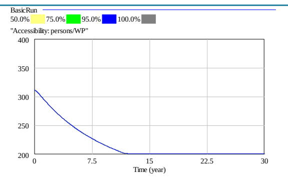
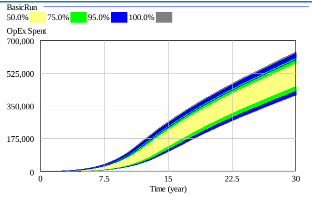
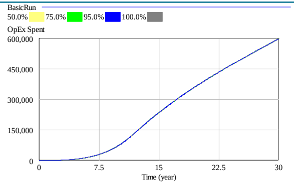
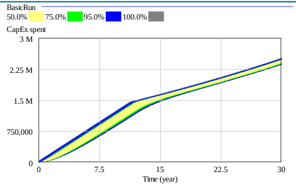
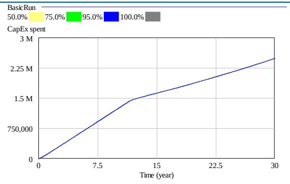
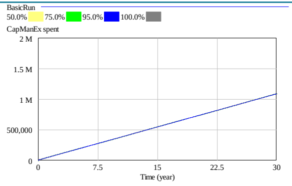
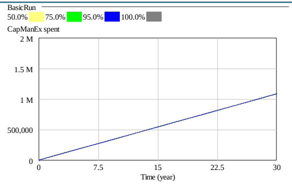
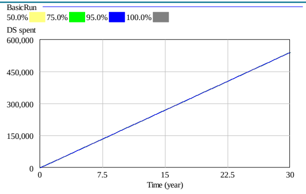
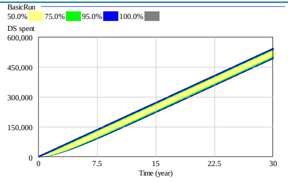
Parameter	average time to execute a CapEx event	time to execute a DS event
Units	years	years
Minimum plausible	0.01	0.01
Maximum plausible	3	3
Sensitivity plot: Quantity		
Sensitivity plot: Reliability		
Sensitivity plot: Accessibility (persons per water point)		
Sensitivity plot: OpEx Spent		
Sensitivity plot: CapEx Spent		
Sensitivity plot: CapManEx Spent		
Sensitivity plot: DS Spent		

Table 102 Testing of Sub-system 4 and 5 (Part D)

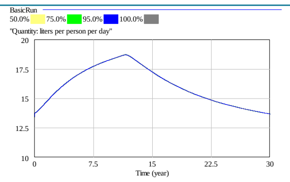
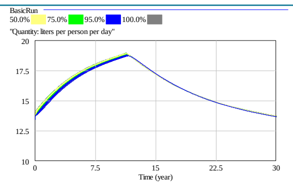
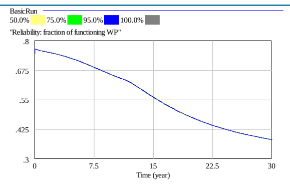
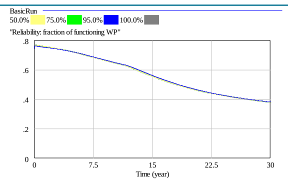
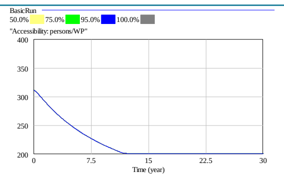
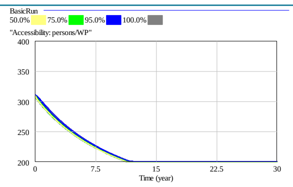
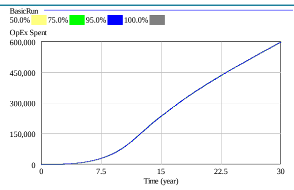
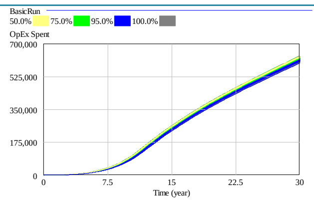
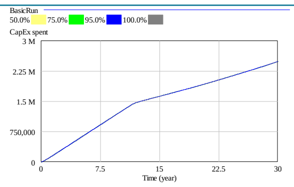
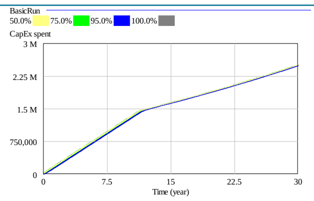
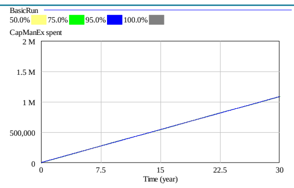
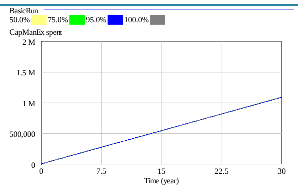
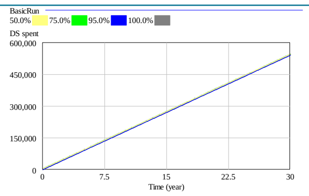
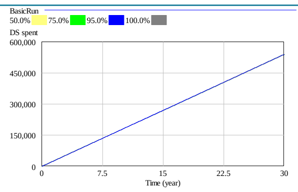
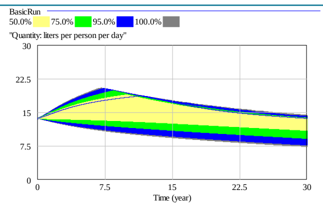
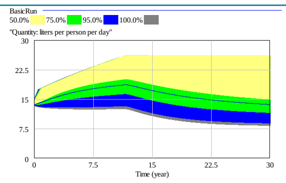
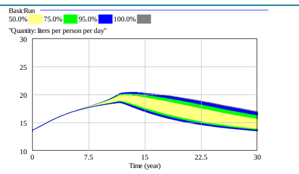
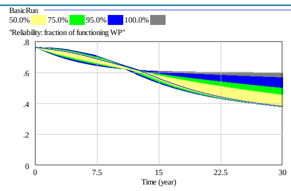
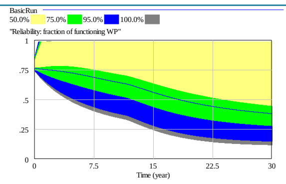
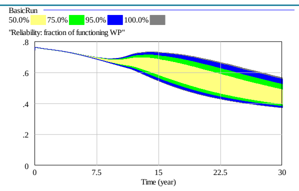
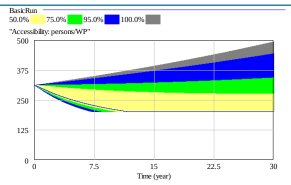
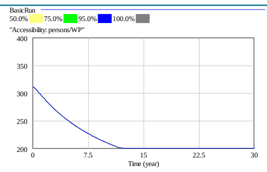
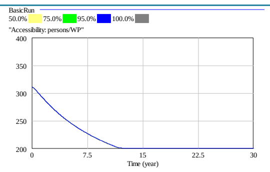
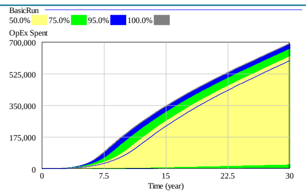
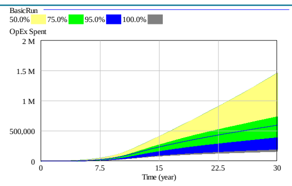
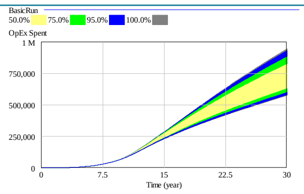
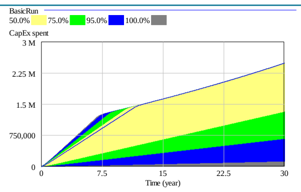
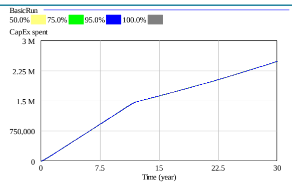
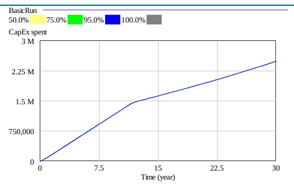
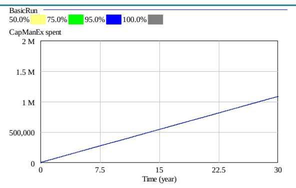
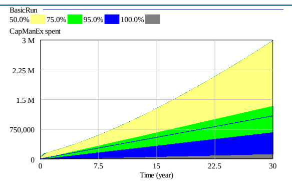
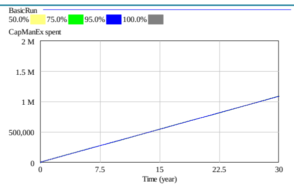
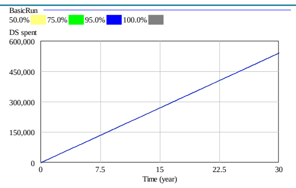
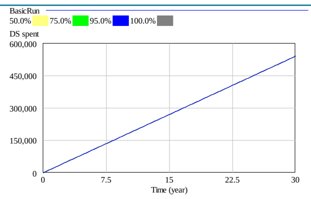
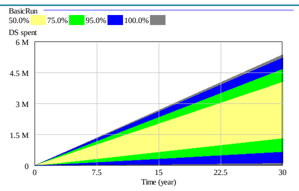
Parameter	DS Capacity	CapEx capacity
Units	Dimensionless	Dimensionless
Minimum plausible	1	1
Maximum plausible	10	10
Sensitivity plot: Quantity		
Sensitivity plot: Reliability		
Sensitivity plot: Accessibility (persons per water point)		
Sensitivity plot: OpEx Spent		
Sensitivity plot: CapEx Spent		
Sensitivity plot: CapManEx Spent		
Sensitivity plot: DS Spent		

Table 103 Testing of Sub-system 4 and 5 (Part E)

Parameter	Allocation ratio CapEx	Allocation ratio CapManEx	Allocation ratio DS
Units	Dimensionless	Dimensionless	Dimensionless
Minimum plausible	0	0	0
Maximum plausible	1	1	1
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

14.1.5 Key performance indicators

Table 104 Testing the key performance indicators (Part A)

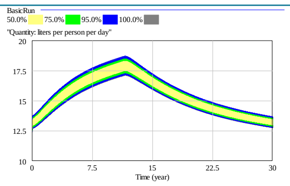
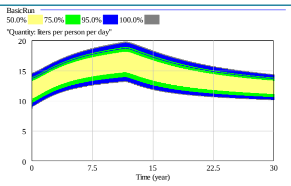
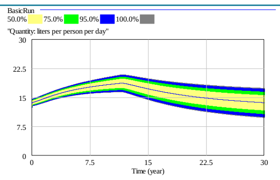
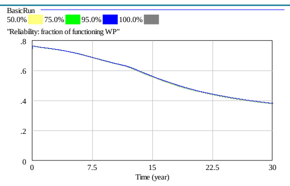
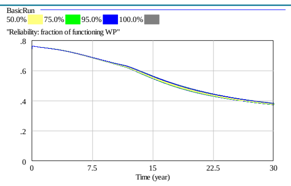
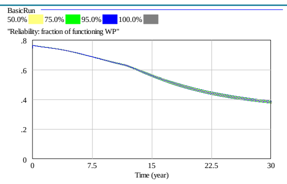
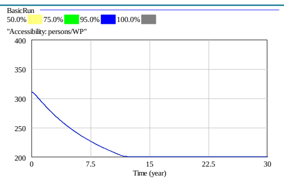
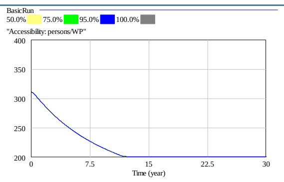
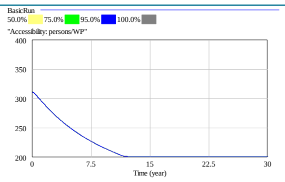
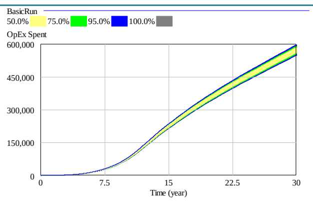
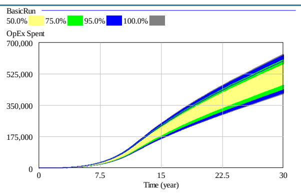
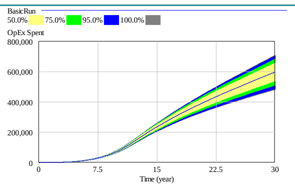
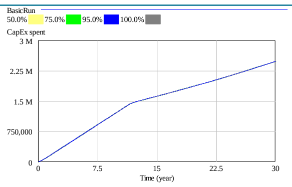
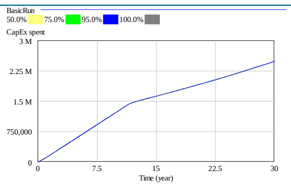
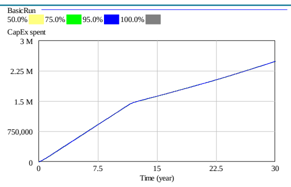
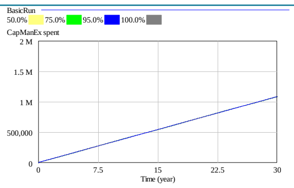
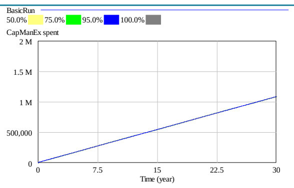
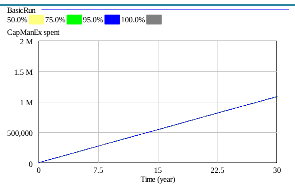
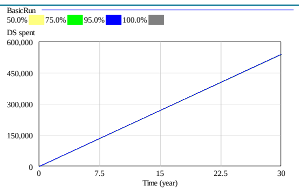
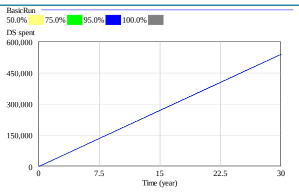
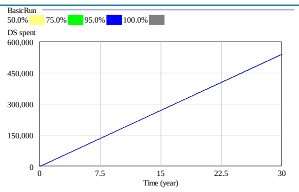
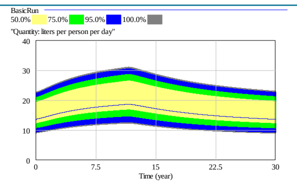
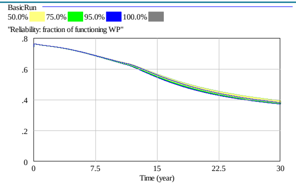
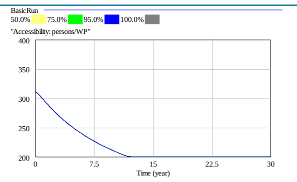
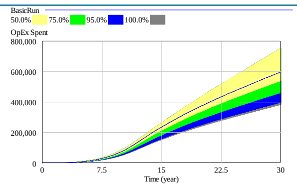
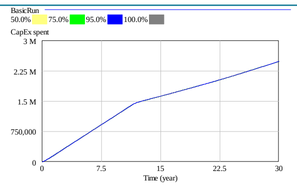
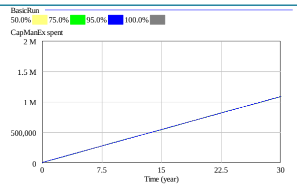
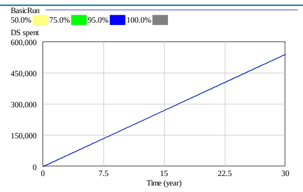
Parameter	new WPs performance	older WPs performance	failed WPs performance
Units	Dimensionless	Dimensionless	Dimensionless
Minimum plausible	0.80	0.30	0
Maximum plausible	1	0.90	0.4
Sensitivity plot: Quantity			
Sensitivity plot: Reliability			
Sensitivity plot: Accessibility (persons per water point)			
Sensitivity plot: OpEx Spent			
Sensitivity plot: CapEx Spent			
Sensitivity plot: CapManEx Spent			
Sensitivity plot: DS Spent			

Table 105 Testing the key performance indicators (Part B)

Parameter	standard liters per day per water point
Units	Liters per person per water point
Minimum plausible	4000
Maximum plausible	10000
Sensitivity plot: Quantity	
Sensitivity plot: Reliability	
Sensitivity plot: Accessibility (persons per water point)	
Sensitivity plot: OpEx Spent	
Sensitivity plot: CapEx Spent	
Sensitivity plot: CapManEx Spent	
Sensitivity plot: DS Spent	

14.2 Interpretation of the sensitivity plots

14.2.1 Sub-system 1

Ratio from charities to public sector and the lifespan of water points influence water service levels in a numerical manner. The number of water points donated by charities increases the quality, reliability and accessibility. The influence of these changes occurs within the first 10 years of the simulation, which can be interpreted as the provision of first-time access to water services. However, in a longer term, this variable does not change the behavior of the system: quantity stabilizes at a similar level, reliability continues to drop, and accessibility is not modified (when all water points, including non-functional ones, are considered). A similar effect is caused by the maximum lifespan of a new water point and an older water point on the quantity, reliability, and OpEx spent, all of which are modified numerically. DS spent and CapManEx spent remain without major numerical changes, while CapEx spent is modified by the number of water points donated by charities.

In contrast, the OpEx effect in lifespan has behavioral influence on the quantity and reliability of the system, and on the funding spent in operation and maintenance. The same occurs with the initial state of the system regarding the number of water points (initial new WP, initial older WP, initial failed WP).

Table 106 Sensitivity of key performance indicators to parameters of Sub-System 1

Parameter	Key performance indicator						
	Quantity	Reliability	Accessibility	OpEx spent	CapEx spent	CapManEx spent	DS spent
ratio from charities to public sector	Numerical	Numerical	Numerical	Numerical	Numerical	NA	NA
max new lifespan	Numerical	Numerical	NA	Numerical	NA	NA	NA
Initial new WP	Behavioral	Numerical	Behavioral	Numerical	Numerical	NA	NA
Initial failed WP	Behavioral	Numerical	Behavioral	Numerical	Numerical	NA	NA
Initial older WP	Behavioral	Numerical	Behavioral	Numerical	Numerical	NA	NA
max older lifespan	Numerical	Numerical	NA	Numerical	NA	NA	NA
OpEx effect on lifespan	Behavioral	Behavioral	NA	Behavioral	NA	NA	NA

14.2.2 Sub-system 2

The target set for accessibility is the maximum number of persons that should access a water point. It is used to determine the number of new water points that should be installed, which influences the quantity of liters accessed per person every day (Table 107). It also produces behavioral changes in the funding spent in operation and maintenance. This effect was relatively unexpected, and could be attributed to higher collection of fees from users caused by higher satisfaction of the services received, when a large number of water points is built.

A second influential variable is the annual net population growth rate. This variable, along with the fraction of the population served by water points, determines the persons which water services come from water points. Therefore, increases and decreases in the annual net population growth rate lead to radical changes in the quantity of water enjoyed by users and on the number of users who are served by the water point. Moreover, it influences the funding that is spent in operation and maintenance, possible through its previous influence on quantity and accessibility. The influence of this variable on the water service levels is behavioral, as well as on the funding for operation and maintenance that is spent.

Table 107 Sensitivity of key performance indicators to parameters of Sub-System 2

Parameter	Key performance indicator						
	Quantity	Reliability	Accessibility	OpEx spent	CapEx spent	CapManEx spent	DS spent
Accessibility target: persons/water point	Behavioral	Numerical	Numerical	Behavioral	Numerical	NA	NA
annual net population growth rate	Behavioral	Behavioral	Behavioral	Behavioral	Numerical	NA	NA
fraction of the population served by water points	Numerical	Numerical	Numerical	Numerical	Numerical	NA	NA
standard time to file a CapManEx request	NA	NA	NA	NA	NA	NA	NA
time to repair a WP	Numerical	Numerical	NA	Numerical	NA	Numerical	NA
CapManEx capacity	NA	NA	NA	NA	NA	NA	NA

14.2.3 Sub-system 3

Few variables from the sub-system of management and participation influence the key performance indicators (Table 108). This finding is consistent with discussions held during the interviews, where interviewees explained that the system is not driven by demand. Instead, demand exists and execution is constrained by resources and capacity. From this sub-system, the only two variables with strong influence on the system are the population with a secondary source and the quantity target. The former is an external factor and the latter is a target set by authorities as the ideal liters to be provided to each user every day.

14.2.4 Sub-system 4 and 5

While the key performance indicators are sensitive to most variables, only three variables have behavioral effects on accessibility, funding spent in operation and maintenance, and reliability (Table 109). These variables are the average cost of a CapEx event, allocation ratio CapEx, and allocation ratio CapManEx, respectively. Once again, these findings indicate that the system is constraint by financial resources, and the distribution of funding as a greater effect than a bigger budget alone.

Table 108 Sensitivity of key performance indicators to parameters of Sub-System 3 (management and participation)

Parameter	Key performance indicator						
	Quantity	Reliability	Accessibility	OpEx spent	CapEx spent	CapManEx spent	DS spent
delay of involvement	Numerical	Numerical	NA	Numerical	NA	NA	NA
management's expiration time	NA	NA	NA	NA	NA	NA	NA
population with a secondary source	NA	NA	NA	Numerical	NA	NA	NA
quantity target	Numerical	Numerical	NA	Numerical	NA	NA	NA
cost of operation and maintenance	NA	NA	NA	Numerical	NA	NA	NA

Table 109 Sensitivity of key performance indicators to parameters of Sub-System 4 and 5 (available budget and portfolio allocation)

Parameter	Key performance indicator						
	Quantity	Reliability	Accessibility	OpEx spent	CapEx spent	CapManEx spent	DS spent
return period of the allocation	Numerical	Numerical	Numerical	Numerical	Numerical	Numerical	Numerical
public periodic allocation	Numerical	Numerical	Numerical	Numerical	Numerical	Numerical	Numerical
average cost of a CapManEx event	Numerical	Numerical	NA	Numerical	NA	Numerical	NA
average cost of a CapEx event	Numerical	Numerical	Behavioral	Numerical	Numerical	NA	NA
average cost of a DS event	Numerical	Numerical	NA	Numerical	NA	NA	NA
average time to execute a CapEx event	Numerical	Numerical	Numerical	Numerical	Numerical	NA	NA
time to execute a DS event	NA	NA	NA	NA	NA	NA	Numerical
DS Capacity	NA	NA	NA	NA	NA	NA	Numerical
CapEx capacity	Numerical	NA	Numerical	Numerical	Numerical	NA	NA
Allocation ratio CapEx	Behavioral	Behavioral	Behavioral	Behavioral	Numerical	NA	NA
Allocation ratio CapManEx	Behavioral	Behavioral	NA	Numerical	NA	Numerical	NA
Allocation ratio DS	Numerical	Numerical	NA	Numerical	NA	NA	Numerical

14.2.5 Key performance indicators

The parameters use to calculate the water liters received per person every day only have numerical influence in the model results (Table 110).

Table 110 Sensitivity of key performance indicators to parameters in their calculation

Parameter	Key performance indicator						
	Quantity	Reliability	Accessibility	OpEx spent	CapEx spent	CapManEx spent	DS spent
new WPs performance	Numerical	NA	NA	Numerical	NA	NA	NA
older WPs performance	Numerical	NA	NA	Numerical	NA	NA	NA
failed WPs performance	Numerical	NA	NA	Numerical	NA	NA	NA
standard liters per day per water point	Numerical	NA	NA	Numerical	NA	NA	NA

15 Annex 1 Indirect causes of the lack of funding

Table 111 Social causes of the lack of funding for operation and maintenance of water points, which result in water point failure

Type	Causes
Social	The members of the Water Point Association mistrust the managerial actions of the Water Point Committee (Harvey and Reed, 2007, Jiménez and Pérez-Foguet, 2010, Kamruzzaman et al., 2013, Kleemeier and Narkevic, 2010, Montgomery et al., 2009). Water users do not trust each other. When a user does not know if other users will pay their contributions, he or she is not likely to pay its own contribution (Hanatani and Fuse, 2012). Users tend to pay only when water points break down and need renewal, replacement or rehabilitation (Whittington et al., 2009). The members of the Water Point Committee are not willing to work voluntarily and free of charge, lack training, do not apply their initial training, or change their residence (Harvey and Reed, 2007, Lockwood and Smits, 2011, Quin et al., 2011). The members of the Water Point Committee do not enforce regulations, because enforcing regulations causes local conflicts (Golooba-Mutebi, 2012). The decision of users to participate in the management of the water point may or may not act rationally (Cleaver, 1999). This decision may be driven by differences in individual characteristics and perspectives (Hanatani and Fuse, 2012, Holmes and Scoones, 2001). Water users are more interested in individual and immediate benefits than in collective and long-term ones (Hanatani and Fuse, 2012).

Source: adapted from Van Den Broek and Brown (2015).

Table 112 Historical causes of the lack of funding for operation and maintenance of water points, which result in water point failure

Type	Causes
Historical	General belief, dating back to the state-led era, that water should be free of charge (Jones, 2011, Quin et al., 2011, Whittington et al., 2009). Expectation of external funding by government and NGOs (Jones, 2011, Quin et al., 2011, Whittington et al., 2009). Communities often reject the economization of water and fail to exclude defaulting debtors. While local CBM institutions may manage water resources during normal years, those institutions are sometimes replaced by pre-colonial ones during times of crisis (Van Den Broek and Brown, 2015, Schnegg and Bollig, 2016). Because the design of CBM was promoted and enforced by recent governmental actors, no long standing customs and traditional penalties are in place to support the implementation of this approach (Van Den Broek and Brown, 2015).

Source: adapted from Van Den Broek and Brown (2015).

Table 113 Political causes of the lack of funding for operation and maintenance of water points, which result in water point failure

Type	Causes
Political	Political promises of free water in return for votes (Carter et al., 2010, Quin et al., 2011). Lack of legal and *de facto* authority of Water Point Committees (Harvey, 2007, Lockwood and Smits, 2011).

Source: adapted from Van Den Broek and Brown (2015).

Table 114 Implementation causes of the lack of funding for operation and maintenance of water points, which result in water point failure

Type	Causes
Implementation	Local users are not satisfied with the service that they receive from the water point (Barnes et al., 2014, Bhandari and Grant, 2007, Harvey, 2008, Jiménez and Pérez-Foguet, 2010). Local users are unaware of the need for funding to keep water points functional and sufficient in number (Harvey, 2008). Powerful groups may be overrepresented in the Water Point Association and in the Water Point Committee (Brown, 2013, Van Koppen et al., 2012). Because access to water is a Basic Human Right, the exclusion of users has deep ethical implications and cannot be easily enforced (Bakker, 2003). CBM assumes that after contributing to the construction of a water point, users develop a sense of ownership over the local infrastructure and will be willing to contribute to future expenses. In practice, developing a sense of ownership does not necessarily result in an increase in the willingness to pay (Van Den Broek and Brown, 2015). Some tasks that should be performed by volunteer members of the Water Point Committee are being performed by salaried officials (Van Den Broek and Brown, 2015). Currently, the implementations of CBM relies, at a great extent, on the continuous efforts and presence of NGOs and development partners. However, the effect of their presence and action is ambivalent because it weakens the sense of responsibility that the members of the Water Point Association have over the water point (Van Den Broek and Brown, 2015). Projects do not always include gender perspective (Ramoroka, 2014, Quin et al., 2011). Promises by organizations and development partners involved in the initial phases of CBM projects that water will be free (Carter et al., 2010). Some users expect to obtain services for uses other than drinking water, such as small-scale productive uses. When these services cannot be provided by a water point alone, these users opt out or partially switch to other approaches (Moriarty et al., 2013).

Source: adapted from Van Den Broek and Brown (2015).

Table 115 Geographical causes of the lack of funding for operation and maintenance of water points, which result in water point failure

Type	Causes
Geographical	Access to alternative water sources reduces willingness to pay (Parry-Jones et al., 2001, Hanatani and Fuse, 2012). The group of users that benefit from a water point cannot be accurately delineated. Populations tend to be dispersed and they tend to change their location, which prevents the enforcement of sanctions (Van Den Broek and Brown, 2015, Rivett et al., 2013).

Source: adapted from Van Den Broek and Brown (2015).

16 Annex 2 Parameters for Case Study

Table 116 Sub-system 1

Parameter	Units	Value	Comment	Source
Ratio from public charities to public sector	Dimensionless	0.25		Educated guess. See Appendix 2.
Max new lifespan	Years	10	Estimate for point sources.	Biteete et al. (2013), p10
Max older lifespan	Years	10	Estimate for point sources.	Biteete et al. (2013), p10
OpEx effect on lifespan	Dimensionless	0.25	Estimate for point sources. The lifespan of a water point with ideal maintenance is 20 years, whereas that of a poorly maintained water point is 5 years (25%).	Biteete et al. (2013), p10
Initial failed WP	Water points	352		Biteete et al. (2013), p7
Initial older WP	Water points	478	The total functional water points reported was divided in two, obtaining 478.	Biteete et al. (2013), p7
Initial new WP	Water points	478		Biteete et al. (2013), p7

Table 117 Sub-system 2

Parameter	Units	Value	Comment	Source
Technical solutions?	Dimensionless	1		Educated guess. See Appendix 2.
Standard time to file a CapManEx request	Years	0.1		Educated guess. See Appendix 2.
CapManEx capacity	Dimensionless	30	There are 30 hand-pump mechanics in an association in the district.	Biteete et al. (2013), p11
Time to repair a water point	Years	0.02		Educated guess. See Appendix 2.
CapEx capacity	Dimensionless	1	One District Water Office.	Republic of Uganda (2013)
Average time to execute a CapEx event	Years	0.5		Educated guess. See Appendix 2.

Table 118 Sub-system 3

Parameter	Units	Value	Comment	Source
Frequency of OpEx collection	Years	0.08		Educated guess. See Appendix 2.
Cost of operation and minor maintenance	USD	5		Estimate.
Duration of operation and maintenance	Years	0.08		Educated guess. See Appendix 2.
Effective time of operation and maintenance	Years	0.08		Educated guess. See Appendix 2.
Population with a secondary source	Dimensionless	0.13		Biteete et al. (2013), p12
Delay of involvement	Years	0.25		Estimate.
Management's expiration time	Years	1		Estimate.

Table 119 Sub-system 4 and 5

Parameter	Units	Value	Comment	Source
Return period of the allocation	Years	1		Republic of Uganda (2013)
Public periodic allocation	USD	180000	Based on the District Conditional Grant for 2012/2013.	Biteete et al. (2013), pii
Average cost of a CapManEx event	USD	469		Estimate based on Biteete et al. (2013), piii
Average cost of a CapEx event	USD	2087		Estimate based on Biteete et al. (2013), piii
Average cost of a DS event	USD	500		Estimate based on Biteete et al. (2013), p19
Time to execute a DS event	Years	0.3		Educated guess. See Appendix 2.
DS capacity	Dimensionless	1		Estimate.
Effective time of DS	Years	0.5		Estimate.
Allocation ratio CapManEx	Dimensionless	0.2		Estimate based on Biteete et al. (2013), piii
Allocation ratio CapEx	Dimensionless	0.7		Biteete et al. (2013), piii
Allocation ratio DS	Dimensionless	0.1		Estimate based on Biteete et al. (2013), piii
Budget left from previous period	Dimensionless	0.3		Estimate.

Table 120 Population growth

Parameter	Units	Value	Comment	Source
Annual net population growth rate	Dimensionless	0.0153		Biteete et al. (2013), p36
Fraction of the population served by water points	Dimensionless	0.6		Estimate based on Biteete et al. (2013), p8
Initial Total Population	Persons	415000		Biteete et al. (2013), pii

Table 121 Key performance indicators

Parameter	Units	Value	Comment	Source
New WP's performance	Dimensionless	1		Estimate.
Older WP's performance	Dimensionless	0.8		Estimate.
Failed WP's performance	Dimensionless	0.2		Estimate.
Standard liters per day per WP	Liters per day per water point	10000		Estimate, based on WaterAid (2013)

17 Annex 3 Model evaluation

17.1 Thematic block 1: CBM paradigm

Table 122 Aspects of literature regarding the CBM paradigm that are represented in the model

Statement: The model represents…	Very good	Good	Neutral	Poor	Excluded	Sub-system	Explanation
Concepts central to CBM.[8]			X			NA	The tool represents the implementation of the CBM paradigm through CBM systems.
The Demand Responsive Approach.		X				3	Based on the interviews, demand for a new water point does not drive the installation of new water points. See Appendix 2 for further detail.
Water Users Associations.		X				3	Participation represents the Water Users Associations.
Post Construction Phase.		X				1 – 5	The tool integrates the life-cycle of water points.
Water Point Committee.		X					Management represents the Water Point Committee.
Capital expenditures.		X				1 – 5	The tool integrates the life-cycle of the water points, and their associated costs.
Capital maintenance.		X				1 – 5	
Operation and minor maintenance.		X				1 – 5	
Expenses in Direct Support.		X				1 – 5	
Expenses in Indirect Support.					X		Due to the system boundaries delineated, the tool excludes the costs of macro-level policies.
Cost of Capital.					X		

[8] Concepts central to the CBM paradigm: rival good, excludable good, common-pool resources, the tragedy of the commons, the problem of free riding, Community-based Management, Community-based Management of Natural Resources Management. See Chapter 4 and Annex 1 for further detail.

Table 123 Aspects of literature regarding the CBM paradigm that are represented in the model (Part 2)

Statement: The model represents...	Very good	Good	Neutral	Poor	Excluded	Sub-system	Explanation
Physical water infrastructure.		X				1	The tool integrates the life-cycle of water points.
The complete life-cycle of infrastructure.						1	The tool integrates the life-cycle of water points.
Funding from local users.		X				2, 3	Collection of funding for operation and minor maintenance is determined by participation. Moreover, local involvement increases capital maintenance.
Provision of training to local managers.		X				2, 3	Direct support influences management.
Includes multiple levels of governance.			X			1 – 5	The tool represents the meso-level and its interaction with the micro-level (participation and management) endogenously, and the macro-level (allocation from national authorities) exogenously.
Actions by external actors.		X				1, 2	Development partners are included through the provision of funding for the public sector. Charities are included through the installation of new water points. Capital maintenance by external partners is not included.
Projects initiated by external stakeholders.		X				1	Charities are included through the installation of new water points.
Inclusion of gender perspective.					X	NA	The tool does not consider gender factors or perspective.
Assesses whether direct support is sufficient.					X	NA	While direct support is included, its effect is yet to be quantified in a real situation.

17.2 Thematic block 2: CBM systems

Table 124 Aspects of literature regarding CBM systems that are represented in the model (Part A)

Statement: The model represents...	Very good	Good	Neutral	Poor	Excluded	Sub-system	Explanation
Promotion of collective action and local capacity.		X				2, 3	Direct support influences participation, management and local capital maintenance.
Provision of support in Post-Construction Phase.		X				2, 3	
Idealization of groups of users as communities.		X				3	Participation acts as a proxy for users' involvement as a community.
Technical solutions for early information.		X				2	Included in the time to report the need for capital maintenance.
Lack of funding.		X				2 – 5	The tool integrates the life-cycle costs of water points.
Mismatch between demand and supply.		X				2	The tool estimates both, demand and supply.
Failure rates of water points.		X				1	The tool integrates the life-cycle of water points, including failure.
Users' satisfaction.		X				3	Satisfaction influences participation.
Lack of operation and minor maintenance.		X				1, 3	The tool integrates the life-cycle of water points, including failure.
Political causes of the lack of funding.					X	NA	The tool represents the meso-level and its interaction with the micro-level (participation and management) endogenously, and the macro-level (allocation from national authorities) exogenously. The level of granularity of the model did not consider micro-level dynamics.
Historical causes of the lack of funding.							
Geographical causes of the lack of funding.							
Lack of awareness of the need for funding, exclusion of debtors, lack of a sense of ownership, low sense of responsibility, low willingness to pay.							

Table 125 Aspects of literature regarding CBM systems that are represented in the model (Part B)

Statement: The model represents…	Very good	Good	Neutral	Poor	Excluded	Sub-system	Explanation
Direct support for motivation.		X				2, 3	Direct support influences participation, management and local capital maintenance.
Functioning relations between levels of government.			X				
Reliable and repeated investment from development partners.		X				1, 2	Development partners are included through the provision of funding for the public sector. Charities are included through the installation of new water points. Capital maintenance by external partners is not included.
External support.		X					
Groups of users acting as a community.		X				3	Participation acts as a proxy for users' involvement as a community.
Availability of funding provided by users.		X				2, 3	Collection of funding for operation and minor maintenance is determined by participation. Moreover, local involvement increases capital maintenance.
Life-cycle perspective.		X				1	The tool integrates the life-cycle of water points.
Quality of the water infrastructure.		X				KPI	The quantity of water provided by a water point decreases as the water point ages.
Dependence on international aid.		X				1, 2	Development partners are included through the provision of funding for the public sector. Charities are included through the installation of new water points.
Alternative water sources.		X				3	Access to an alternative source influences

							satisfaction, which in turn influences participation.
Dropout from volunteer positions.		X				3	Management's motivation has an expiration time.
Lack of good governance structures.			X			3 – 5	Participation, management and decision rules for funding allocation represent governance structures at meso and micro level.
Unanticipated population growth.		X					Annual population growth rate is included as an external factor, enabling the study of contextual scenarios.
Migration flows.		X