# Creating a conceptual framework for a deeper understanding of evolving processes in socio-technical systems:

## Applied to the water services delivery system in rural areas of Uganda in an agent-based model design.

Simone A.E. van Tongeren
Student number: 1364758

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Chairman: Prof.dr.ir. P.M. Herder
First supervisor: Dr.ir. I. Nikolic
Second supervisor: Dr. J.H. Slinger
External supervisor: MA D.C. Casella

TPM Faculty of TU Delft
Department of Energy and Industry

## Summary

A reliable water flow from safe water sources is not a certainty, as in many parts of the world the delivery of water services are currently not functioning at a desired level of performance (Schouten & Moriarty 2013).

The purpose of this Master thesis research is to support IRC International Water and Sanitation Centre with their project Triple-S: Water Services That Last. The mission of the Triple-S project is to stimulate more sustainable water services delivery systems.

The goal of this research is to generate a deeper understanding concerning evolving processes in socio-technical systems[1] in the form of a conceptual framework, which is tested in a rural Ugandan water services delivery agent-based model design. A conceptual framework is valuable to IRC International Water and Sanitation Centre as it gives them the knowledge and capacity to explore policies that stimulate evolution of a local system towards a more sustainable water services delivery system.

Therefore, the main research question is: *What conceptual framework can generate a deeper understanding of evolving processes in socio-technical systems, applied to the water services delivery case in rural areas of Uganda?* The questions that assist in answering the research question are:

1. How can evolution in a socio-technical system be formalized in a conceptual framework?
2. How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case?

In this research the chosen methodological typology is to understand complex phenomena (Tashkkori & Teddlie 2003). The chosen research strategy is the design science strategy, because it allows a conceptual framework to be designed and tested during the research (Bots 2007; Tashkkori & Teddlie 2003). The agent-based model design is used instrumentally to validate the current value of the conceptual framework and to provide IRC International Water and Sanitation Centre an extensive description of the current and possible future situations of the water services delivery system in rural areas of Uganda. Interviews are conducted as a sub-method to validate the fit between the Ugandan context and the model design and to populate the model design with case specific knowledge.

The conceptual framework's starting point is the theory of Universal Darwinism. This theory is the most simple theory that explains the mechanism of natural selection and evolution in biology. Darwin and many other theorists suggest that Darwin's principles (variation, selection and heredity) are applicable in describing evolution in all open socio-technical systems (e.g. Blackmore, 1999; Darwin, 1859; Dawkins, 1976; Hodgson & Knudsen, 2006; Stoelhorst, 2008; Veblen, 1899). To successfully apply Universal Darwinism a gene-like entity, the gene-like entity carrier and the translation of mechanisms concerning variation, selection and heredity need to be found in the socio-technical system.


[1] Socio-technical systems, like the water services delivery system, are viewed as Complex Adaptive Systems. Which inter alia entails that socio-technical systems are complex, contain heterogeneous decision making entities and technical artifacts and are guided by public policy in a multi-scale institutional context (Ghorbani 2013; Waldorp 1993).

Universal Darwinism is a meta-theory, which means that this theory does not explain every detail. The theories of institutional analyses and theories related to Universal Darwinism (Memetics and molecular genetics) have assisted to operationalize Universal Darwinism for socio-technical systems.

The gene-like entity carrier in a socio-technical system is regarded as interactor (Hull 1988a; Hodgson & Knudsen 2010a). The interactor is a relative cohesive entity that hosts gene-like entities and can interact with its environment so that it leads to changes in the population of interactors and their gene-like entities. Individuals and social organizations are candidate interactors (Hull 1988a; Hodgson & Knudsen 2010a).

Memes are likely to be the gene-like entity of socio-technical systems (Blackmore 2000; Dennett 2007). Memes are everything that is passed on from person to person, which includes skills and habits that you have picked up from others. Here an analogy is made between molecular genetics (which describes genes) and memes, as the same distribution is chosen. In molecular genetics there are coding genes and regulatory genes (J.B. Reece & Urry 2010). The coding gene stands for a particular property of the entity. The regulation gene governs the coding gene, by determining where and when the property is expressed (J.B. Reece & Urry 2010).

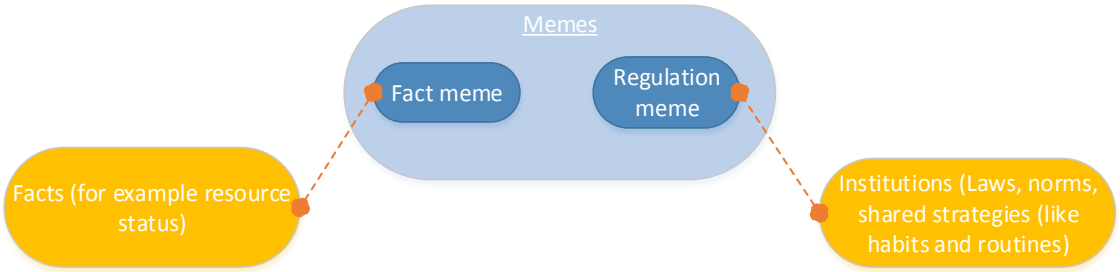


**Figure 1 Memes division (fact and regulation meme)**

Accordingly, the memes are divided into coding (hence forth: fact) memes and regulation memes, see Figure 1. A particular fact meme can stimulate the decision for a particular regulation meme. The chosen regulation meme can in turn 'guide' a the particular fact meme into a particular direction, which can change the fact meme.

Additionally, to specify regulation memes further, institutions (norms, values and shared strategies) are chosen to be the content of the regulatory memes. The reason for choosing institutions as content of regulatory memes is that institutions give structure to socio-technical systems, are relatively stable, durable and have a way to adapt to new situations which is transferred from interactor to interactor (Veblen 1899; Ghorbani 2013).

The Darwinian principles are interpreted as follows. The variation mechanism in socio-technical systems can be seen as the innovation and copy-errors of memes by interactors. Whether a meme variation becomes the new standard depends on the selection mechanism. Selection entails the personal decision to replicate a particular meme, which is dependent on a person's personal priority, scope of memes and constraints memes impose. The final Darwinian principle is heredity. Imitation and information transfer are the mechanisms which cause memes to be passed on from person to person.

These three mechanisms help to study how relative stable information is adapted to the changing environment. In Table 1 an overview of the Universal Darwinism concepts' interpretation is given. It can be seen that, besides the Universal Darwinian principles' mechanisms, the world is reduced to personal priorities, two types of memes and interactors.

**Table 1 Summary - UD concepts interpretation**

| Concept | Concept translation |
|---|---|
| **Gene-like entity** | Fact and Regulatory memes |
| **Gene-like entity carrier** | Interactor |
| **Variation** | Innovation and copy errors |
| **Heredity** | Information transfer and imitation |
| **Selection** | Personal priority and memes |
| **Environment** | Fact and Regulatory memes |

Institutional analyses contribute, besides the support in relation to the regulatory meme, to the measurability and applicability of Universal Darwinism (UD) in socio-technical systems, as it helps to:

1) Identify the influence of physical and material conditions, rules-in-use and community attributes (like cultural values) on the behavior of an actor (Polski & Ostrom 1999).
2) Identify and evaluate patterns of interactions, which is the behavior in the action arena and the outcomes from these interactions (Polski & Ostrom 1999).
3) Identify the human selection process of memes (Bandura 1999; Polski & Ostrom 1999).
4) To identify the different foundations and change rate between institutions (Williamson 1998; Crawford & Ostrom 1995).

With the instrumental use of agent-based modeling, the conceptual framework is tested in a model design with the help of the Ugandan water services delivery case. Agent-based modeling is chosen because of the bottom up and non-stationarity/non-linearity approach, which opens the door for simulating socio-technical systems (Van Dam et al. 2012; Ghorbani 2013). Using this modeling approach, it is realized that the traditional validation methods cannot be used because the agent-based model is exploring possible future states (Van Dam et al. 2012, p.127).

The Ugandan case's initial hypothesis is that the policies and knowledge, as mentioned in Table 2, have an effect on the key drivers of the water services delivery system. The key drivers, which have been identified with help of the conceptual framework and case interviews, affect the water service level[2]. The key drivers of change in this case are:

1. The motivation of certain actors (mainly the water service provider (Water User Committee (WUC)) and the mechanic (Hand Pump Mechanic (HPM))) (Nabunnya 2013; Bey 2013b).
2. The satisfaction of the water users (WUs) with the WUC (as water users often do not trust the WUC) (Lieshout 2013).

[2] The water service level is defined by IRC International Water and Sanitation Centre and its partners to be able to define different service levels, based on quantified 'service delivery indicators'(Moriarty et al. 2011; Fonseca et al. 2011).

3. The water users' dependency on a particular water point (Lieshout 2013).
4. The water point's functionality (Schouten & Moriarty 2013).

In Table 2 it is shown that in the **model design** these policies have a (direct or indirect) effect on the water service level (as well as the other key drivers). It should be tested whether the effects are positive or not in an agent-based model. Additionally, whether the list of key-drivers is comprehensive and truly affect the water service level (WSL) should be proven in a real world pilot.

**Table 2 Policy and knowledge (direct and indirect) effects on the Ugandan model design**

| Policy: | Direct effects[3]: | Indirect effects: |
|---|---|---|
| **WP Management Knowledge** | Monthly payment (or incidental) request by WUCs, Relative budget[4] of WUs, Maintenance contracts, Stock of spare parts | WSL, WUC motivation, Functionality |
| **WP Mechanic Knowledge** | Evaluation (sanction) | HPM motivation, WSL, Functionality |
| **Sanctioning policy** | Motivation of WUC/HPM | WSL, Monthly payment, Maintenance contract, Functionality |
| **M4W[5] policy** | Conditional Grant proposal | Conditional Grant, WSL |
| **HPMA[6] Policy** | Maintenance contracts, repair/installation of WP | WSL, Functionality |
| **Maintenance Policy** | Maintenance contract, WSL, Functionality | Satisfaction of WUs, Relative budget, WSL |
| **New WP policy** | Dependency | Relative budget, WSL |
| **WUC payment policy** | Motivation of WUC | WSL, Satisfaction of WUs |

The **value of the model design for IRC** International Water and Sanitation Centre lays in the fact that the model gives the possibility to explore the effects of different policies on the water services delivery system. This model design can be educative for IRC International Water and Sanitation Centre, development partners and local Ugandan parties, because people can recognize the situation presented and maybe even themselves in the descriptive model design.

Additionally, the model design subscribes the by IRC International Water and Sanitation Centre promoted policy/shared strategy, as people can see what the possible outcomes of such a change can have on the systems' outcome. Finally, due to the bottom up approach of the model, local 'normal' people can see that they can have an effect on the outcome of the system, by for example paying the water service provider. Showing this (worked out) model design to these people can therefore also have an empowering effect on the local actors.

[3] All terms are explained in chapter 9.7.1.
[4] The relative budget is the percentage of the WUC's requested money the water users are willing to pay.
[5] Mobiles for Water initiative (IRC et al. 2013).
[6] Hand Pump Mechanic Association (HPMA) policy (IRC & SNV 2013).

The explanatory value of the **conceptual framework in the agent-based model design** is currently as follows:

In the model design the gene-like entity division, fact and regulation memes, subscribes the different functions and foundations of information. Imitation and information transfer contribute to the understanding where and when a pattern of interaction stagnates or continues, due to the attention on the replication of memes. The value of heredity in the model design (and the conceptual model) can be improved by incorporating the possibility of imitating a 'neighbor's' meme. Currently the meme-scope is determined by the received level of knowledge, implemented policies, personal properties and pattern of interaction rules.

The value of (bottom up) variety is not tested in the model design. Due to the fact that this model design is very elaborate and descriptive, the variation mechanism (innovation and copy-errors) could not be tested as it would enlarge the complexity greatly. It has potential to be incorporated in an agent-based model design, as soon as the operationalization of this mechanism is further researched in small agent-based model that is less descriptive and has more exploratory possibilities for this mechanism. As a consequence the institutional grammar and four-layer model, which can assist the variation mechanism in a socio-technical system, also have not proven its added value. However, the variation mechanism is not completely left out of the scope of the model design, as variation imposed by the environment (top-down) is implemented.

The third Darwinian principle, selection, assists to understand why a certain meme is imitated or not. As the interactor's personal priority, known memes and conditions influence the decision making process of the interactor. Conditions are created by memes that have an influence on the attractiveness of a particular meme.

The main contribution of the Institutional Analysis and Development (IAD) framework in the conceptual framework is that it incorporates social structures, without excluding the Darwinian principles' mechanisms because these mechanisms can be incorporated in the IAD framework.

During the interviews for the model design it became clear that people find it difficult to define specific norms, laws and shared strategies which are in use, as people do not organize their knowledge within the borders of institution 'types' (norms, values and shared strategies). However, by reformulating the interview questions, the people told all the necessary institutions but embedded in a story.

Overall, the **conceptual framework** can be useful for situations/problems that contain:

- Regularity, as otherwise there are not institutions guiding the behavior.
- People, as they carry and replicate the memes.
- Variation of memes, as various decisions should possibly be made during a decision making process.
- Information transference, as the memes are transferred from person to person.

Situations that are less suitable to be analyzed with the formulated conceptual framework entail extreme situations (like unexpected disasters, where the chance of 'decision-making errors' are high

(McKenzie 2003; Burns et al. 2013)), high bottom-up changing/variation rate of institutions and/or no regularity in behavior (and therefore no guidance of institutions).

For future research it is advised to IRC International Water and Sanitation Centre to choose a direction. The first option is to further program the Ugandan model design in an agent-based modeling program, so that it can empower local parties and developing parties to continue their way of working or stimulate a different approach. The second option is to focus on the explanatory value of the conceptual framework, by designing a small agent-based model that can research the operationalization of the variation and heredity mechanisms, so that evolution can be modeled from within the action arena.

# Preface

Here I would like to take the opportunity to express my appreciation and respect to all the people who have supported me with feedback and ideas during this research. My gratitude goes out to you,

Prof.dr.ir. P.M. Herder, for taking the time reading my report carefully and motivating me to take the outcomes in the larger context. For making the meetings very professional and humorous. Without you the Energy and Industry section would not have been so enthusiastic, critical and motivated. You have been an example to me.

Dr.ir. I. Nikolic, for inspiring me during your lectures, for giving me the chance working with you and IRC International Water and Sanitation Centre and for taking the time for me during 'crazy' busy times. Your ideas and feedback have been essential for the formulation of this thesis research. Thank you for seeing my potential, for being realistic, critical, supportive and incredibly friendly.

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IRC International Water and Sanitation Centre, for taking the time and effort to invest in a deeper understanding of evolving systems. I think that your efforts concerning the water and sanitation sector is unique and very valuable for the water and sanitation sector. In my opinion the thorough knowledge is what makes IRC International Water and Sanitation Centre different from another developing partner. A core value that should be cherished.

# Content

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# Part I: Introduction to problem and methodology

# 1. Introduction

## 1.1 Background

*Before I start writing my thesis, I walk to the tap and pour myself a glass of water…*

Water is present everywhere and without water it is simply not possible to continue to exist (Biswas 2004). Safe, clean drinking water is not yet available to everyone. 880 Million people live without access to safe drinking water (Biswas 2004; United Nations 2010b). About 90 per cent of these people live in rural areas (Schouten & Moriarty 2013). There are even 1.5 million children under the age of 5 years old dying every year as a result of water- and sanitation-related diseases (United Nations 2010b), despite investments made by governments and donors to meet the Millennium Development Goals. The goals that are related to water are '*improve maternal health*' and '*reduce child mortality*'(United Nations 2010a; Lockwood & Smits 2011; World Health Organization 2013).

Poor rural water services delivery has caused a large number of health, socio-economic and environmental problems, which makes it difficult to achieve the above mentioned water related Millennium Development Goals (Dungumaro & Madulu 2003).

In the rural areas of Uganda reliable water flow from safe sources is not a certainty. The reality is that water points often break down and services failure is frequent and often lasts for many days or weeks. Local people are then forced to drink from unreliable unprotected sources. There are numerous reasons for this failure which are multi-layered, multi-faceted and sometimes intractable and clearly things have to change (Schouten & Moriarty 2013).

This thesis project is performed to support IRC International Water and Sanitation Centre – a The Hague-based global think and do tank – with their action research project Triple-S: Water Services That Last. The project members work closely with key-actors in countries in Africa and South Asia to identify and test promising solutions to the problem of water services failure.

The purpose of this Master thesis is to create a deeper understanding of evolving processes in socio-technical systems, applied to the water services delivery case in rural Uganda. Socio-technical systems, like the water services delivery system, are complex, contain heterogeneous decision making entities and technical artifacts and are guided by public policy in a multi-scale institutional context (Ghorbani 2013).

A profound understanding of the evolution[7] of a socio-technical system is interesting to IRC International Water and Sanitation Centre, as they are then able to explore and promote policies that fit the characteristics of the system and which stimulates the evolution towards a more sustainable (water services delivery) system.

[7] The words 'evolution' and 'change' are used interchangeably and are seen as synonyms.

## 1.2 Problem formulation

Darwin himself suggested to generalize the core principles (variation, heredity and selection) to cover the evolution of all open[8] socio-technical systems (Aldrich et al. 2008; Stoelhorst 2008). Proponents of Universal Darwinism claim that the core Darwinism principles offer a general over-arching explanatory framework for beginning to understand the evolution of social systems (Aldrich et al. 2008; Hodgson & Knudsen 2006). However, Darwin's principles themselves do not provide a complete explanation, as the theory does not provide an explanation of everything, from human society to cells. Darwin's principles is a theory in which theorists can place specific explanations[9] (Aldrich et al. 2008; Hodgson & Knudsen 2006).

Currently, there is no conceptual framework that helps IRC International Water and Sanitation Centre to distill the right information/mechanisms from the real world that helps to analyze the evolution of processes in socio-technical systems and that gives a handle to explore the effect of policies. Universal Darwinism is the theory from which a conceptual framework is formulated.

Here the case problem (the water services delivery problem in rural areas of Uganda) is explained below followed by an extensive description of Uganda. The case is finally used for testing the explanatory value of the conceptual framework.

The currently observed emergent pattern is that a relatively low percentage of water points, and thereby civilians, receive a basic level of water services (Schouten & Moriarty 2013). At the moment 30 to 40 per cent of the rural water points are not functioning at all and a larger percentage are not functioning the way it is designed for (Schouten & Moriarty 2013).

The problem that causes the current water service level[10] (WSL) in rural areas in Uganda is that, as formulated by IRC International Water and Sanitation Centre, the focus of development partners[11] and the Ugandan government has been on the construction and finance of new water points. This 'encouraged' the neglect of existing water infrastructure. Furthermore, despite water services delivery responsibilities are allocated (see Figure 2), the water points are neither regularly repaired nor maintained, which reduces the level of service water users receive and causes larger and more costly repairs and replacements (Schouten & Moriarty 2013).

See appendix 9.1 for a comprehensive description of the water services delivery level, which provides a handle for measuring water services delivery.

The reason why a relatively low percentage of water points, and thereby water users, receive the desired level of water services is further explained here. As soon as water points are constructed in rural areas of

[8] An open system can be defined as a system that is open to resources as in- and out-put (Stoelhorst & Huizing 2006).

[9] There is nothing in Darwinism that belittles or excludes self-organization, human intentionality, or Lamarckian inheritance (Hodgson & Knudsen 2006).

[10] The water service level is defined by IRC International Water and Sanitation Centre and its partners to be able to define different service levels, based on quantified 'service delivery indicators'(Moriarty et al. 2011; Fonseca et al. 2011), see appendix 9.1.

[11] Development partners are the donor community, Development Bank, Development partners.

Uganda, they are handed over to the local community. The developing partners do not pay for the life-cycle costs[12] (Schouten & Moriarty 2013). Local civilians are often not used to pay for their drinking water and uninformed of the dangers of drinking unprotected water (Schouten & Moriarty 2013).

The community based water service providers, like Water User Committees (WUCs), should charge a small amount of money for the water that local people use, to maintain and repair small defects of the water points, see Figure 2. This is however a difficult step to take for WUCs, as water users don't want to pay for their water (as politicians promise water for free), don't necessarily trust the WUC, the WUC is not motivated to collect money (as it is an volunteer job) or simply may be too poor to do pay the WUC (Bey 2013b).

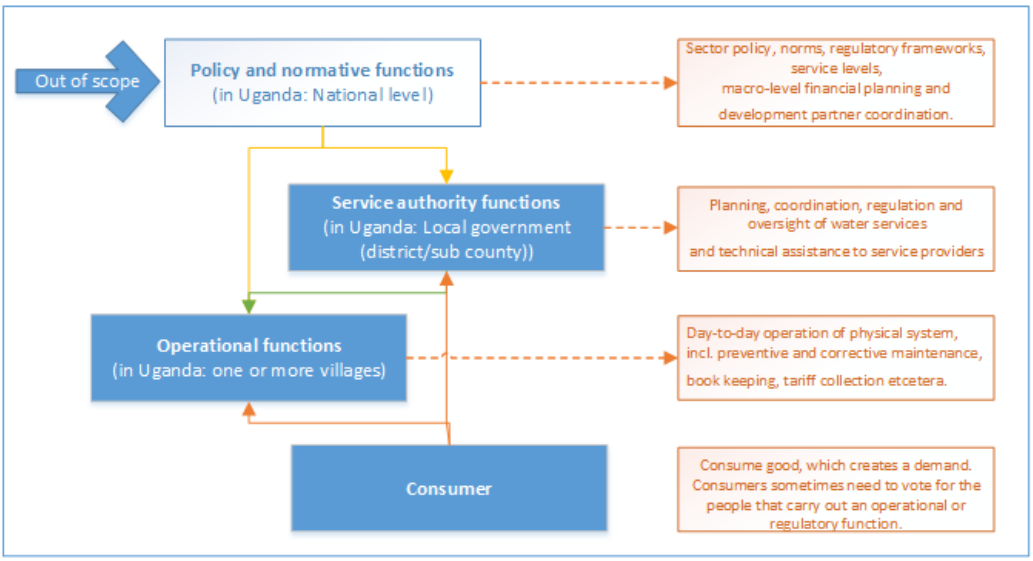


**Figure 2 Functions of Water services delivery system (adapted from** (Schouten & Moriarty 2013)

### 1.2.1 Description of the Republic of Uganda

In this section an elaborate, empirically rich description of the Republic of Uganda is given. The actual situation and problems are described and the parties that are dealing with the water services delivery system are portrayed.

**Background**

The colonial boundaries, which are created by the British, delimits Uganda. Uganda currently houses a wide range of ethnic groups with different political systems and cultures (CIA 2014). It has been difficult to create a working political community after independence was achieved in 1962, due to big differences between ethnic groups. The dictatorial regimes of Idi Amin (1971-79) and Milton Obote (1980-85) were responsible of at least 400,000 deaths (CIA 2014). The rule of Yoweri Museveni (1986 – now) has brought a relative stability and economic growth to Uganda (IMF 2010). However, a constitutional referendum (2005) banned multi-party politics for 19 years (CIA 2014).

[12] Life cycle costing (LCC) includes all direct costs plus indirect variable costs associated with the purchase, operation & support and removal of the system. Indirect costs can be for example the costs of an additional tool and additional administrative staff.

**Geographical information**

Uganda is a landlocked country in East Africa. The southern part of the country includes a substantial part of Lake Victoria. Uganda is situated within the Nile basin and has a varied but generally equatorial climate. On a total of approximately 240 thousand square meters live an estimated 36 million people (CIA 2014). The terrain is mostly plateau (with a rim of mountains), fertile and well-watered with many lakes and rivers (CIA 2014). In Uganda there are 111 districts and the capital (and largest city) is Kampala, see Figure 3 (Nabunnya 2013). Each district is divided into sub-districts, counties, parishes and villages (Lockwood & Smits 2011).


**Figure 3 Map of the Republic of Uganda** (CIA 2014)

**National situation**

Since the National Resistance Movement (NVM) of President Museveni came to power in 1986, Uganda has undertaken an ambitious set of political and economic reforms (ISSUU 2009). These reforms had led to establishment of a solid administrative, legal and institutional framework (ISSUU 2009). The state, however, faces considerable challenges in its ability to enforce the legislative framework. Furthermore, corruption remains widespread at all levels of society, in spite of President Museveni announced 'zero-tolerance for corruption'. Global Integrity's 2006 report on Uganda estimates that more than half the government's annual budget is lost in corruption each year (950 million) (ISSUU 2009).

The economic reforms, which were initiated in the '90s, have resulted in strong economic growth due to a focus on investments in infrastructure, a lower inflation rate and better domestic security (IMF 2010). However, the global economic downturn has hurt Uganda's export. Fortunately, the GDP growth is still relatively strong due to sound management of the downturn and past reforms. Uganda is classed as a less developed country as its GDP per capita is US$1,196 (IMF 2010).

The population is young, often uneducated and illiterate (BBC 2013). Life expectancy of the Ugandan population is approximately 54 years and the median age of Ugandan people is 15,5 years (CIA 2014). There is a lot of anger due to unemployment (BBC 2013). Despite these problems, the people have a

drive to do better in the future and the knowledge that it can be done better (Smet 2013; Nabunnya 2013).

Lately Uganda has been in the international press, due to the fact that President Museveni enforced a law which punishes homosexuals with life in prison (BBC 2013). Kivumbi (2014) claims that the homosexuality law is adopted to keep the attention off the 'real' problems of Uganda, like unemployment, healthcare and corruption. The homophobia is said to be stimulated by foreign, religious groups. These groups anticipate on the fears in society and prevent 'intelligent' discussions concerning homosexuality (Kivumbi 2014; Vermeulen 2014).

**Water services delivery situation**

In the National Water Policy of the government of Uganda there is a policy framework defining and specifying water services delivery models (Ministry of Water Lands and Environment 1999). The currently applied model in rural areas is the Community Based Maintenance System (CBMS) (Lockwood & Smits 2011; Ministry of Water Lands and Environment 1999). The CBMS model has limitations, but is currently considered to be the most appropriate option as there are mainly point sources (hand pumps and springs) in rural communities (Lockwood & Smits 2011). In the future this management model can change towards a more piped-scheme oriented management model (see appendix 9.10.2).

The Ministry of Water and Environment (MWE) through the Directorate of Water Development (DWD) is the main agency responsible for the management of water resources, together with coordinating, regulating and monitoring all water activities and providing support services to local governments (see Figure 4). In the process of decentralization the DWD has set up eight Technical Support Units (TSUs) to support the districts to build their capacity to implement sector mandates (Ministry of Water and Environment 2011; Ministry of Water and Environment 2007), see Figure 4.

Water is politically attractive, because local people prioritize water (Smet 2013). During election periods local councilors (LC5s) promise free, good quality and reliable water (see Figure 4). The LC5s do not say that they will provide water for free, but that the government should provide it for free (Smet 2013; Magara 2013). This shows a clear tension between the politicians (for example the LC5) and technocrats (MWE) (Smet 2013). The District Water Offices (DWOs) are representatives of the DWD at district level, so the district water services delivery authorities. The DWO is responsible for big repairs on water points, installation of new water points, planning and monitoring in a particular district. The monitoring focusses on construction works (Magara 2013). The means and resources of DWOs are extremely limited (Bey 2013b). If lucky, the DWO is staffed with two well educated men (Nabunnya 2013). The DWO can receive District Water and Sanitation Conditional Grant (DWSCG, hence forth: Conditional Grant) from the DWD to spend on the water services delivery system. The grant is inter alia related to the amount of failures projected for the coming (financial[13]) year.

[13] '*The financial year starts in July and ends in June for the government. The DWO should predict how many repairs will take place in the next political year. Sometimes it is difficult to estimate and the money can be gone after the second month. In this case, repairs of many water points are pushed to the next financial year. Sometimes, when*

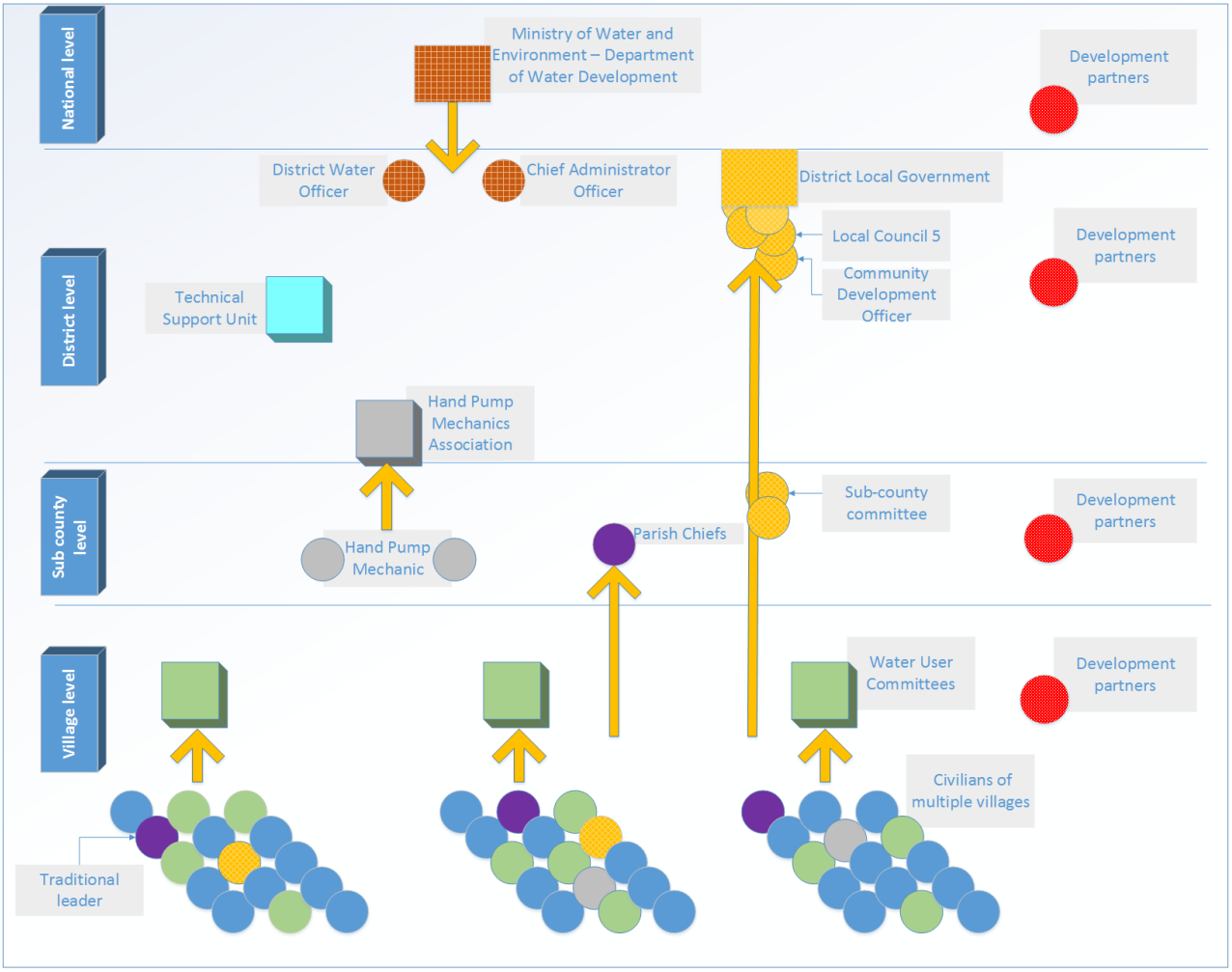


**Figure 4 Actor overview of the rural water services delivery system in Uganda.**

Another important actor in the water services delivery system, see Figure 4, is the Hand Pump Mechanic (HPM), as people need specialized tools and expertise to maintain/check the status of a water point. Per district there are only a few HPMs, who can do failure assessments, smaller repairs and maintenance of water points. Hand Pump Mechanics (HPMs) are taught to repair water points by a TSU or a development partners (like SNV) (Magara 2013; Lieshout 2013).

Hand Pump Mechanic Associations (HPMAs) are widely set up by the HPM themselves and stimulated by the government (Nabunnya 2013; IRC & SNV 2013; Magara 2013), see Figure 4. The existing HPMA policy gives the HPMs the chance to organize themselves and the supply of spare parts better (Nabunnya 2013; IRC & SNV 2013; Magara 2013). TSUs and development partners have been helpful to the HPMA, as they provide workshops and knowledge.

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*the need is very high, people go the NGOs or Ministry. To go to the Ministry, you should know the right people* (Nabunnya 2013)*'.*

The water service provider in this CBMS[14] are the Water User Committees (WUCs), see Figure 4. They are responsible for day-to-day operations, money collection, maintenance and administration of one point of water supply (Lockwood & Smits 2011). The WUC is elected by the local community. The WUC that gets trained is, however, often reelected the next time too, as they are the only ones with the necessary knowledge. The main indicators for the functioning of a WUC is the knowledge and motivation that should be in place (Bey 2013b).

If a water point breaks the WUC informs the HPM and asks to make an assessment of the water point failure and costs. The money then needs to be collected by the WUC or the DWO (depending on the costs of the repair). This is, however, a difficult step to take for WUCs, as mentioned in the problem description (Bey 2013b). Money collection for the DWO is not easy either, as the DWO is dependent on the money of the DWD.

As described in the previous section (Problem formulation) the development partners are not always supporting the water system in a sustainable way. However, they can and some are assisting the water services delivery system sustainably by providing inter alia knowledge, money and management support in line with governmental policies (Schouten & Moriarty 2013).

## 1.3 Research questions

The problem as introduced in the problem formulation implies that there are two main challenges. Firstly, the formulation of a conceptual framework that helps to get a deeper understanding of the evolution of a socio-technical system over time and that gives a handle to explore the effect of policies on the water services delivery system.

Secondly, to make a first attempt in describing the water services delivery system in Uganda, with the formulated conceptual framework, to provide IRC International Water and Sanitation an extensive description of the system and to test the current value of the conceptual framework.

While formulating the conceptual framework, first a meta-level understanding of evolution within a socio-technical system is sought with the help of theory, followed by deeper understanding of evolution at a local level (Aldrich et al. 2008; Hodgson & Knudsen 2006).

The main research question –*What conceptual framework can generate a deeper understanding of evolving processes in socio-technical systems, applied to the water services delivery case in rural areas of Uganda?* – is answered with the help of two sub-research questions:

3. How can evolution in a socio-technical system be formalized in a conceptual framework? (descriptive)
    a. *How do processes in socio-technical systems evolve over time? (descriptive)*
    b. *How can processes in socio-technical systems be formalized? (descriptive)*
4. How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case? (empirical and design oriented)

[14] Community Based Maintenance System

a. What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda? (empirical)
b. How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda? (design oriented)

The sequence in which the research questions are answered is described in the next section.

## 1.4 Outline of the report

The report has four parts, see Figure 5. The first consists of the chapters that involve the introduction to the problem and methodology of this report. The second one entails a formulation of the conceptual framework. The third section focusses on a deeper understanding of the case and the model design. The final part of the report consists conclusions, discussion and recommendations for the future.

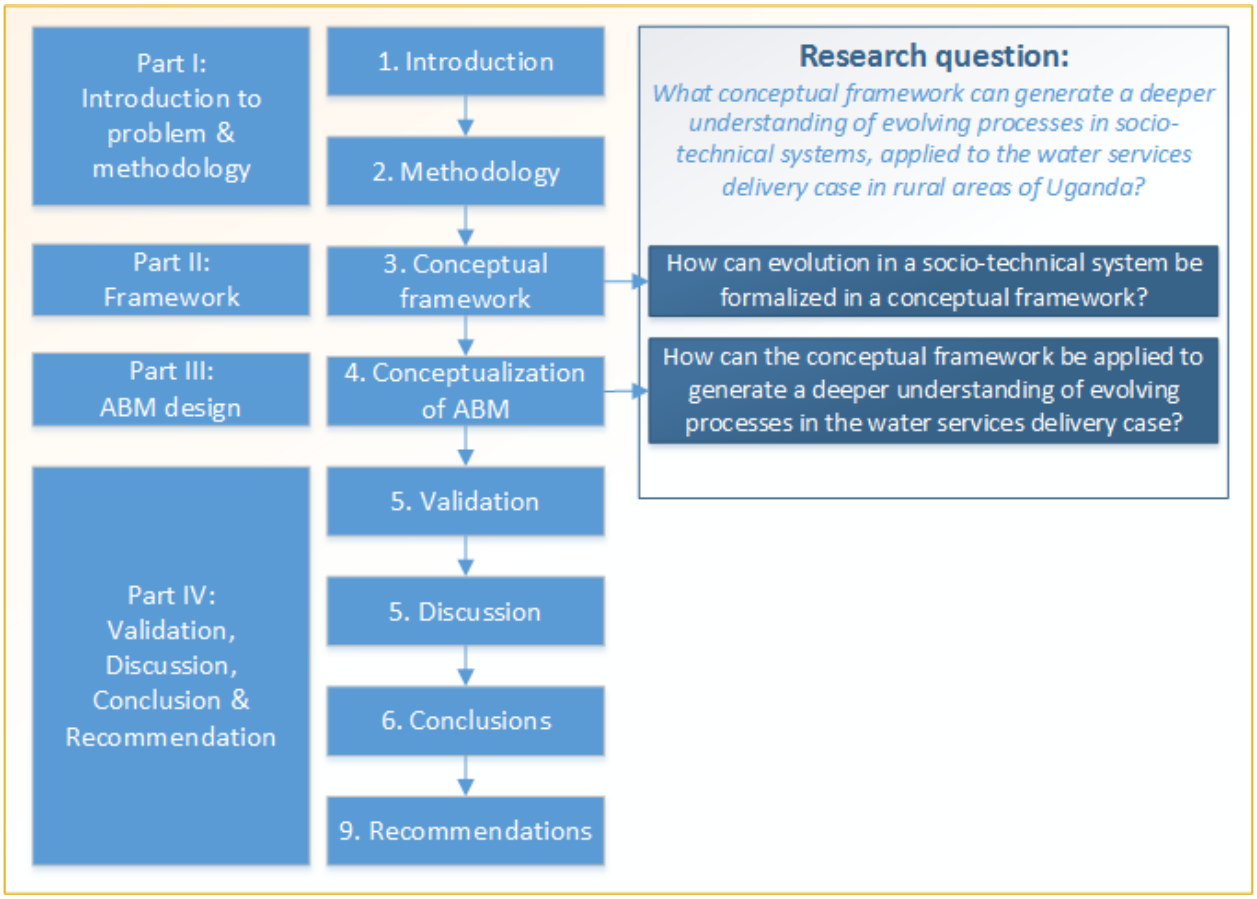


Figure 5 Report structure

# 2. Methodology

This chapter first elaborates on the research strategy, followed by a research approach.

## 2.1 Research Strategy

The typology as formulated by Newman et al. (2002) of this thesis research is chosen to 'understand complex phenomena', such as people, change and culture. *'This kind of research intends to delve below the surface of the phenomena, to investigate the meaning of an action. This research aims to develop a better understanding of the reason why certain processes occur. To understand the current phenomena a conceptual framework (a lens) needs to be developed* (Tashkkori & Teddlie 2003)'.

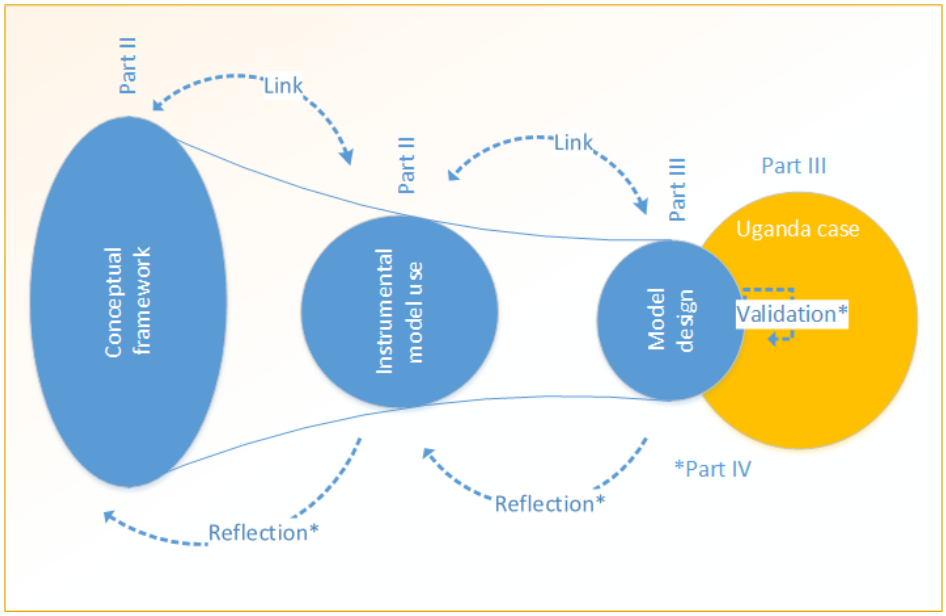


**Figure 6 Methodology approach of the translation and iteration between the socio-technical system, lens and simulation design.**

A design science strategy is chosen for this thesis research, because it allows a structure to be designed and tested during the research, see Figure 6. The conceptual framework (the lens) is designed as something static, which guides something dynamic (a socio-technical system) (Bots 2007; Tashkkori & Teddlie 2003).

The conceptual framework allows to couple theories together in a useful way, to gain insights in practical situations and about the use of a model. The instrumental model use is as a means of accessing and using theories from the conceptual framework, see Figure 6. This set up is tested on the water services delivery case, in the light of the Ugandan context (see Figure 6), in a model design.

The validation process is going backward, from applied model, model method to conceptual framework, see Figure 6. As mentioned above, the model design is an instrumental entity as it is a validation tool of the model method and the conceptual framework. It shows the advantages and disadvantages of the choices made. The interviews are a sub-method within the overarching research strategy. The interviews are a validation step to also check whether the Ugandan context fits the model design. It is realized that

there is personal interpretation (or bias) of the current situation. The bias is not visualized in Figure 6 because here the focus is on why complex phenomena occur, as the typology describes, and not on the appreciation of these phenomena.

## 2.2 Research approach

The main methodological elements to study the research question *'What conceptual framework can generate a deeper understanding of evolving processes in socio-technical systems, applied to the water services delivery case in rural areas of Uganda?*' are discussed in this section.

First, a desk research to study literature is conducted to obtain insights into the meta-level evolutionary principles, followed by desk study that is focused on the operationalization of the meta-level mechanisms at local level. This research approach is taken because Universal Darwinism is a meta-theory that explains evolution (Aldrich et al. 2008; Hodgson & Knudsen 2006) in socio-technical systems.

Secondly, a literature study, in combination with semi-structured interviews, is conducted to gather information on the Ugandan context and the water services delivery problem and a sub-method, within the overarching research strategy, to check the fit between the Ugandan context and conceptual framework. The interview method is chosen to be semi-structured because this interview methodology gives the possibility to keep a 'check-list' with (possibly) important subjects during the interviews. Additionally, there is still room to adopt an additional subject during the interview even though that particular topic did not come out of the literature study (Creswell 1994).

Thirdly, a model design is formulated by transforming the conceptual framework and the Ugandan case into a model description that explores the possibilities and added value of the conceptual framework. The design steps that are taken to come to a model design are (Van Dam et al. 2012):

1. Problem formulation and actor identification
2. System identification and decomposition
3. Concept formalization
4. Model Formalization

These steps are extensively explained at page 53 in chapter 3.5.

# Part II: Conceptual framework

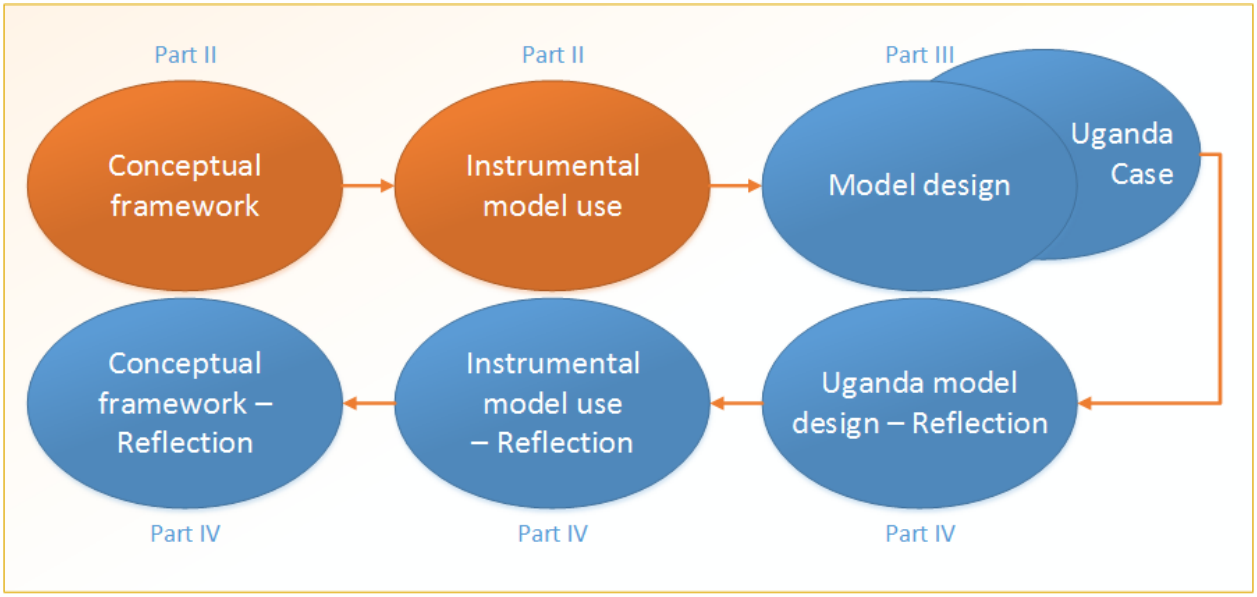


**Figure 7 Reading guide 1**

# 3. Conceptual framework

There are two lacks of insight which should be investigated during the literature research, to answer the first sub-research question - *How can evolution in a socio-technical system be formalized in a conceptual framework?*

1. *How do processes in socio-technical systems evolve over time?*

To appropriately apply a Darwinian view (which comes from biology) on a socio-technical situation, the conceptual framework should at least cover:

a. Gene-like entity and carrier, to study which form of information carrier and entity is present in a socio-technical system.
b. Selection, variation and heredity mechanisms of a gene-like entity to study how relative stable information is adapted to the changing environment.

2. *How can processes in socio-technical systems be formalized?*

The theories should at least cover the following aspects to design appropriate decision-making behavior of the participants in the socio-technical system:

a. Decision making of humans, to study how (changing) decisions come about.
b. Institutions[15], to study what rules affect personal decisions.

These lacks of insight imply that the problem should be analyzed from a macro level, to analyze the first lack of insight and from a micro level to solve the second lack of insight. Macro level focusses on the aggregate and emergent change patterns (section 3.1 and 3.3), while the local level focusses on the agents' decision making processes and interactions (section 3.2). Section 3.4 is dedicated to two extensive examples of the conceptual framework. The final section 3.5 focuses on the modeling method which can further test the conceptual framework in the Ugandan context.

Before starting to answer the first lack of insight, the angle from which the socio-technical system is viewed is further elaborated.

**Complex adaptive system**

Processes in socio-technical systems can be analyzed from a lot of different angles and for many different purposes. Here the socio-technical system is seen as a Complex Adaptive System (CAS) (Van Dam et al. 2012). While adopting the thoughts of CAS, one should have an understanding of the systems perspective and complexity (see Appendix 9.2). Kauffman formulated CAS as:

'*Complex Adaptive Systems are a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents* (Waldorp 1993)*.'* The fitness of a CAS depends on the perspective that is

[15] Institutions are rules which are accepted by all those involved, are used in practice and have some sort of durability (Ghorbani 2013).

adopted, see appendix 9.4. A different perspective causes a different outcome of the system. So, the 'success' or 'failure' of the CAS is normative (Aldrich et al. 2008).

The reason for selecting CAS is because socio-technical systems, like Uganda, are always changing and adapting to new ideas and influences. Uganda cannot be managed by one leader, as the system is dispersed and decentralized over the residents of the system. In the Uganda case people are (in parallel) constantly adjusting their belief they have in the water service provider and reacting on what they have heard from others etcetera (Lieshout 2013). In other words, the contextual setting of current day Uganda fits the definition of CAS.

## 3.1 Universal Darwinism

This section focuses on the lack of insight - *How do processes in socio-technical systems evolve over time?* The most simple meta-theory that explains evolution is Darwin's theory on natural selection.

*'One general law, leading to advancement of all organic being, namely, multiply, vary, let the strongest live and the weakest die* (Darwin 1859)*'.*

Processes driving species' variety and ability to adapt to a changing environment, is widely accepted and can be explained by the theory of evolution (Dawkins 1976). This evolution theory explains how ancestors with the same origin can diverge and adapt to a changing environment (Darwin 1859).

As mentioned in the problem description, Darwin himself made the suggestion that the core principles (variety, heredity and selection) help to understand the evolution of all open socio-technical systems (Aldrich et al. 2008; Stoelhorst 2008). An open system can be defined as a system that is open to resources as in- and out-put (Stoelhorst & Huizing 2006). Universal Darwinism is a theory that has the space to put specific explanations by theorists[16] (Aldrich et al. 2008; Hodgson & Knudsen 2006). In order to investigate the compatibility of Universal Darwinism with a socio-technical system, the emergent properties and evolution's driving forces need to be illuminated.

A review of the existing literature on Universal Darwinism (UD) (and its various mechanisms, characteristics):

The potential compatibility between Universal Darwinism and a socio-technical system is investigated by many theorists (e.g. Blackmore, 1999; Darwin, 1859; Dawkins, 1976; Hodgson & Knudsen, 2006; Stoelhorst, 2008; Veblen, 1899). They show that the main principles of Darwinism can be applied in other realms than biology, in for example socio-technical systems.

The existence of evolution within other disciplines than biology has been largely debated (Mulder 2012). Foster (1997) criticized several evolutionary studies that make analogies with biology while analyzing economic processes (Foster 1997). There is a broad consensus that no version of Darwinian evolutionary biology is directly applicable to the evolution of human societies (e.g. Aldrich et al., 2008; Hodgson & Knudsen, 2006). However, there is still a debate on whether or not some generalization of some version

[16] There is nothing in Darwinism that belittles or excludes self-organization, human intentionality, or Lamarckian inheritance (Hodgson & Knudsen 2006).

of Darwinism might be helpful for a better understanding of the evolution of human and economic societies (Pelikan 2010).

Geoffrey Hodgson (2002) argues that the core of the evolutionary mechanism is variation and he thereby suggests that *'evolution can occur in any system substrate where there are mechanisms generating continued variation* (Hodgson, 2002, p. 272)'. Variation can be random or purposive in origin, but without variation natural selection cannot operate (Hodgson, 2008, p. 401). The survival of for example HPMs is driven by its competitive advantage, which is for the biggest part driven by the way it differentiates itself from competitors, for example its ability to adopt an appropriate variation in both products (services) and operations. The variety of entities are a result of continuous innovation and copying errors (Hodgson & Knudsen 2010b).

The second mechanism is heredity or continuity, through which characteristics are passed on. The final central principle is selection, as in biology better adapted organisms have a higher chance to produce offspring. It is of importance that information is transferred and gets imitated, to assure continuity socio-technical system (Hodgson & Knudsen 2010b). Information imitation/transfer ensures that knowledge regarding both successful and unsuccessful operations are inherited from day to day and person to person within an organization. An elaboration on the definitions variation, heredity and selection can be read in appendix 9.3.

The system continually evolves due to changes within the behavior of individuals or organizations, which influence parts of the socio-technical system and as a whole (Schouten & Moriarty 2013). From a Universal Darwinism perspective, the existing situation is the current local optimal, otherwise it would have adapted to other (stronger) selection pressures (Kasmire et al. 2011). A selection pressure in the Uganda case is for example that people (water users) do not want to pay a particular WUC (Bey 2013b). Therefore, to understand the current situation it is important to get familiar with the underlying pressures (Kasmire et al. 2011).

Instead of working upwards from detail to generality, it is chosen to use the Universal Darwinism principles (selection, variation, heredity) and work that out into more detail. The translations of the three key principles of Universal Darwinism (variation, selection and heredity), the gene-like entity and carrier in a socio-technical system are researched in the coming sections (3.1.1-3.1.2).

### 3.1.1 Replicator and Interactor

What actually is selected and replicated is debated. Hodgson and Knudsen (2010) regard information as a replicator, as a gene-like unit. This replicator is held by an interactor (Hodgson & Knudsen 2010a), for example a genome is a biological interactor. The information contains adaptive solutions to problems and guides the development of interactors (Stoelhorst & Huizing 2006). Decoding accumulated information gives reason to repeat successful behaviors in future interactions with the environment (Stoelhorst & Huizing 2006).

The interactor is a relative cohesive entity that hosts replicators and can interact with its environment so that it leads to changes in the population of interactors and their replicators. Individuals and social organizations are candidate interactors (Hull 1988a; Hodgson & Knudsen 2010a).

### 3.1.2 Generative replicators

To explain why evolution sometimes leads to dramatic gains in complexity[17] and sometimes leads to nowhere Hodgson and Knudsen (2010) formulated four axioms that jointly form sufficient conditions for the existence of a generative replicator (Hodgson & Knudsen 2010a). Generative replicators increase the complexity of an evolving social or biological population. Examples, that are mentioned in literature, of these special types of replicators are memes, routines, habits and genes (Blackmore 2000; Hodgson & Knudsen 2010a; J.B. Reece & Urry 2010).

The four axioms which are the conditions for a generative replicator, are (Hodgson & Knudsen 2010a) :

1. *'Causal implication: There must be a causal link between the source and the copy. At least in the sense that a particular copy would not be created without the source existing.*
2. *Similarity: The copy should have the capacity to replicate. The conditional generative mechanisms (defined at point 4) in the copy should similar to the those in the source. The errors and/or mutations that exist in these mechanisms have to be copied with some degree of fidelity.*
3. *Information transfer: The process that creates the copy has to obtain the conditional generative mechanisms that make akin to its source* (Hull 1988a).
4. *Conditional generative mechanisms: Generative replicators are material entities that consists of construction mechanisms that can be triggered by cues, containing information about a particular environment. The construction mechanisms produce further instructions from the generative replicator to the interactor, to guide its development* (Hodgson & Knudsen 2010a)*'.*

The spirit of Hull's (Hull 1988b, p.408) early definition of a replicator "an entity that passes on its structure" is captured in the four conditions (Hodgson & Knudsen 2010a). An entity that is able to satisfy all four conditions can be described as a generative replicator.

One of the obstacles of defining the replicator concept is what exactly 'information' means. Hodgson & Knudsen (2010) helped to fill this gap. Information here is not seen as the information that is communicated by humans, but it is information in a cruder sense of a signal or code, as manipulated and stored in computers or DNA. So, '"information" involved consists of signals with the potential to trigger generative mechanisms that guide the production of further replicators or the development of interactors (Hodgson & Knudsen 2010a).'

A review of the existing literature on generative replicators (memes, habits and routines):

A short introduction of memes, as explained by Blackmore her book Meme Machine (Blackmore 2000) is given in this section. Everything that is passed on from person to person is a meme. This includes all the words in your vocabulary, the skills and habits you have picked from others and the games you like to play.

[17] 'Social evolution has led to increases in cultural complexity that can be compared to the evolution of the human eye. Emergence of increasingly complex social institutions and organizations starting from the evolution of pre-linguistic culture, human language, and tribal customs, to writing and records. Each new transition in the evolution of culture has retained core features of prior developments and then added a new layer of complexity (Hodgson & Knudsen 2010a).'

Imitation is the mechanism by which religions and languages persist over generations and why games are explained to your friend. People unconsciously imitate others (Blackmore 2000). It is the reason why we learn the same language as our parents and have the same regional accent. As with genes, memes can be tracked down through populations by their phenotypes (Blackmore 2000; Blackmore 1998).

Memes, like genes, are selected against the background of other memes. As a result, mutually compatible memes are found cohabiting in individual brains (co-adapted meme complexes or memeplexes) (Blackmore 2000). Memes 'cooperate' with memeplexes which are mutually supportive. Supportive within the memeplex and, in turn, hostile to rival memeplexes (Blackmore 2000).

As Blackmore described, some memes are habits. Hodgson and Knudson focus on habits and routines as replicators (Hodgson 2008; Hodgson 1998). They presume that habits and routines are the most obvious examples of generative replicators in a social context. In 1899 Veblen wrote a book called The Theory of the Leisure Class, in which he argues that the Darwinian principles apply to individual habits and social institutions (Veblen 1899). Hodgson & Knudsen (2010) defined habit and routine as follows:

*'A habit is a disposition to engage in previously adopted or acquired behavior – triggered by an appropriate stimulus. Habits replicate indirectly, by means of their behavioral expressions. They can impel behavior that is followed by others, as a result of incentive or imitation. Eventually, the copied behavior becomes rooted in the habits of the follower, thus transmitting from individual to individual an imperfect copy of each habit. Routines are organizational dispositions made up of habits that are developed in an organizational context* (Hodgson & Knudsen 2010a)*.'*

Habits and routines reliably map certain input signals onto specific behaviors and are adapted to past circumstances. '*Habits and routines will never be in full accord with the requirements of the present…. At the same time, men's present habits of thought tend to persist indefinitely, except as circumstances enforce a change (Veblen, 1899, p.191)*' It is important to note that routines and habits are characterized by two components, namely an observable and cognitive part (a phenotype and genotype). The observable behavior is like the signature of a routine or habit. However, its core is the cognitive component that 'maps the reading of cues onto behavior (Hodgson & Knudsen 2010a)'. The status of generative replicator is given to habits and routines because of the possibility to replicate the underlying cognitive component.

Points of discussion concerning habits and routines:

Whether routines and habits are a generative replicator is still under discussion. Stoelhorst and Huizing for example do not agree with Hodgson and Knudson to take routines as a replicator. Stoelhorst and Huizing (2006) believe that the 'codex' is the accumulated information about which behavior, with the environment, works or doesn't work. This information would not be within a routine or habit (Stoelhorst 2008). They however do not have another generative replicator that they propose. Hodgson and Knudsen (2010) define routines to have, as mentioned above, a cognitive together with a behavioral component. The cognitive part guides the process of adjusting to an (changed) environment. This makes that here routines are seen as possible replicators.

Another point of discussion is that routines and habits are difficult to measure in the field. The cognitive part of a routine may stay the same, while the behavioral part has changed completely. Furthermore, people often do not know why and how they do the things they do. There is a famous example of a routine that evolved in the military (Hodgson & Knudsen 2010a). This example illustrates that routines can function as generative replicators. The gun firing routines had been replicated in a reliable way by military regime. During the endless hours of training the routine, the behavioral and cognitive component of the routines was also transferred, but had gradually faded beyond conscious awareness.

In Table 3 a sub-conclusion is given, which just shows possible generative replicators and the generative replicator carrier, the interactor. The concept translation of the three key principles are described are explained later in this chapter.

*For now, no decision is made to either choose the meme or routine perspective or combine them*.

**Table 3 start of UD concepts interpretation for socio-technical systems**

| Concept | Concept translation |
|---|---|
| **(possible) Generative replicator** | Memes, habits and routines |
| **Generative replicator carrier** | Interactor |

## 3.2 Institutional analyses

The reason to adopt another theory as pillar is to get more insight in the second lack of insight, which is - *How can processes in socio-technical systems be formalized?* The theory that is adopted should at least cover the decision making of humans (to study how decisions come about) and institutions (to study what rules affect personal decisions).

Without deciding on the generative replicator, as discussed in section 3.1.2, it is chosen to use institutional analyses to analyze the patterns of interaction and personal decision making processes of human entities in a socio-technical system with, because:

1. Institutions give structure to socio-technical systems (Ghorbani 2013; Crawford & Ostrom 1995).
2. While understanding individual behavior is complex, social rules and institutions are fairly well extractable and therefore measurable (Ghorbani 2013; Crawford & Ostrom 1995).
3. Institutional analyses incorporate human decision making in their framework (Polski & Ostrom 1999).

The combination of both Universal Darwinism and institutional analyses in socio-technical sphere has been promoted by various scientists (Hodgson 2008; Hodgson 1998; Veblen 1899; Lewis & Stienmo 2012; Liagouras 2009; Hodgson 2010). In 1899 Veblen came with the idea that social evolution is a natural selection of institutions: *'The life of man in society, just like the life of other species, is a struggle for existence, and therefore it is a process of selective adaptation. The evolution of social structure has been a process of natural selection of institutions. The progress which has been and is being made in*

*human institutions and in human character may be set down, broadly, to a natural selection of the fittest habits of thought and to a process of enforced adaptation of individuals to an environment which has progressively changed with the growth of community and with the changing institutions under which men have lived* (Veblen, 1899, p188)*'.*

An institution can be seen as nothing more than a pattern of behavior that is sustained by mutual expectations of behavior of others (Dawkins 1986; Crawford & Ostrom 1995, p.582; Ghorbani 2013). An institution gradually changes over time in search of a better fit with the environmental, economic and social influences (Williamson 1998; Crawford & Ostrom 1995, p.582).

Institutions give the responsibility of social order to the individuals who are part of that system and not to some external 'state' or 'third party enforcer' (Crawford & Ostrom 1995). This view integrates the analyses of how institutions come into place with the analyses from within.

The trap of manifesting institutions as things that exist apart from the shared understandings and behavior of participants should be avoided. Furthermore, institutions are treated as if all behaviors had similar foundations (Crawford & Ostrom 1995), this disadvantage is solved by Crawford and Ostrom (1995) by making a 'grammar' for institutions which acknowledges the different foundations (norms, laws and shared strategies) (Crawford & Ostrom 1995).

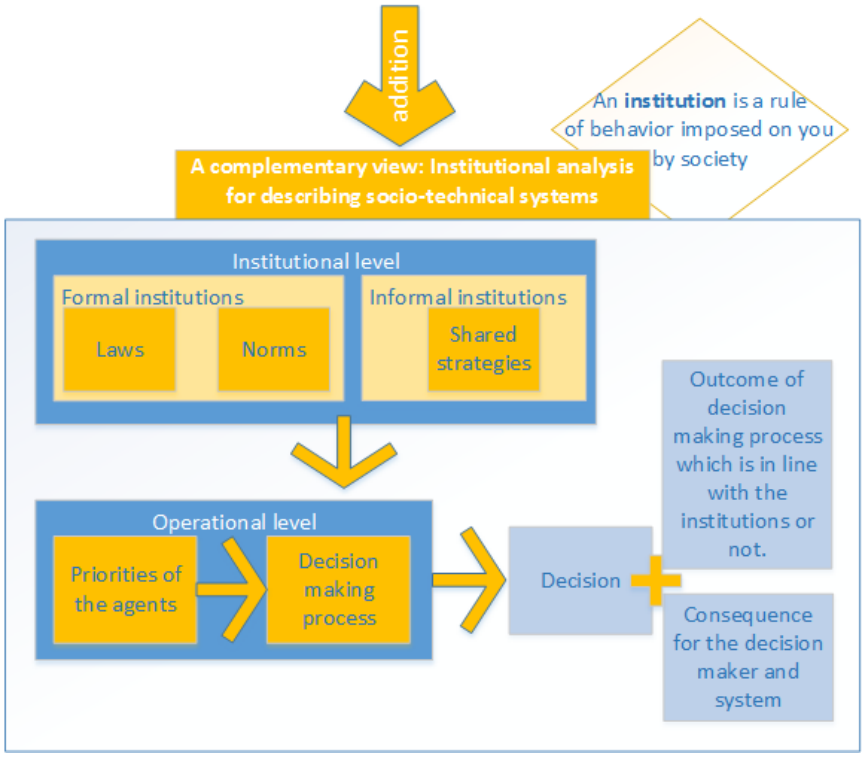


**Figure 8 Line of argumentation 2 (adapted Institutional Analysis and Development framework (Polski & Ostrom 1999))**

Decision making within institutional analyses: in Figure 8 the separation between operational level and institutional level is made. The operational level shows two boxes 'priorities of the agents' and 'decision making process'. On operational level institutions humans/organizations are imposed by institutions

while making their decisions. Priorities of the agents are also taken into account while deciding (Polski & Ostrom 1999).

The 'priorities of the agents' reflect the ability of a human to self-reflect. A human's personal priority is included in the decision making process as the human entity is, within the social cognitive theory, embedded in the self-theory (Bandura 2013). This theory shows that humans affect their own behavior because humans know what they are doing. This means that the human is a self-reflective, proactive, self-organizing and a self-regulative mechanism (Bandura 1999). The theory of consciousness and decision making errors are not adopted in this Master thesis research, instead humans are seen as purposive entities. In appendix 9.5 can be read why and how this decision is made.

On the institutional level the formal institutions and informal institutions are apparent. There are many different definitions of institutions. Here institutions are defined as the set of devised rules to organize repetitive activities and shape human interaction (Ostrom 1991). *'Institutions are rules that are accepted by all those involved, are used in practice and have some sort of durability* (Ghorbani 2013)*'*.

The decision that comes out of the decision making process is either in line with the institutions or not, see Figure 8 (Polski & Ostrom 1999). When the decision is not in line with the institution, there may be a consequence on the decision. For example, when a person drives through a red light, his priority is not to obey a law that states that you should stop for a red light. His priority is for example to be as fast as possible, as he needs to be at the hospital rather sooner than later.

In the next section the institutional analyses which are incorporated in the conceptual framework are explained.

### 3.2.1 IAD framework and Institutional Grammar

First a description of the institutional grammar is given, followed by the Institutional Analysis and Development (IAD) framework explanation.

Institutional grammar as developed by Ostrom and Crawford (1995) helps to see the differences between institutions, as institutions can have different foundations (norms, laws and shared strategies). The core of the institutional grammar, the ADICO syntax, are the repetitive elements that make up the institutions. The repetitive elements of the institutional grammar can be seen in Table 4.

**Table 4 Explanation of the repetitive elements of institutional grammar**

| | | |
|---|---|---|
| A | Attribute | *The organization or individual to which the institution is applicable and the description of the subject(s).* |
| D | Deontic | *The prescriptive indicator that describes what is permitted, obliged, forbidden. It can also be found in implicit forms (may, must and should). Both forms have the same force.* |
| I | aIm | *The aim describes the goal or action of an institution.* |
| C | Condition | *The condition entails the 'when', 'if', 'unless' and 'where' for which the aIm is required/allowed or forbidden.* |
| O | Or else | *The Or else indicator is the corrective action if the rule is not obeyed.* |

Applied to the sentence “You must open the gate to the house or I’ll be angry with you” the coding would be applied as the following:

> *You (A) must (D) open the gate (aIm) to the house (C) or I’ll be angry with you (O).*

Three types of institutions can be formulated, based on different combination of repetitive elements:

> *Rule: ADICO; “I should open the gate to the house or you’ll be angry with me”.*
> *Norm: ADIC; “I should open the gate to the house”.*
> *Strategy: AIC; “I open the gate to the house”.*

The institutional grammar is combined with the four layer model of Williamson (1998) to better understand institutions and its variation rate.

However, two problems arose. Firstly, as institutional statements distinguish norms, values and rules in a concrete way, as in a socio-technical system, the boundaries may be more vague than that the coding indicates. Secondly, some institutions are tacit knowledge of actors. The consequence these drawbacks are that the more conceptual or abstract institutions may not be included (Crawford & Ostrom 1995, p.595).

Here the Institutional Analysis and Development framework is explained. The IAD framework (Figure 9) helps to comprehend a complex social situation (Polski & Ostrom 1999). The IAD analysis focusses, after the formulation of the (policy) problem, on the behavior in the action arena (action situation, individuals and groups who are ‘routinely’ involved in the situation), see Figure 9. The goals of the IAD analysis are to:

1. Identify the influence of physical and material conditions, rules-in-use and community attributes (like cultural values) on the behavior of an actor.
2. Identify and evaluate patterns of interactions, which is the behavior in the action arena and the outcomes from these interactions (Polski & Ostrom 1999).

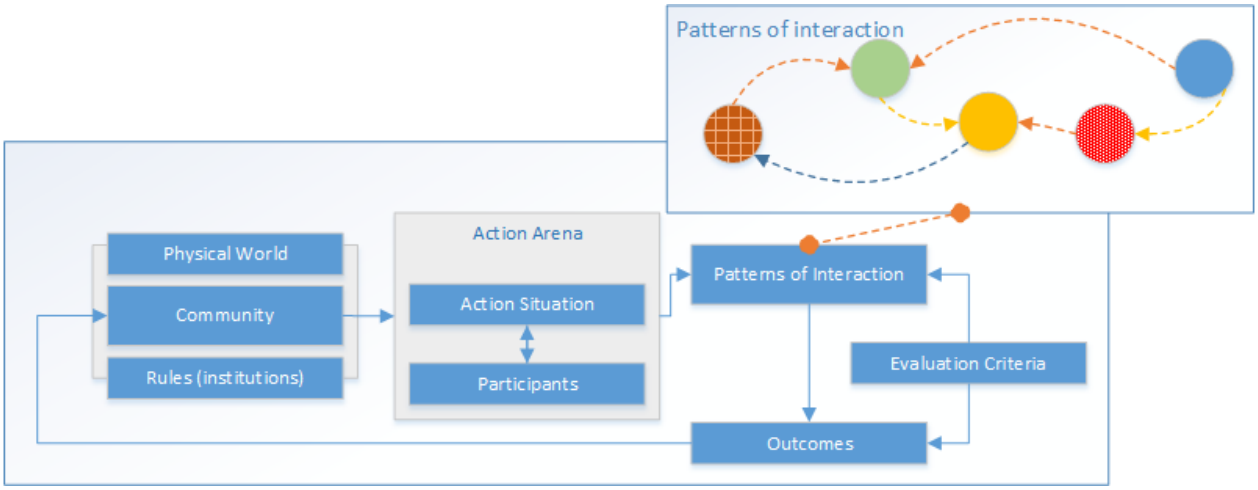


**Figure 9 IAD framework** (Polski & Ostrom 1999)

People interact in an action arena and get influenced by the external pressures (of the community, institutions and the physical world) (Ghorbani 2013). Ostrom and Polski (1999) state that '*Actors' decision choices are often influenced by access to stocks of capital, labor, knowledge, technology, time, and social influence. These resources endow actors with the capacity to act unilaterally, bilaterally, or multilaterally, over short, medium, and longtime horizons. This capacity fundamentally determines the relative strength of one actor or group of actors. The extent to which relative strength may be exercised to circumvent or change existing rules is itself a function of higher order institutional arrangements* (Polski & Ostrom, 1999, p. 22)*'.*

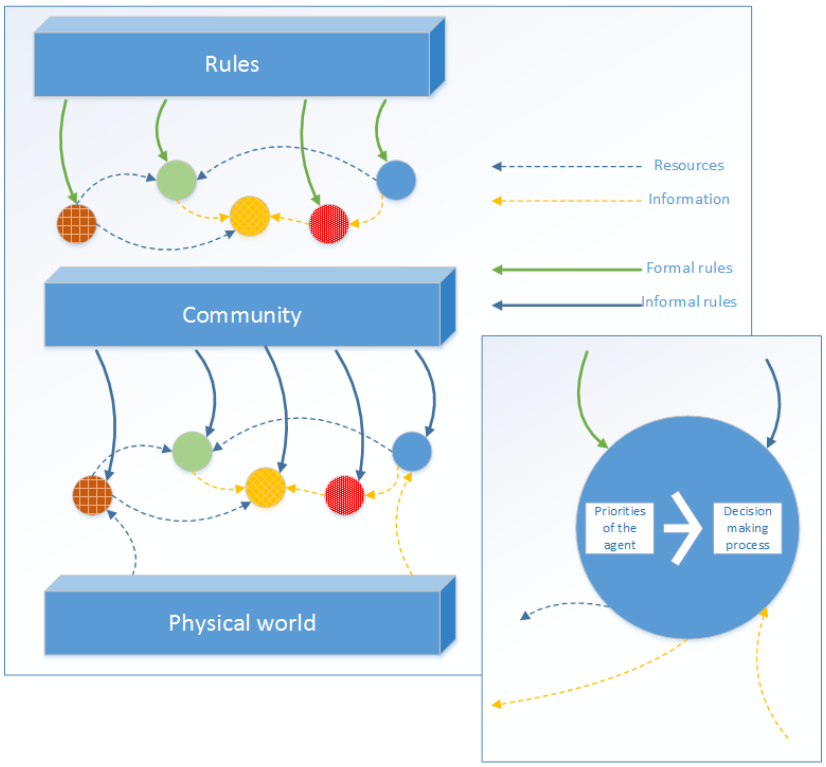


**Figure 10 Visualization of the *current* understanding of processes**

The goal of Figure 10 is to show that processes are influenced by the actors in the action arena, the rules, the community and physical world. From the conceptual framework's perspective, the circles are the interactors who make a decision to, for example replicate a piece of information, or not.

## 3.3 Gene regulation

This section carries on to answer the first lack of insight *How do processes in socio-technical systems evolve over time?* Which was started off in section 3.1. In section 3.1.2 it did not become clear what kind of generative replicator is applicable to the researched socio-technical system (memes or routines/habits). In this section it becomes clear that memes have potentially the quality of a generative replicator. To come to this point molecular genetics and Memetics are further investigated. Followed by an exploration of the three Universal Darwinism principle mechanisms (section 3.3.1).

As thoughts of Memetics have analogies with molecular genetics[18] (Mesoudi et.al., 2006), this part of biology is further investigated. In molecular genetics there are coding genes and regulatory genes (J.B. Reece & Urry 2010). The coding gene can for example be the blue color of the eyes. The regulation of gene expression is governed by the regulator gene. This type of genes often code for repressor or activator proteins, which can activate or repress the production of specific gene products (protein or RNA). In other words, sophisticated programs of gene expression are governed by regulatory genes (J.B. Reece & Urry 2010).

> *Here it is assumed that memes can be divided into two types: regulation memes and coding memes (henceforth fact memes),* Figure 11*. The way to respond to a cue (fact meme) is the way you govern certain information (regulation meme).*

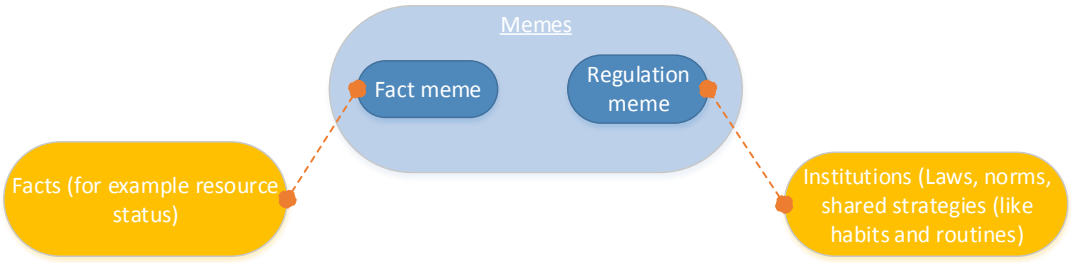


**Figure 11 Meme division which includes a fact and a regulation meme**

Continuing the institutional/UD[19] thinking:

> *The regulation memes are assumed to be institutions.*

The reason for choosing institutions as the content of the regulatory memes is that institutions have a way to adapt to new situations which is transferred from person to person and are relatively stable, durable (Veblen 1899). There are two different theories selected to help to organize the different institutions (which are laws, norms and shared strategies). Firstly, as mentioned in section 3.2.1, the grammar of institutions (ADICO) and, furthermore, the four layer model of institutions of Williamson (1998) to understand the variation rate of and differences between institutions.

The four layer model, see Figure 12, the highest level are the informal institutions (where norms and culture are embedded). At this level changes occur every 100 to 1000 years. The second layer are the formal rules (where laws and regulations are embedded). At the second level of institutions changes occur between 10 to 100 years. Agreements and contracts change between 1 and 10 years. The lowest level, operational rules, changes occur continuously.

[18] It is realized that the classical view of Mendel (1866) on genes has undergone significant changes trough the past 150 years. The classical unitary gene concept saw the gene as a indivisible unit of transmission, recombination, mutation, and function. Advances in genetics have shown that the unitary gene concept is inadequate and overly restrictive (Mesoudi et al. 2006).

[19] Henceforth UD also covers the thinking of Memetics.


**Figure 12 Four layer model adapted from Williamson (1998)**

> *It is assumed that the fact meme is information that triggers a certain regulatory meme. The fact meme is transferred from one interactor to another with help of regulatory memes. What an interactor does when it receives a fact meme depends on its personal priority and known regulatory memes (memeplex). An example of an fact meme is the number on your bank balance.*

In the next paragraphs Figure 13 & Figure 14 are explained, Figure 14 explains Figure 13 by giving an example.

Figure 13 gives an overview of the institutional/UD system. The middle oval shows the action arena in which a or several meme(s) enter and leave the system. In the top oval the personal sets regulatory memes (like laws) are shown as nodes. One node can be a habit, norm, shared strategy or law. The lines visualize the relationships that regulatory memes have with other regulatory memes. A relation between regulatory memes arises when certain regulatory memes are used after or in parallel of each other.

> *A set of regulatory memes, that are triggered in sequence or parallel by the same fact meme, is seen as a routinized pattern of interaction.*

At the bottom of Figure 13 the interactors' network is shown. The lines between the interactors show the current connections (the direct network) between the interactors.

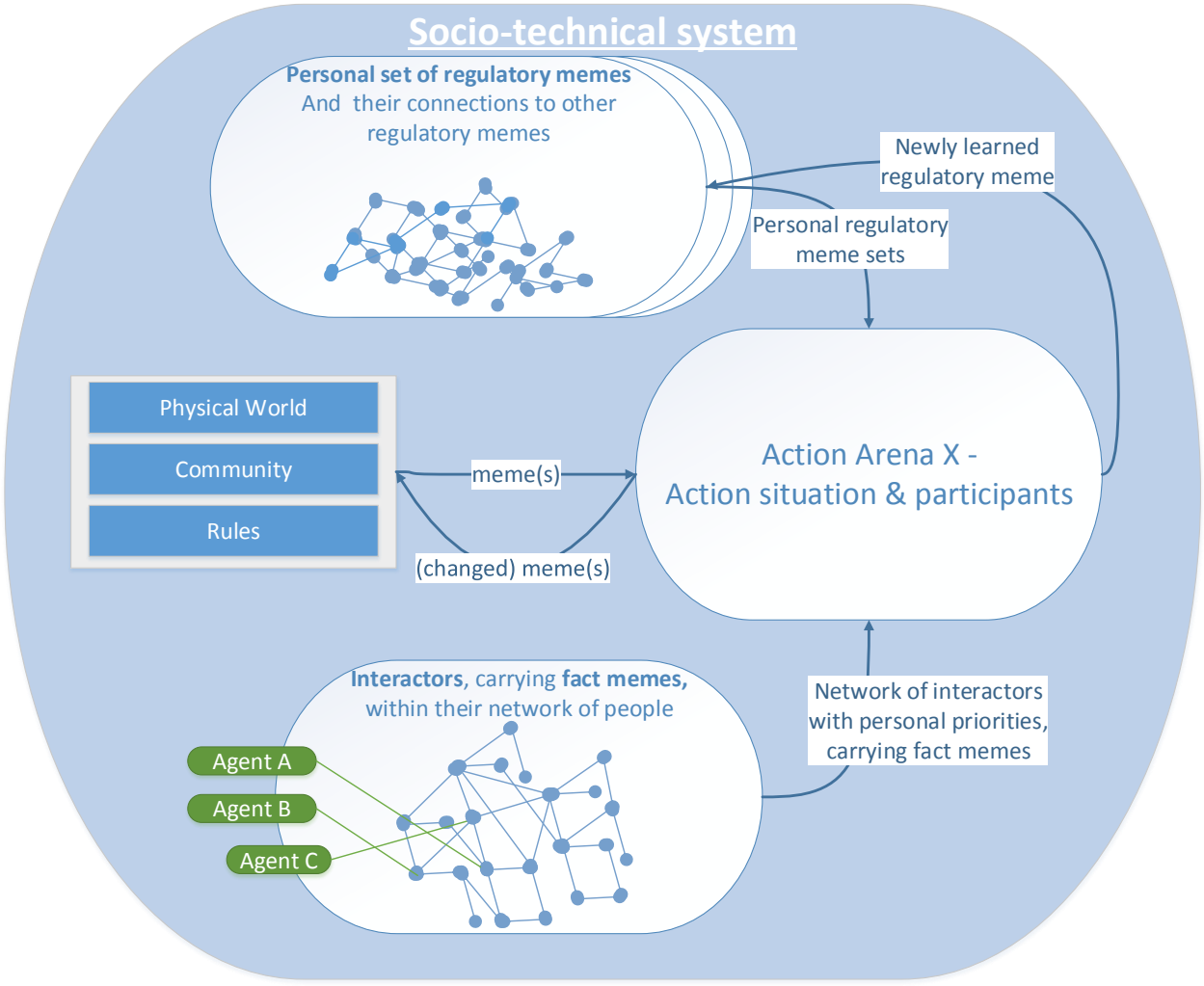


**Figure 13 Meme types and their influence on the system**

The two types of memes are each other's environment, see Figure 14. The difference between Figure 13 and Figure 14 is that in Figure 14 the 'personal set of regulatory memes' became 'shared set of regulatory memes', to keep the overview in the visualization. The red arrows show that regulatory memes are used by the interactors in the action arena. The small circles in the upper part are regulatory memes. The links between these memes appear when a pattern of interaction is routinized.

An example is given of a fictive pattern of interaction. An important assumption in this example is that the involved actors and the environment have the personal priority to fix the water point. The example in Figure 14 starts off by the fact meme 'Water user notices that the water point broke down' that enters the action arena (1). This fact meme is picked up and replicated by the water user, whose action is influenced by a certain regulation meme (Water user goes to the water user committee to inform about the broken water point(1)). Subsequently the fact meme is replicated by the WUC to inform the HPM (2). The HPM on his turn identifies the problem and repairs the water point for free (clearly this is a fictive example) (3).

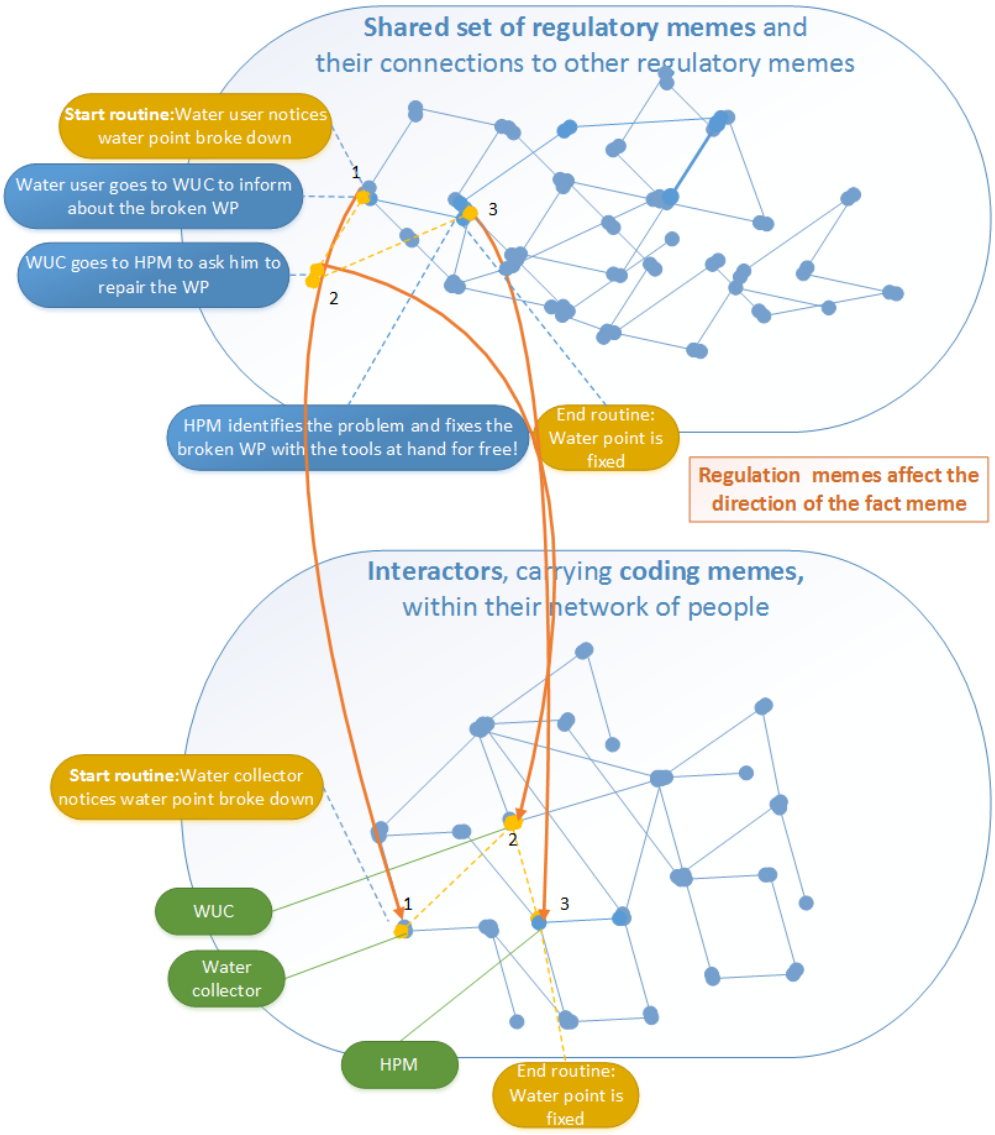


Figure 14 Operationalization of memes

Adaptation of memes is not shown in this example, as in the read literature it did not become clear how, under which settings and what is varied at operational level (Aldrich et al. 2008).

> *It is assumed that the decision to change the memes is given to the environment (the community).*

**Revised visualization of the (influenced) processes**

Now that the meme division is introduced, the visualization of the (influenced) processes (Figure 10, page 40) needs an adaptation, see Figure 15. It can be seen that the interactor receives memes from the environment (which entails community, physical world and rules) or from within the action arena. The action arena here are the five interactors.

*It is assumed that an interaction incorporates the two types of memes.*

The interactor receives a fact and regulatory meme from the environment by for example watching the television (red line) that people in Uganda have elections (blue line). The interactor can reproduce this fact (blue line) by using a particular regulatory meme (red line).

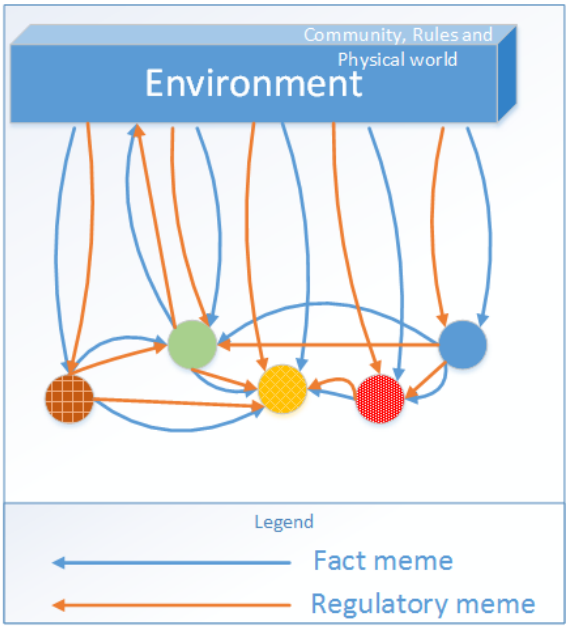


**Figure 15 Revised visualization of the (influenced) processes on operational level**

**The environment**

In Figure 13 the environment is (just like in the IAD framework) community, physical world and rules. The environment is dependent on the scope of the action arena. Fact and regulation memes represent the different kinds of streams coming from the environment into the action arena.

### 3.3.1 Darwinian principles – Variation, Selection, Heredity

To understand how processes in socio-technical systems evolve over time (part of the first lack of insight), the mechanisms of variety, heredity and selection are researched.

**Variation**

The variation or the change of a meme is either a copy error or an innovation. There are different kinds of copy errors and innovations. First the copy errors will be explained, followed by an explanation of innovation.

It is however important to realize that, as mentioned above, there a lot uncertainties concerning the interpretation of variation in socio-technical systems (Aldrich et al. 2008). In literature it is not found how, what and under which conditions a new variation of a meme is produced in a socio-technical system.

*Copy errors*

There are two kinds of copy errors, namely a copy error occurs in the behavioral part of the meme or a copy error occurs in the cognitive part of the meme.

The copy error which changes the cognitive component of a meme, so that cues are associated with different kinds of behaviors. Hodgson & Knudsen (2010) state that this kind of error is detrimental to the evolution of complexity. The second error is reading errors. Such a read error changes the behavior, but not the cognitive component. So, the replicator's cognitive part stays the same with the second error type, however this error erodes order in the observable trait pattern (Hodgson & Knudsen 2010a). For example, in South Uganda a station attendant learned that every day he has to push a button to record what the status of the pump is. But by pushing this button he resets the whole recording system. So, no data was recorded at all. This is clearly a wrong understanding of the regulatory meme. This is a behavioral copy error, because he did it with the right intention which is in line with the regulatory meme, as he wanted to record the status of his pump, but he did the wrong action.

This example doesn't only have a consequence on the execution of a certain regulatory meme, but also on other regulatory memes, fact memes and the pattern of interaction. The record of the pump station (the fact memes show zero failures, days off etcetera) goes to the district authority, who concludes that no money needs to go to this pump station as the pump functions perfectly. So, due to this mistake the pump does not receive any subsidy.

*Innovation*

Innovation is the more deliberate version of a variation. A person or a group of people can deliberately change a meme. For example, people can change a law, by adding a paragraph, or a fact (Hodgson, 2008, p. 401).

**Selection**

Selection pressures influence the decision of an interactor. Veblen (1899) described the effect of selection pressures on social institutions in a clear way: *'In whatever way usages and customs and methods of expenditure arise, they are all subject to the selective action of this norm of reputability; and the degree in which they conform to its requirements is a test of their fitness to survive in the competition with other similar usages and canons* (Veblen, 1899, *p.166*)*'.*

A more or less popular meme means that a certain meme gets less replicated. As an example to illustrate selection pressures, see Figure 16. A fact meme's popularity is influenced by other fact memes their popularity. The selection pressure '*Health*[20]*'* has a high priority to a civilian. The selection pressure '*less friends*[21]*'* has a lower priority for the civilian during the decision making process. Other selection pressures are resources and objective selection pressures, like temperature/natural climate change.

[20] (read: clean drinking water is important)

[21] *less friends at the water point than at the river*

*The fact meme can be a (stimulating or repressing) selection pressure for another fact meme. The regulatory meme can be a (stimulating or repressing) selection pressure for another regulating meme.*

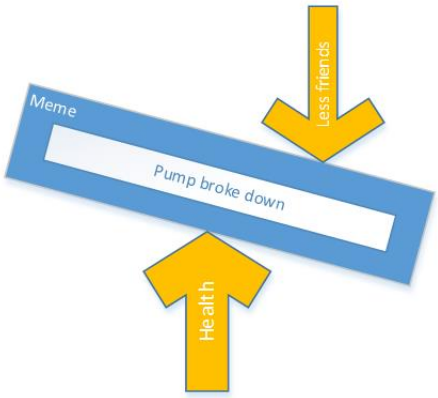


**Figure 16 Selection pressures affect the popularity of a meme**

Before a person selects a fact and regulatory meme, he/she can think about whether he wants to transfer the information or not. So, a decision of a person is not just a compilation of different external selection pressures. People also have self-reflection and personal priorities that they take into account during the decision making process of replicating a meme/habit or not. In other words, personal priorities are a form of internal selective environment[22] (Blackmore 2000).

**Heredity**

The third Darwinian principle is heredity. In this research heredity is understood as imitating/passing/ copying problem-solving or developmental information from one entity to another.

In the real world a person can copy a 'way of doing' from another person. By imitating this regulation meme the meme scope and memeplex is enlarged. This phenomena is explained in the next section. Imitation is an important mechanism that makes humans different from (most) other animals (Blackmore 2008).

**Memeplexes and memeplex scope**

The definition of a memeplex that is adopted in this thesis report is visualized in Figure 17. The memeplex is a 'co-adapted meme complex (Blackmore 2000)' and more specifically: *'The memeplex is assumed to be a compilation of adopted fact memes, regulatory memes and personal priorities. New memes can be adopted in the memeplex, depending on the interactor, his direct environment and current memeplex.'*

[22] Blackmore points out that a meme succeeds of fails due to the nature of human beings ('with its clever thinking brain(Blackmore 2000)'. No further explanation of this replicating process is given, in the area of psychology the answers need to be sought.

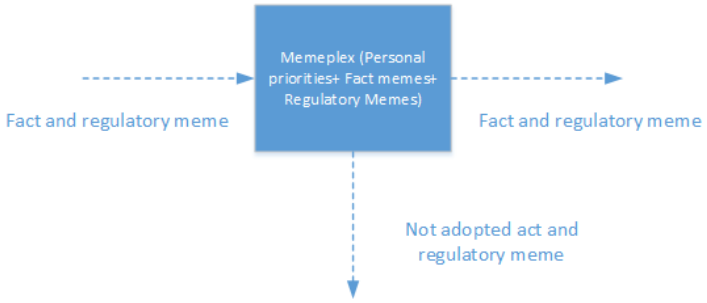


Figure 17 Interactor's memeplex

The network theory shows that a person (interactor) who is surrounded by people who adopted a certain meme, it is probable that that person will also adopt that meme. For example, if most of your family eats a lot of potatoes and chicken (as in Uganda), it is more likely that you will adopt the same habits of eating many potatoes with chicken (Christakis 2010).

> *Whether a meme is adopted in the individual memeplex depends on the controversy of the meme with respect to the current memeplex.*

The way people judge or perceive a certain physical reality is personal. For example, there is a situation where there are no women in the WUC-board. Whether a person thinks this is good or not depends on a person's memeplex.

> *The perspective of a person depends on the set of adopted memes and personal priorities of him/herself.*

**Meme scope of an interactor**

The meme scope, which was introduced in Figure 13 the explanation of is continued here. An interactor knows a certain amount of regulatory and fact memes, but has a bounded rationality (Simon 1982). This amount can grow due to information transfer and imitation (see circle with orange outer line in Figure 18) (Blackmore 2000).

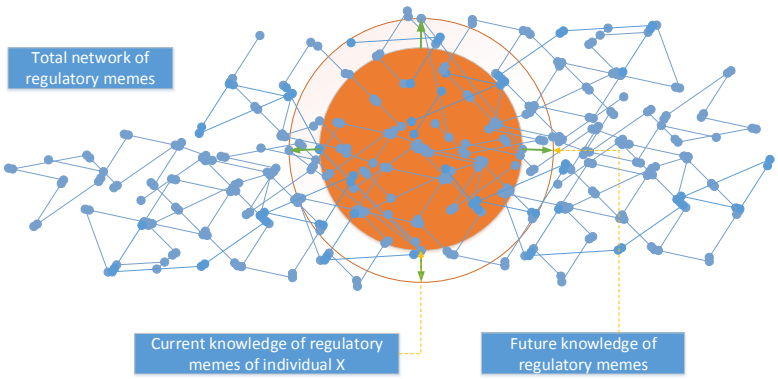


Figure 18 Regulatory meme network

The people that deal with each other in an action arena, like the people of our water services delivery case, have a set of regulatory memes which is for some part shared. For example, a local hand pump

mechanic (HPM) knows less and other regulatory memes than the district water office (DWO), see Figure 19. The yellow ball is the scope of the regulatory memes of the DWO and the orange ball is the scope of the HPM. Regulatory memes that are outside the scope of a HPM can be added to his scope by information transfer and imitation of other interactors.

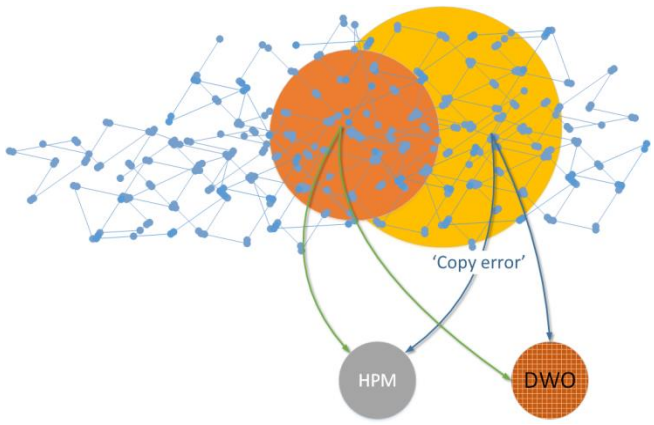


**Figure 19 Meme scope of a hand pump mechanic (HPM) and a district water office (DWO)**

In the next section two fictive examples are given illustrating the UD-institutional framework.

## 3.4 Applications of conceptual framework

In this section two situations are described from the conceptual framework' perspective. For the first example, a short description of the problem is given, which is in line with the IAD analysis questions of Polski and Ostrom (1999). In this example all the interactors have the same goal. Beside the IAD aspects, also the three key Darwinian principles are analyzed. Followed by a generative replicator analysis. This section is concluded with the second example, now with the integration of two goals.

### 3.4.1 Single goal example

The *fictive* example is about the repair of a water point:

*The morning that the water point broke down, a water collector notices a particular water point failed. This interactor takes action by going to the Water User Commission (WUC). The WUC in his turn goes to the failed water point and checks the condition of the water point and notices that he himself cannot repair the water point. The WUC therefore informs a local Hand Pump Mechanic (HPM) about the failure. After the HPM is asked to fix the failure and the HPM has confirmed to do the job, he gets paid by the WUC for the repair. The HPM collects all the necessary tools and spare parts from the local spare parts 'warehouse' and walks to the defect water pump. When he gets there, he is able to repair the water point immediately. Within 6 days the water point is repaired. The outcome is positive for all the present interactors, as the water pump is repaired quickly, providing clean water to the local civilians.*

**Analyze community attributes**

The community knows that water from the river can contain viruses and bacteria that can cause illnesses. They also know that maintenance is important for the total lifespan of a water point. It is seen as your 'duty' to inform the WUC as soon as the water point shows a failure.

In this fictive example community's attributes are:

1. The community believes that it is important that clean drinking water is available.
2. Every 2 year they vote for a new WUC.
3. The WUC ask a small contribution for the drinking water of the civilians, to pay repairs and maintenance from.
4. The money is collected once a month. The very poor do not have to pay, as they cannot afford it.
5. The community gets well informed on the expenditures of the WUC.

**Analyze rules-in-use**
The main regulatory memes are:

1. AIC (shared strategy): The water collector goes to the WUC to inform about the water point failure.
2. ADIC (norm): WUC should go to the water point to identify the failure as soon as there is a reason to.
3. ADICO (law): WUC has to make sure the water point gets repaired within a period of 6 days after the WUC paid the HPM or else he will get a fine from the District Water Officer (DWO).
4. AIC (shared strategy): People, inter alia HPMs, go by foot when possible, as it is less expensive.

The fact meme that comes in the action arena is 'Water point broke down'. This meme can be changed due to copy errors. As soon as the water repair pattern of interaction has finished successfully, the fact meme ' water point broke down' is irrelevant to replicate.

**Actor situation**
Water collector - The information that the local water collector gets is that the water point broke down, as no water is coming out of the water point, which can be seen as an important fact meme in this story. From the action that the water collector takes it can be concluded that he acts in line with the community belief, that clean water is important. The regulatory meme that gives direction to this fact meme is the shared strategy *'The water collector goes to the WUC to inform about the water point failure*'.

WUC – As the norms says that the WUC should check the water point as soon as he receives a signal of failure of a water point, he does so, even though he might not feel like it. For him, the responsibility of the water point has a high personal priority.

HPM – The HPM receives a description of the failure of a water point and also the money for repairing it. There are many things that he could do with the money. His highest priority is to buy the necessary spare parts for the broken water point, as this is essential for keeping his job and good relationship with the local WUC. As he bought the spare parts and collected his tools, he goes to the water point, by foot. As time is less expensive than petrol for his scooter.

The direction that the regulatory memes give to the fact meme is:

$$Water\ collector\ < WUC\ < HPM$$

**Analyze outcomes**
The pattern of interaction is fit as is suits the selection pressures (memes) and results in the desired emergent pattern.

**Selection**
The memeplexes (known memes) of the interactors, conditions and personal priority have a great influence on the fitness of a meme, as they together the outcome of the decision.

In the example, the selected regulatory and fact memes is in line with the personal priority of the interactor. The memes cause/guide a pattern of interaction which repairs a water point. In this example there are no conditions which influence the decision of the interactor, as all actors in the action arena aim for the same goal.

**Variation**
The phenotype of the fact meme in the example stays the same, as no copy error/innovation appeared during the pattern of interaction. The new information that the water point communicated with the water collector, by being broken, is a variation or combination of old memes (Blackmore 2000). From the available information it cannot be said whether an innovation or copy error of a meme occurred in the genotype.

> *Here it is assumed that the genotype of the routine stays the same as long as it is triggered by the same fact memes*.

In the next paragraph an example of change of a selection pressure is given and the heredity of memes/routines is further explained.

**Heredity**
The heredity of memes happens via information transfer and imitation. In this example heredity takes place via information transfer (for example via talking).

***Four conditions of a generative replicator***
Hodgson (2010) stated that conditions of a generative replicator are: causality, similarity, information transfer and conditional generative mechanism. Here the four conditions are analyzed, to verify whether the fact meme and regulatory meme are a possible generative replicator or not.

**Causality**
The cue that the water pump gave to the water collector by being broken is the reason for the water collector to replicate the fact meme 'pump broke down' to the WUC (which is a regulatory meme). In other words, the water point broke down and this gave rise to two generative replicators.

**Similarity**
Here the fact meme stayed completely the same. In the example it was not mentioned that neither the personal priority nor the genotype of the fact meme changed. In line with the assumption (*Here it is assumed that the genotype of the routine stays the same as long as it is triggered by the same fact memes*) it is assumed that the regulatory meme has stayed the same/similar.

**Information transfer**
In the example there has been information transfer, in the form of spoken word.

**Conditional generative mechanism**
The final condition of a generative replicator is the conditional generative mechanism, which can enhance complexity. This mechanism uses signals from the environment and produces further instructions from the generative replicator to the interactor to guide its development (Hodgson & Knudsen 2010a). No literature has been found that shows how this conditional generative mechanism can be proven.

> *The assumption is made that regulating and fact memes have a conditional generative mechanism and therefore can be seen as a generative replicator.*

### 3.4.2 Multiple goal UD-Institutional example

In this fictive example there are two personal priorities trying to be accomplished by interactors. In Table 5 there is an overview given of the actors' IDs (first column), their function (second column), their priority (third column), their connections (fourth column) and sometimes the decision power on personal priority number 1 or 2.

**Description**
*The personal priority number 1 is to maintain the current WUC president (A). The HPM and the WUC treasurer are also in favor of the WUC president being reelected. The interactors (A, B and C) are rather lazy than active collecting money for a repair of a water point.*

*The second goal is to repair a particular water point (2). This is advocated by interactors D and E, so the tribal leader and WUC mechanic. The tribal leader has the decision power over the position of A, so personal priority 1. It is assumed that the interactors know each other's priorities (1>2 or 2>1).*

Table 5 Overview of multi-goal actors, connections and priorities

| Id of interactor | Function | Priority | Connections | Decision power |
|---|---|---|---|---|
| **A** | WUC president | 1>2 | B, C, D, E, F | 2 |
| **B** | HPM | 1>2 | A, E | |
| **C** | WUC treasurer | 1>2 | A, E, D | |
| **D** | Tribal leader | 2>1 | A, B, C, E | 1 |
| **E** | WUC mechanic | 2>1 | A, B, C, D | |

**Pattern of interaction**
The water point that the tribal leader uses breaks down one morning. The WUC and HPM would rather do nothing with this news (fact meme). However, as the WUC president knows that his position is at stake, he decides to take action and stimulate the WUC and the HPM to do their job properly. The HPM assesses the water point and communicates this information with the WUC. The WUC collects the necessary money and pays the HPM. After the spare parts have arrived the HPM repairs the water point.

The tribal leader is positive about the attitude of the WUC president, as it is in line with the personal priority of the tribal leader. Now it is in the advantage of the tribal leader that the current WUC president keeps his position.

An evaluation of the conceptual framework and these examples is given in the next section.

## 3.5 Sub-conclusion

Here the gained insights concerning the sub-research question - *How can evolution in a socio-technical system be formalized in a conceptual framework?*- is summarized. The two lacks of insight that assist answering the sub-research question are: *How do processes in socio-technical systems evolve over time? How can processes in socio-technical systems be formalized?*

As mentioned above, the starting point of this study is Universal Darwinism, as it is the most simple theory that explains evolution. During the literature study it became clear that the operationalization of UD is still in an development phase. The translation of the Darwinian principles (selection, heredity and variation) have been sought in the fields of Universal Darwinism and institutional analyses.

Memes are chosen to be the generative replicator, because memes contain adaptive solutions to problems and guides the development of interactors (Stoelhorst & Huizing 2006; Blackmore 2000; Dennett 2007). Decoding accumulated memes gives reason to repeat successful behaviors in future interactions with the environment (Stoelhorst & Huizing 2006).

To specify memes further, an analogy is made between Memetics and molecular genetics, by taking the gene-distribution for memes. In molecular genetics a coding gene codes for a particular property of an entity. Where and when the property is expressed is organized by the regulatory gene (J.B. Reece & Urry 2010; Mesoudi et al. 2006). Accordingly, memes are divided into coding (hence forth: fact) memes and regulation memes.

The content of regulatory memes in socio-technical systems is assumed to be determined by institutions (norms, values and shared strategies) are chosen to be the content of the regulatory memes. The reason for choosing institutions as content of regulatory memes is that institutions give structure to socio-technical systems, are measurable, are relatively stable, durable and have a way to adapt to new situations which is transferred from interactor to interactor (Veblen 1899).

The link between UD and institutional analyses has been made in the first place because institutional analyses complements the Universal Darwinism theory in its measurability and proven applicability in socio-technical systems (Polski & Ostrom 1999).

In Table 6 an overview of the UD concepts' interpretation is given. The world is reduced to personal priorities, two types of memes, interactors and the Darwinian principles' mechanisms. Which is within the borders of the formulated conditions, as it contains all three Darwinian principles, has a gene-like entity, incorporates institutions and decision making of humans.

Heredity is operationalized as an imitating and information transferring mechanism. Variation of memes come about due to innovation and copy errors of memes by interactors. Selection happens due to

internal (personal priority and memeplex) and external selection pressures (memes that impose a pressure on the 'fitness' of the particular meme).

Table 6 Adapted UD concepts interpretation

| Concept | Concept translation |
|---|---|
| **(possible) Generative replicator** | Fact and Regulatory memes |
| **Generative replicator carrier** | Interactor |
| **Variation** | Innovation and copy errors |
| **Heredity** | Information transfer and imitation |
| **Selection** | Personal priority and other generative replicators |
| **Environment** | Fact and Regulatory memes |

The conceptual framework is tested in two fictive examples, which is reflected upon per element and overall below.

**Evaluation**

The two examples show how information is transferred from one interactor to another, due to the fact that 'need' each other to achieve their personal goals. It can also be seen that personal priorities are taken into account by the interactors.

The IAD framework helps to define the actors involved, pattern of interaction, rules opposed from the community and outcome of the system. In the example there is, however, no distinction made between influence of the environment and other actors.

The operationalization of the Universal Darwinian principles are, however, not yet fully developed:

a) Heredity is about transferring a meme from person to person. Here it is adopted as copying a fact meme. However, no regulation memes are transferred from person to person.
b) Variation of memes is not included in the two examples, as the fact memes stay the same and it does not become clear whether a variation is made concerning a regulation meme. The operationalization of variation is complicated as it is still unknown how and under which circumstances a variation is produced in a socio-technical system.
c) The selection of a meme during a decision making process incorporates the known memes, personal priority and conditions. The conditions are created by memes that have an influence on the fitness on the particular meme, as it can make the particular meme less attractive to decision maker.

The institutional grammar gives a clear overview of the used regulation memes in the first example. However, now that the variation mechanism is not yet incorporated fully, the added value of this analysis is limited. When the memes vary, the ADICO framework can show which repetitive elements stay constant and which are adapted.

In the examples of the conceptual framework it is shown that the institutional theories and UD theory overlap each other, as the institutional analyses helps the UD theory to identify:

- The 'gene-like entity' in the socio-technical system.
- The different foundations of the replicators (Crawford & Ostrom 1995).
- The different change rates of existing replicators (Williamson 1998).
- The network of interactors that (possibly) influences the replication of replicators (Polski & Ostrom 1999).
- The human selection process of replicators (Bandura 1999; Ghorbani 2013; Polski & Ostrom 1999).

In the next section an instrument is chosen to bring (and test) the combination of theories together to further test the conceptual framework.

## 3.6 Modeling approach – agent-based modeling

A model is a simplified representation of the reality, which can be used to solve problems under constraints (like money, time, information etcetera). Furthermore, implicit assumptions, rules and strategies to solve the real world problem are made explicit in a model. The modeling approach is important as certain problems can or cannot be modeled with a certain modeling and simulation approach.

Agent-based modeling is used instrumentally to put the theories (Universal Darwinism and institutional analyses) together. Important reasons to select agent-based modeling as modeling and simulation approach are:

- Contrary to other modeling techniques, like System Dynamics and Discrete Event modeling, it is possible to model emergent[23] behavior, due to a bottom-up approach, which is important as IRC International Water and Sanitation Centre is interested in the possible evolution of the water services delivery system (Van Dam et al. 2012).
- Consist of agents that are pro-active, autonomous, spatial aware, reactive, able to learn and have social abilities, are driven by behavior rules defined by 'state charts' and 'live' in an environment (Csala 2012).
- It incorporates inter alia evolutionary programming (Csala 2012).
- There are no unrealistic assumptions like linearity, normality and stationarity (Ghorbani 2013).
- A general advantage of simulations is that different theories can be tested together, which is not possible in the real world (Gilbert 2004).

[23] Emergence is formulated by van Dam et.al. (2012) as *'Complex systems display properties that cannot be understood by just looking at the properties of the individual components, but are created as a result of the structure and organized interactions between these components. For example, the price of tomatoes cannot be directly determined by just looking at the costs of the facilities and resources used to grow them, nor even by looking at the total production and demand. The price of a tomato is determined by many things, not all of which are operating at the level of tomato production'.*

However, these benefits also have a downside. The modeler cannot, like for example with System Dynamics, validate and verify the model with traditional validation methods (Van Dam et al. 2012, p.127). The Ugandan model is exploring possible future states (with testing the different policies), there is not 'real' system available to compare the outcomes of the model with.

Agent-based modeling (ABM) is a well-developed technique for modeling complex adaptive systems in a bottom-up approach. Due to this bottom-up approach, important actors of a system are modeled as agents which act and interact with one another and with the environment. This behavior eventually leads to emergent system behavior (Van Dam et al. 2012). The structure of an ABM is visualized in Figure 20. The basic entity of an ABM is an agent, which consists of rules, states and exists within an environment. By following the (behavioral) rules an agent can change its own and other agents' state. Furthermore, an agent can exchange information with other agents and its environment (Van Dam et al. 2012). The first step of building an ABM is to identify agents, rules, states, actions, environment and the flow of information as they are observed in the real world by the modeler.

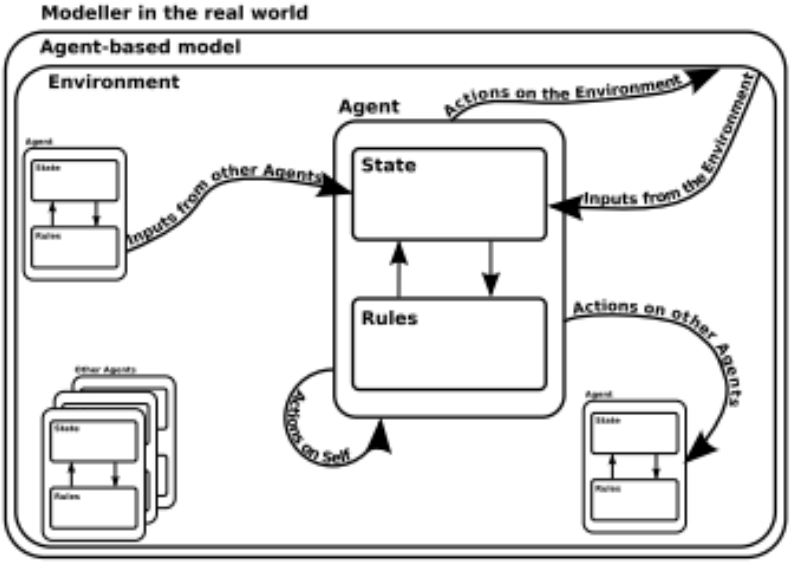


**Figure 20 Structure of an agent-based model** (Van Dam et al. 2012)

A complete step plan for building an agent-based model is explained in van Dam et al. (2012), which consists of 10 steps: 1) problem formulation and actor identification, 2) system identification and decomposition, 3) concept formalization, 4) model formalization, 5) software implementation, 6) model verification, 7) experimentation, 8) data analysis, 9) model validation and 10) model use. The first four steps, which are relevant for agent-based model design, are explained below, because within this Master thesis project there is not enough time to go through all the agent-based modeling steps.

1) Problem formulation and actor identification: This step consists of identifying the purpose and therefore the lack of insight of the problem. To do this, one should examine the whole system to see if there is emergent behavior apparent. If there is emergent behavior, a hypothesis has to be formulated on how this behavior is caused (bottom-up approach). As a result, at this point it is important to identify actors that are involved in the emergence of such behavior (Van Dam et al. 2012).

2) System identification and decomposition: To be able to specify the agents and the interactions that take place, it is necessary to do an inventory on all the information necessary about the system. Information that should be identified are: important concepts to the system, actors (and its states), the behavior of the actors, objects, the environment, and the flow of information. This information is used to build a structure of the model (as in Figure 20) (Van Dam et al. 2012).

3) Concept formalization: The basis structure, which is formulated in step 2, is then converted into information that can be used for programming the model. The information becomes variables, classes, lists, tables, objects etcetera. When this is done, the ontology is made. This means defining (hierarchically) the elements of the model and the relationship between them (Van Dam et al. 2012).

4) Model formalization: Now that the structure is clear it is time to first write the model narrative. This narrative puts down in words what the model supposed to do: How should actors perform actions? What triggers them to do a specific action? And when is information supposed to flow? Furthermore, the narrative also contains the sequence of actions that should happen during one time unit step. The narrative can be turned into a pseudo-code which is the algorithm of the model behavior (Van Dam et al. 2012).

In line with the assumptions made, Figure 21 is adapted to the assumptions made in the conceptual framework, see Figure 21. The agent in the ABM model is an interactor, with fact memes and personal priorities (state(s)), regulation memes (rules). An interactor is defined here as an *agent which carries memes and personal priorities*. An agent is defined by Nikolic & Dam (2012, p. 57) as reactive, proactive, autonomous and social software entities.

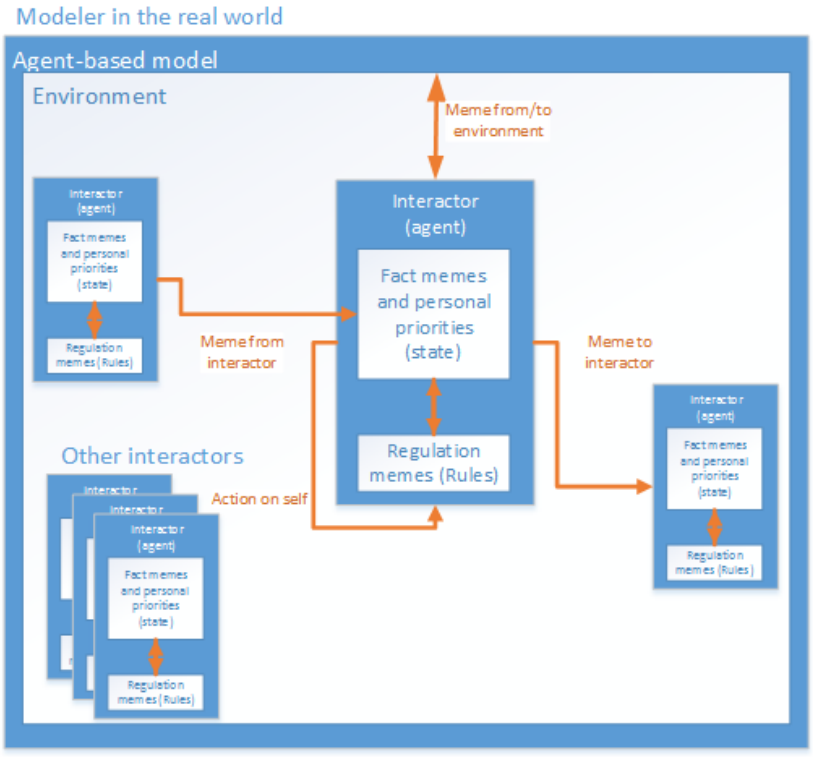


**Figure 21 Adapted structure of an agent-based model from Nikolic and Dam (2012)**

The state of an interactor is ‘a collection of parameters which defines an agent (Nikolic & Dam, 2012, p. 58)’. The collection of parameters fact memes, which are public or private and composed of all the values of the current (financial) balances, water use etcetera.

The rules of an interactor (henceforth the regulation memes) are the ‘*internal models* (Holland, 1996 sited in Nikolic & Dam, 2012)’. The rules of interactor describes how to translate a fact meme (state) to an action and/or an new fact meme (state). The type of rules in the agent-based model are *Rules based* (Nikolic & Dam, 2012, p.59). Rules based rules are usually in form of if-then-else (Nikolic & Dam, 2012, p. 60).

# Part II: Model Design

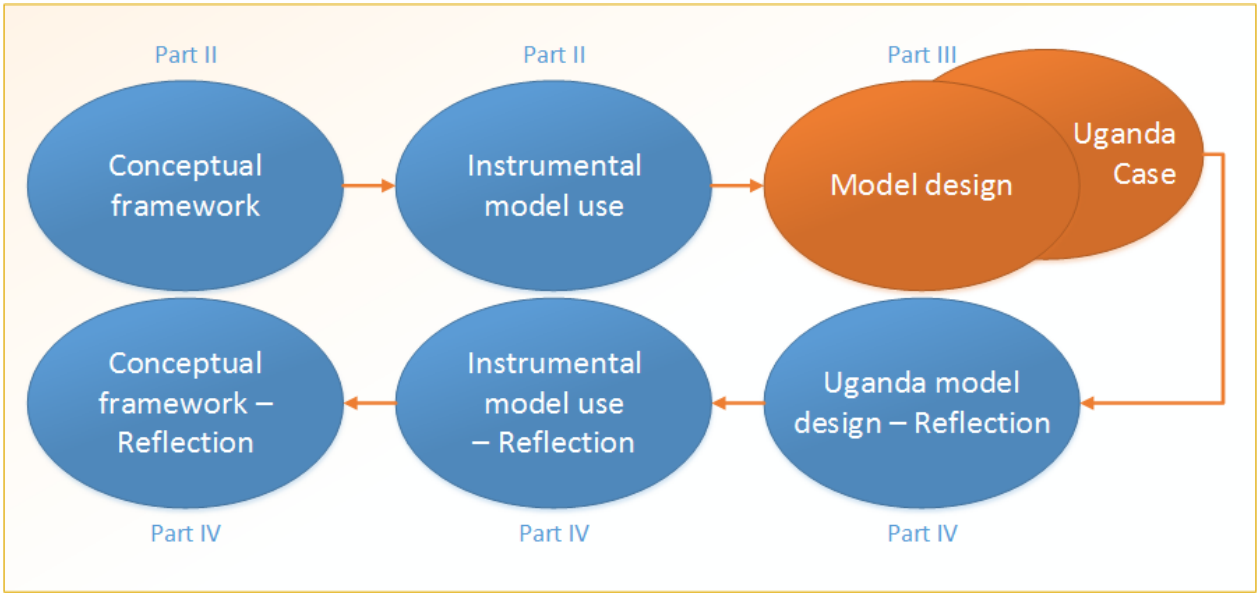


Figure 22 Reading guide 2

# 4. Conceptualization of agent-based model design

In this chapter the first four steps of the design of an agent-based model are described, starting with a deeper understanding of the problem and actors involved, followed by the model design. The model design contains the second (system identification and decomposition), third (concept formalization) and fourth (model formalization) step.

In this chapter there are two lacks of insight that need to be answered before the second sub-research question - *How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case?* - can be answered:

- *What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda? (empirical)*
- *How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda? (design oriented)*

## 4.1 Problem formulation and actor identification

A deeper understanding of the water services delivery problem is sought, by trying to answer the agent-based model development questions as short and as complete as possible (Van Dam et al. 2012). Echoing the modeling development questions, it is tried to extract the most important mechanisms that cause the current water services to fail, which in the meantime answers the first lack of insight - *What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda?*

**Data collection – interview setup**

The data comes from literature, which was written by IRC International Water and Sanitation Centre, development partners, the Ugandan government and from interviews with experts in the field of water services delivery in rural areas of Uganda. The experts are all IRC staff members (based in the Netherlands and Uganda), see appendix 9.6 for the interview summaries and the interview questions.

The interview questions are inspired on the IAD framework interview questions (Polski & Ostrom 1999). The IAD framework questions are focused on inter alia rules-in-use and the pattern of interaction, which is in line with the information that needs to be gathered to populate the 'conceptual framework'-model design. The interview questions are evaluated by Maartje E.D. van den Boogaard, who is a researcher at the Technical University in Delft and a teacher in interview techniques, as the interview is essential for populating the model design with useful data.

The interview, which had been communicated at forehand, starts with an quite extensive introduction of the purpose and background of this research. This gives the interviewee the chance prepare themselves and to understand the reason why the interview is conducted.

During the interview, some interview questions are adjusted, because the interviewees find it difficult to structure their knowledge within the boundaries of the prepared questions. Especially questions concerning specific values/norms are difficult to answer. The questions were too straight forward for the Ugandan interviewees as they prefer to tell a story concerning about a certain subject. These stories are

full of norms, values etcetera, however, they could not be explicitly named by the interviewees. For the 'Western' people the questions were often too specific, but they could point out articles for me to read.

In the end, the model design could be populated with sector knowledge and in the meantime the conceptual framework is reflected upon. As Ostrom and Crawford also notified, during the interviews it became clear that the actual boundaries between laws and norms are more vague than that the coding allows. Furthermore, people often are not aware of certain 'unknown-known' institutions, as it is tacit knowledge (Crawford & Ostrom 1995, p.595). No other problems encountered during the interviews in relation to the conceptual framework.

**Agents-based model development questions**

First the agents-based model development questions, as shown below in Figure 23, are answered. Followed by an conclusion on the 1st lack of insight.

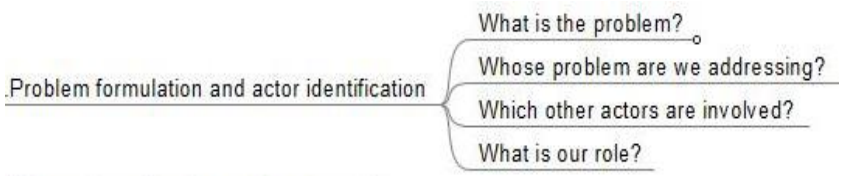


Figure 23 Agent-based model development questions (Van Dam et al. 2012)

**Problem owner and actors involved**

Starting with the second, third and fourth question of Figure 23, the problem owner in this thesis research is IRC International Water and Sanitation Centre, as it supports the change manager. The goal of IRC International Water and Sanitation Centre in this research is to gain more information on how the system functions and changes over time, to later facilitate change.

**Overview of interactors:**

The interactors that are considered in the action arena of the Water Services Delivery System in rural areas of Uganda at district level and down: District Water Offices (DWOs), Hand Pump Mechanics (HPMs), Water User Committees (WUCs), Water Users (WUs), local government (LG) and the Environment. These interactors fulfil the functions Water Service Authority, Water Service Provider and Water Service Consumer at district level in Uganda. The object that are considered are Water Points (WPs) and Database of Failed Water Points (Database of Failed WPs).

The environment consist of all the actors that are active above the district level, like the Ministry of Water and Environment, development partners, Technical Support Unit (TSU) or are a bit more vague to describe, like the physical world and the community.

**What is the problem?**

As mentioned in the introduction, reliable water flowing from safe sources is not a certainty in rural areas of Uganda. Due to the fact that WPs often break down, services fail and often last for many days or weeks (Schouten & Moriarty 2013). The **problem** is that there is a water services delivery system, within a region/sub national service area (district), which fails to deliver water services at a desired level of performance(Schouten & Moriarty 2013).

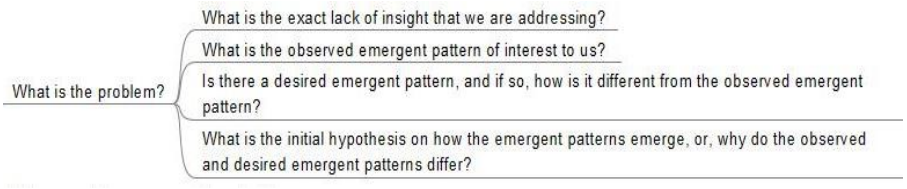


**Figure 24 Detailed questions on problem formulation (Van Dam et al. 2012)**

As mentioned above, the first lack of insight, that is addressed in this research, is *What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda?* In other words, how does the water service level (WSL) get affected. The **emergent pattern** that is observed at the moment, is water service providers fail to maintain/repair the water points. Therefore a relatively low percentage of water points, and thereby water users, receive the desired level of water services (Schouten & Moriarty 2013). Furthermore, water service authorities and water users do not put pressure on or incentivize the water service providers, to do their job in a more sustainable manner (Smet 2013).

Some highlights of the current situation (Nabunnya 2013; Schouten & Moriarty 2013; Smet 2013; Lieshout 2013; Magara 2013):

- Low WSL is often reality for water users.
- Too little/no maintenance of the WP is practiced by the HPM.
- Usage/repair/maintenance money is often not collected by WUCs or takes a long period of time.
- WUs don't easily pay the WUCs for the repair of a WP, if the dependency on the WP is low and the trust/satisfaction with the WUC is low.
- No fines/incentives are given to WUCs or HPMs to stimulate a better functioning entity.

Water users (with different roles) have different priorities, values, norms etcetera. They tend not to act in line with processes which are designed to improve and/or maintain the WSL and develop different kinds of attitudes and perceptions towards water services delivery processes. As in Uganda *'all the institutions (laws, directives) are in place to make the water services delivery system work* (Nabunnya 2013)'. '*Now, the difficult thing is to let people live by the rules* (Nabunnya 2013)', due to inter alia different priorities.

**Desired emergent pattern:**
The desired emergent pattern is that there is at least a basic level of service for water users (WUs). The WSL is constructed from the Service Delivery Indicators: Water Quantity, Crowding at WP, Reliability, Distance and Quality of the water (these indicators are explained in section 4.1.1). Important desired patterns in the water services delivery system are:

- Sustainable, well-functioning water points
- Basic WSL or higher for WUs
- Suitable response to failures by WUC, HPM and DWO
- Healthy money balance of the WUC, HPM and DWO
- Regular maintenance, facilitated by the WUC and executed by HPM
- Adequate supply of means (knowledge, spare parts, new WPs and money)

Key indicators that have been named during the interviews, that (indirectly) influence the WSL, are described in next paragraphs:

**Dependency and satisfaction**
During the interviews it became clear that a water user is more motivated to maintain a particular WP well if a water user is dependent on a particular water point and/or satisfied with the particular WUC. The dependency and satisfaction of a water user have a direct influence on the amount of money (henceforth: relative budget) a WU wants to give to a WUC for maintaining and repairing a WP (Lieshout 2013).

> *The 'satisfaction with the WUC' (henceforth: satisfaction) and 'dependency on the WP' are assumed to be indirectly related to the water service level a WU receives from the WP.*

**Motivation**
The motivation of the WUC and HPM is taken into account, because during the interviews it became clear that the motivation of WUC and HPM can influence the WSL (Nabunnya 2013). The motivation of the HPM and WUC indicates the extent to which they are dedicated to doing their job in line with the desired emergent pattern. If the motivation is low, it is difficult to keep the WP working, as it needs a lot of care and time. It takes for example a lot of time to collect money for the repair/maintenance/day-to-day management of the WP.

*Motivation is assumed here to be the operationalization of 'personal priority'.*

The motivation of other interactors are not taken under consideration in the model design, because:

- Motivation of WUs is represented by its dependency and satisfaction with a certain WP/WUC, as these indicators influence the WUs' behavior (Lieshout 2013).
- DWOs are well educated and genuinely motivated people (Bey 2013b). 'They are genuinely interested in improving the water services delivery system/technique (Bey 2013b)'.
- The motivation of the local government is assumed to be in line with the motivation of the DWO.
- The motivation of the HPMA is taken into account and explained in chapter 9.7.1.

In the model design the motivation of the WUC and/or HPM can be influenced by several factors:

- **'Sanctions'** influence the WUC's and HPM's motivation, of the Sanctioning policy is implemented (see next paragraph).
- **'Relative budget'** Water users give when the WUC requests money for a repair/maintenance job or day-to-day management of the water point (see next paragraph). If there is a negative vicious cycle, of water users not willing to give money and low WSLs, the WUC can break this negative cycle by asking backup of the local government. They will make the WUs pay the amount of money the WUC asks them to (Bey 2014).This will give a positive boost to the WUCs' motivation.

**Functionality of WP**
The functionality of the WP is an evident indicator that firstly influences the WSL and secondly gets influenced by the amount of maintenance and repair the water service provider provides.

In the model design, as soon as a WP gets repaired, installed or maintained, the WSL, functionality of the WP, the dependency and satisfaction of the WU needs to be adapted.

***Initial hypothesis***

The initial hypothesis is that if some or all the policies (as formulated below) are implemented in the model design, the water service level becomes relatively higher than before the implementation, because it can affect the key drivers of the water services delivery, namely: Water Service Level, motivation of WUC and HPM, satisfaction of WU, functionality of WP and dependency of WU. Furthermore, knowledge input is assumed to have a (direct or indirect) effect on the key drivers of the water services delivery system. The knowledge inputs that are taken into account are:

- WP Management Knowledge (from environment (TSU/development partner) to WUC or/and HPMA)
- WP Mechanic Knowledge (from environment (TSU/development partner) to HPM)

***Sanctioning policy***

Sanctioning, which is a common method of the Western community to make people live up to rules/standards, is not often practiced in Uganda. The reason for this is that people are afraid that bad spirits are sent to them, if they evaluate/speak of another person negatively (Smet 2013; Lieshout 2013).

In this model design the possibility is implemented to make evaluations and give positive and negative sanctions to WUCs and HPMs by the DWO, so that there is a consequence to not performing adequately. The evaluations are composed by the local government.

***M4W policy***

The Mobiles for Water (M4W) policy is adapted from the existing M4W initiative by the Ministry of Water and Environment, IRC International Water and Sanitation Centre and SNV Netherlands Development Organization. At the moment the M4W initiative is in its pilot stage (Magara 2013; IRC et al. 2013).

This initiative has been initiated because it appears to be difficult to contact HPMs. HPMs tend to move to other districts and are difficult find to speak face-to-face. The M4W speeds up the communication process. Furthermore, it helps the DWO to get an overview of failed water points. This overview is important as this information needs to be communicated with the Ministry of Water and Environment to receive the District Water and Sanitation Conditional Grant (DWSCG, hence forth: Conditional Grant).

If the M4W policy (and thereby the object *Database of failed WPs*) is implemented in the agent-based model, then the water service providers can (if they have a mobile phone and prefer mobile contact over face-to-face communication) send a message to the *Database of failed WPs*. This database can be seen by the DWO and the concerning HPM receives a text message concerning the failed water point. These information streams help the DWO composing the Conditional Grant proposal and the HPM responding to WP failures.

*Currently in the model design the speed of things is not measured, therefore, in case of the HPM, the M4W policy only causes a different route of information.*

***HPMA policy***

Hand Pump Mechanic Associations are widely set up by the HPM themselves and stimulated by the government with the HPMA (Nabunnya 2013; IRC & SNV 2013; Magara 2013). The existing HPMA policy gives the HPMs the chance to organize themselves and the supply of spare parts better (Nabunnya 2013; IRC & SNV 2013; Magara 2013).

The adjusted HPMA policy for the model design basically provides spare parts and new WPs if requested by the HPM. Depending on its knowledge level, the HPMA has a smaller or larger stock of products, see chapter 9.7.1 for more details. The HPMA can, under certain conditions, also provide a maintenance contract, see next policy.

***Maintenance policy***

The Local Government Act states that currently maintenance is a responsibility of the District Local Councils (LC 5) in liaison with the Ministry who is responsible for the national resources (Ministry of Water and Environment 2011). *'The Act empowers the different levels of government to plan and implement development interventions according to identified local priorities, i.e. planning and allocation of resources towards Operations and Maintenance Support activities, and together with extension staff monitoring and follow-up support to established community structures. The Act also empowers Local Councils to make by-laws, subject to certification by the next higher Council or the Attorney General to ensure consistency with the Constitution, or any law, Ordinance or by-law passed by a higher Council. In this context a WUC may propose a by-law to be adopted by the Village Council regarding the management and maintenance of their communal water facility* (Ministry of Water and Environment 2011)*'.*

In this model design the HPMA is given the possibility to contract the maintenance of a particular WP with WUCs if this particular policy is implemented in the agent-based model. Maintenance contracts are an advancement in the amount of work a HPM has and in the sustainability of the WPs.

If a maintenance contract is made by the HPMA and the quarterly maintenance money is paid by the WUC, the HPMA contacts a HPM for performing a maintenance job four times a year. This policy can only be implemented if the HPMA policy is implemented.

***New WP policy***

The Ministry of Water, and Environment (MWE), through the Directorate of Water Development (DWD) is the lead agency responsible for inter alia the construction of new water points (Ministry of Water and Environment 2013). How exactly a water point can be requested did not become clear during the desk research. At the moment, most WPs are placed by development partners without the community requesting it (Schouten & Moriarty 2013). Now, there are more WPs in better accessible areas (Nabunnya 2013).

Here it is assumed that the equal allocation of WPs can possibly be enhanced, if the WUC knows when to ask for a new WP. In the model design the New WP policy can be implemented, so that WUCs, under certain conditions, can request a new WP.

***WUC payment policy***
The WUC payment policy is a policy which is adjusted from the existing National Water Policy of the Government of Uganda (Ministry of Water Lands and Environment 1999). This policy is based on the Community Based Maintenance Model (Lockwood & Smits 2011). In this model the community carries responsibilities concerning the water service provision (Ministry of Water Lands and Environment 1999).

Additional to the current policy, this policy includes the possibility for WUCs to receive a small salary for the their work by the DWO. At the moment the WUCs are having difficulties with staying motivated, as the WUC is not rewarded by the work and time they put into their job. The WUC should only earn a small salary for the work they perform, if their performance is reasonably well.

> *The WUC payment policy can only be implemented if the Sanctioning policy is also implemented, because otherwise the WUCs can underperform without any sanction.*

Here a description, as understood for the model design, of the WSL is given.

### 4.1.1 Water service level

Before explaining the WSL the divisions between water users and water points in the model design are explained. Water users living within a distance of 1,5 km from a particular water point are appointed to the water point's 'group 1' of water users. Water users that live within a distance of 1,5 to 3 km from the water point are assigned to 'group 2'. Water points (within a distance of 1,5 km) are assigned to the water user's 'group a' of water points. 'Group b' is filled with water points that are in a distance of 1,5 and 3 km distance.

Every WP has a certain amount of WUs within a 1,5 km and 3 km distance. The WSL can differ for the WU, who lives 3 km from the WP, with the WU who lives within a distance of 1,5 km.

> *Which WUs are assigned to a WP (close or far away) is a property of the WP.*
>
> *It assumed that a WU cannot be assigned to a WP that is situated further away than 3 km distance.*

The WSL is, as mentioned above, constructed from the Service Delivery Indicators: Water Quantity, Crowding at WP, Reliability, Distance and Quality of the water, see appendix 9.1. The indicator's rate can vary from 0 (very bad/low) to 5 (very good/high). The basic service level is rate 3.

A short description of all these indicators, as interpreted in this model design, is given here:

***Crowding at WP***
The amount of people that use the WP is the 'Crowding at WP'. Depending on the capacity of a WP the service level is determined for this indicator.

***Water Quantity***
The quantity of water received by a WU from the specific WP is related to the distance of the WU to the WP. If the WP functions perfectly (100%) and is within a distance of 1,5 km from the WUs' house, the Water Quantity is 20 liters per capita per day. The quantity can decrease to 10 liters per capita per day (for a distance of 3 km) (Lieshout 2013).

*Quantity rate is assumed to be 5 for group 1 and 3 for group 2.*

***Reliability***
Reliability is calculated on the basis of functionality rates over time.

*It is assumed that there are no abrupt breakages, so depending on the functionality distribution, which is determined during the setting up of the model and the received maintenance, the WP breaks down now or later.*

***Distance***
It is assumed that a certain amount of WUs live within a 1,5 km from the WP (Lieshout 2013). The WSL is not negatively affected by this distance. As soon as the distance gets larger, the WSL is negatively influenced (Lieshout 2013). A certain percentage of WUs will also live within a distance of 3 km of the WP. WUs who live even further do not receive a WSL from this particular WP (van Koppen et al. 2009; Moriarty 2010).

*The Distance rate is that is received by group 1 is 5 and 3 for group 2.*

***Quality of the Water***
The final WSL indicator is quality. This indicator is not measured in the field yet. The quality is also to determine as the quality of the water is highly influenced by the hygiene of the used jerry cans. These cans are often unhygienic (Bey 2013b; Lieshout 2013). The quality of the water flow coming out of the WP is assumed to be a constant property of the WP (on a scale of 0-5).

## 4.2 Model design

In this section the second lack of insight - *How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda?* – is answered. It has been chosen to only give a short overview of the remaining three agent-based modeling steps in the main text (Van Dam et al. 2012). In the appendixes 9.7 and 9.8 an extensive description of the model design can be found. The conceptual framework is used to distillate useful information from the water services delivery system for the agent-based modeling steps.

In the coming paragraphs agent-based modeling steps are taken in the light of the conceptual framework.

**System identification and decomposition**
Interactors that influence the key drivers of the water services delivery system are: District Water Offices (DWOs), Hand Pump Mechanics (HPMs), Water User Committees (WUCs), Water Users (WUs), local government (LG). The Ministry of Water and Environment, development partners, Technical Support

Unit (TSU), the physical world and the community are embedded in the environment. Important objects are water points (WPs) and the database of failed water points. An extensive description of the interactors, objects and environment can be read in appendix 9.7.

The pattern of interaction concept, as described in the IAD framework, with flows of information that incorporates the distinction between fact memes and regulatory memes has been de basis of describing the interactions between interactors, objects and the environment, see Figure 25 for a small part of the pattern of interaction and appendix 9.7 for the full pattern of interaction.

It has been requested by IRC International Water and Sanitation Centre to give the model design as much detail as possible, so that IRC International Water and Sanitation Centre (hence forth: IRC) can choose which parts of the system (and additional policies) they want to show in the agent-based model(s). This decision has had a consequence on the usability of the Universal Darwinism principle variety and the institutional grammar.

Variation helps to explain the (growing) large variety of regulatory and fact memes. As mentioned in the conceptual framework chapter, it is assumed that fact memes can be changed by interactors from within the action arena and that regulatory memes can only be varied by the environment. Bottom up variety has not been adopted in the model design, as it is not found in literature how, what and under which conditions a meme gets varied by an interactor and the size of the model design makes uncontrollable variations difficult to incorporate in the model design. A smaller model design would have been more suitable for testing the variation principle. As smaller models are more suitable for testing more generic mechanisms, like innovation and copy-errors.

The top down variation of memes is incorporated in the model design. The model user can decide on the environmental decisions, like to activate policies, knowledge input or not.

In the model design the institutional grammar of the conceptual framework is not implemented because the institutional grammar's added value is to show which parts of the institutions' repetitive elements stay constant or adapt during the process of bottom up variation. Additionally, the four-layer model is not implemented either, because the role of this four-layer model is to guide the variation frequency of memes.

The second Darwinian principle heredity has given the focus on the transmission of information from interactor to interactor in the water services delivery system. The function of heredity, namely spreading the meme, is incorporated in the model design and helps to understand where and when a pattern of interaction stagnates. The value of heredity in the model design can be improved by incorporating the possibility of imitating a 'neighbor's' meme, as currently only memes which are a interactor's property or rule can be imitated or transferred. However, in the model design the memeplex, of memes which can be transferred from person to person, can be enlarged if knowledge or a policy is adopted.

In the model design the WP can directly communicate with the WUC. Often, however, in the real world, the information that a '*WP broke down'* is communicated via WUs. During the interviews it did not

become apparent that the information flow between WPs, WUs and WUCs is stagnated in some sort (Lieshout 2013).

> *Therefore the assumption is made that WPs can directly communicate with WUs and WUCs (which are appointed to the particular WP).*

The final Darwinian principle selection helped to understand why a certain meme is chosen or not to be replicated. Whether a meme is selected or not is inter alia related to the motivation of the interactor, in other words a particular meme can be (more or less) in line with the personal priority of an interactor. For example, the WUC chooses the meme that is known to the WUC and is in comparison to other possible memes most in line (fit) with the personal priority of the WUC and section pressures. In the model design the WUC can select a particular regulatory meme '*WUC collect money on a regular basis*'. The WUC will decide to select the specific meme if:

- The WUC is very motivated to maintain the WP well.
- The particular meme is known to the interactor.
- The meme is within the conditions imposed by other memes.
- (most) Fit to accomplish the goal of maintaining the WP well.

In the model design it is also possible that for example some WUCs know and other WUCs do not know a particular meme. For example, a WUC can only request a maintenance contract from the HPMA if the WUC is well educated, as education goes hand-in-hand with the scope of memes an interactor is aware of.

**Pattern of interaction in the model design**

In the pattern of interaction, as described below in Figure 25, there are information/means streams (blue arrows) which represent fact memes, actions (green arrows) which represent regulatory memes and personal decisions/updates (red square arrows). The model design is divided into several phases, so it is easier to understand. In this pattern of interaction the main interactions between actors are shown. In the model concept formalization the updates of actors and some interactions are a bit more extensive. Here, in the pattern of interaction description, the bank balance for example is not updated.

Each interactor is represented by a light blue trunk in Figure 25. The interactions which affect certain interactors are visualized by an arrow that touches the interactor's trunk with the front or back of the arrow. The interaction is initiated by the interactor that is touched by the back of the arrow. The square arrows represent a reconsideration or an update of the interactor.

The *Water Service Basis* (see Figure 25) is the first phase. In this phase it is or becomes apparent whether a water point is broken or not. Furthermore, the Water User Committee (WUC) decides to become active or not. There is a strong relationship between the WUC becoming active and her motivation to sustain the water point (Nabunnya 2013). When the WUC decides not to become active, the WU needs to decide to become active and the local government needs to decide whether to assign a different WUC or not. Finally, in this phase the Hand Pump Mechanic (HPM), WUC and Hand Pump Mechanic Association

(HPMA) can request for some more managerial or mechanical knowledge, depending on their motivation and the environment's 'generosity' in supplying knowledge.

This 'basis phase' of collecting water or not, is followed by the '*Monthly contribution? Phase'* (see Figure 25). This phase is apparent when the WUC did become active and has a certain motivation and knowledge level. The knowledge level is needed, because it asks quite some financial and management education before a committee is capable of monthly money collection (Lieshout 2013; Nabunnya 2013).

In the conceptual framework every interaction is initiated by a particular fact meme that is 'steered' by a regulatory meme. In the pattern of interaction it seems that almost all interactions are started off with a request, so an action, except for some inputs from the environment. In the model formalization it will become clear that this is not the case, as a particular action is performed if certain properties (fact memes) have a certain value/state or if a particular fact meme is requested.

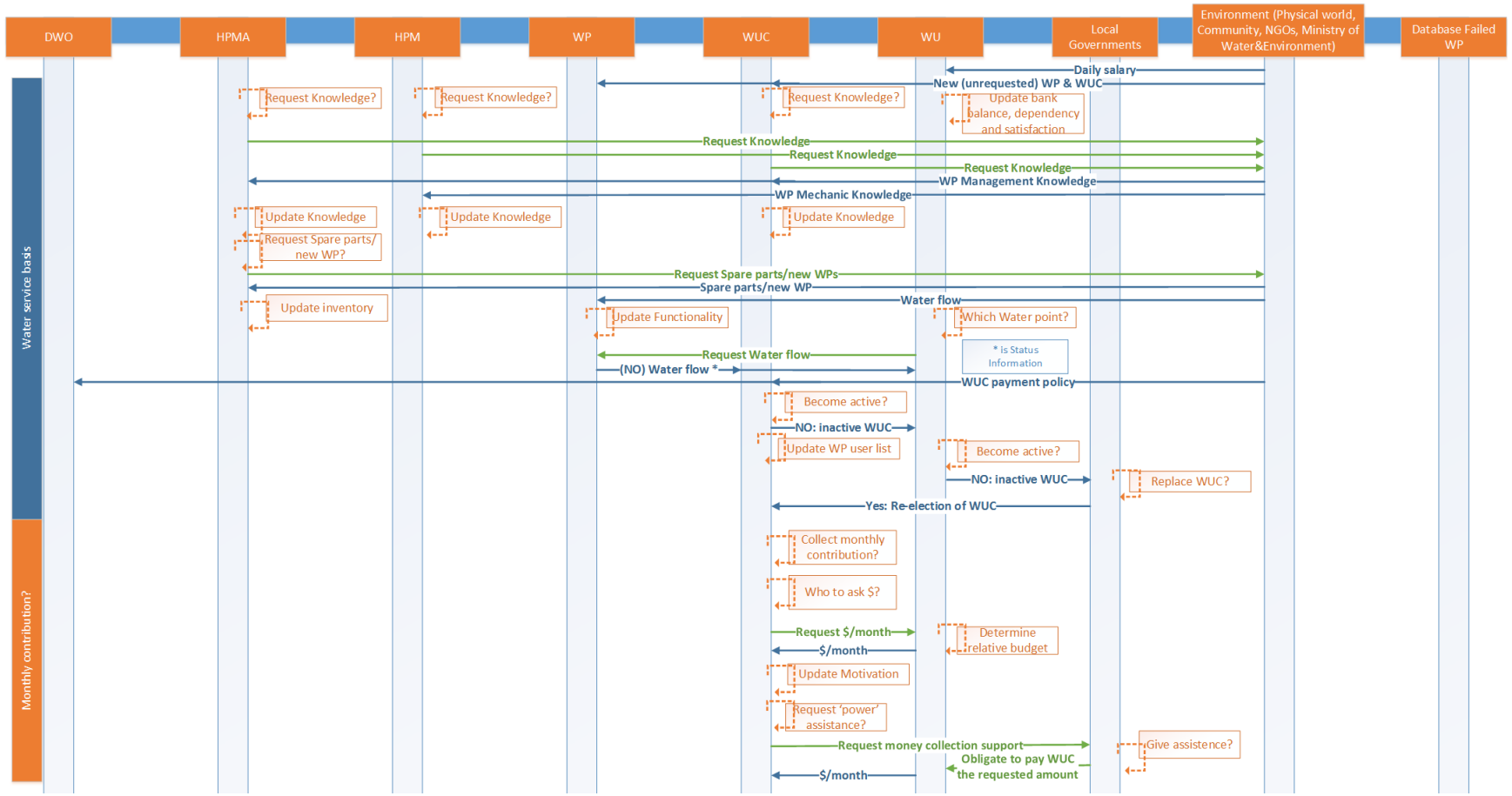


**Figure 25 Pattern of interaction part 1**

The model concept formalization is comprehensively covered in appendix 9.7. Here a glimpse of the concept formalization is given by describing one interactor, namely the WUC.

**Concept formalization of the Water User Committee (WUC)**

In the water services delivery system the WUC has contact with many different interactors, see Figure 27 and Figure 28. In the same figures the interactions (actions and information) can be seen. For example, the WUC interacts with the HPM when a WP is broken en needs to be fixed (Bey 2013b; Bey 2013a). However, first an assessment needs to be made of the costs of the repair (see 1 in Figure 27), as very expensive repairs need to be paid by the DWO (Magara 2013). When the costs are below a certain threshold, the HPM informs the WUC about the costs and requests the WUC to pay for the repair (see 2 in Figure 28) (Magara 2013). The WUC needs to check its bank balance whether there is enough money to pay the HPM immediately or not. If there is enough money, the WUC sends the money and a confirmation to the HPM (see 4 in Figure 28).The network and interactions with itself and others are roughly shown below:

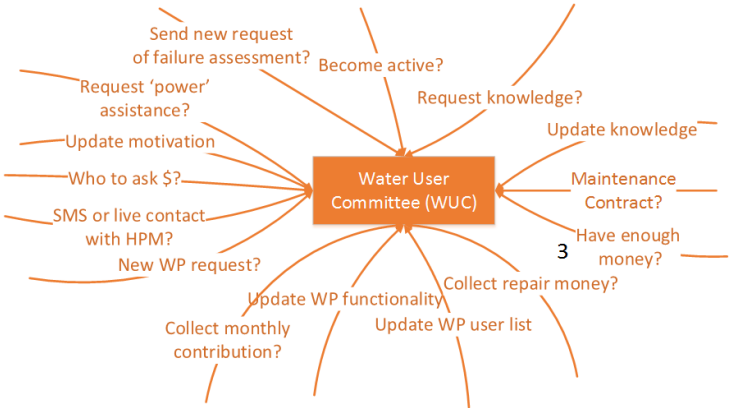


Figure 26 Updates and personal decisions WUC

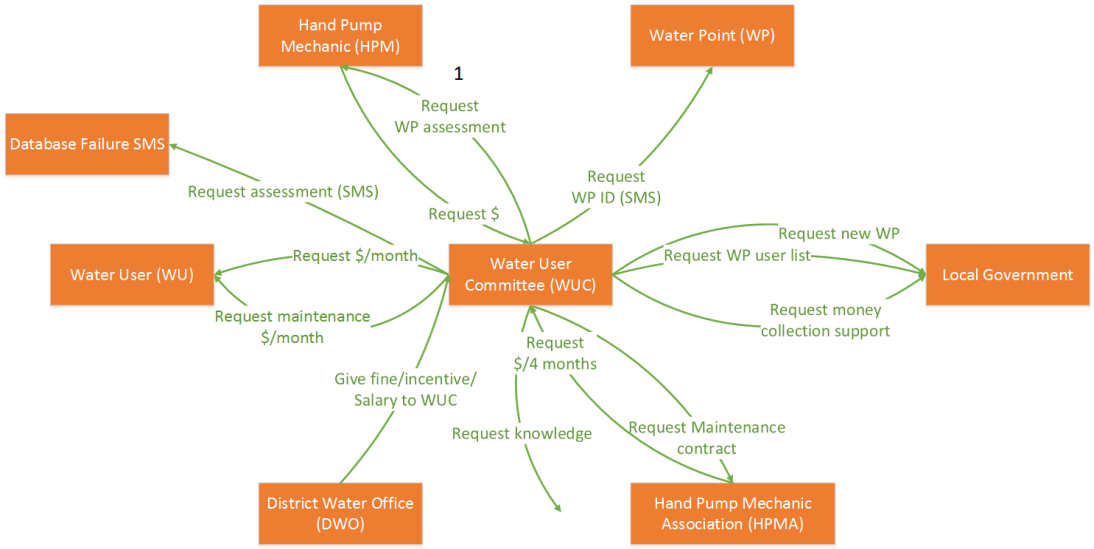


Figure 27 Interactions (actions) of WUC


Figure 28 Interactions (information) of WUC

The properties of the WUC are described in Table 7. This table also contains the personal priority of the WUC. In reality personal priorities are multi-layered and difficult to capture. Personal priorities are, for the purpose of the water services delivery model design, brought back to the motivation of an actor to work in line with the desired pattern of interaction. This decision is satisfactory as the model design has one main problem, the low water services delivery level.

The variables in Table 7 have a type and a range. The type indicates how information is captured. For example, Boolean indicates that the variable is either True or False. The first variable is 'District'. This variable places the WUC in a particular district. The variables in the blue box are also created to place the WUC in a particular 'location' and network. The WUC needs an ID too, to be identifiable for others (variable 3).

As explained in the pattern of interaction 'basis phase' the WUC needs to decide whether to become active or not (variable 17 ('Active?)). Motivation (variable 16) indicates the motivation of the WUC, on a scale from 0 to 5, to inter alia become active or not. Whether a WUC requests a new WP (variable 27), requests a maintenance contract (variable 28) and collects money on a regular basis (variable 29) is related to the 'WP Management knowledge level' (variable 30), motivation and to the implemented policies (variables 10-15). The 18$^{th}$ variable, status information, tells the WUC whether the WP is broken or not. The bank balance (19) keeps record of how much the WUC can still spend.

The possible policies, which are implemented or not, are mentioned in the red box. Whether the WUC needs to decide to prefer live contact with the HPM (if the WP broke down) or prefers the mobile and to send a text message is dependent on whether the M4W policy is implemented or not (variable 13, 23 and 24).

As soon as a WP assessment is requested by the WUC, the 'Assessment requested variable?' is adjusted, so that the WUC does not repeat the same action every time step. The WP user list, variable 9, tells the WUC who to ask money for the repair/maintenance, as the people who are on the list use water from the particular WP (Bey 2013b).

**Table 7 Properties of WUC**

| nr. | Variable | Type | Range |
|---|---|---|---|
| **1** | District | Integer | >=0 |
| **2** | WPs in district | List of integers (IDs) | |
| **3** | WUC | Integer | >=0 |
| **4** | DWO ID | Integer (ID) | >=0 |
| **5** | Local Government ID | Integer (ID) | >=0 |
| **6** | HPMA ID | Integer (ID) | >=0 |
| **7** | WUs in district | List of integers (IDs) | |
| **8** | HPM in district | List of integers (IDs) | |
| **9** | WP user list | List of integers (IDs) | |
| **10** | WUC payment policy | Boolean | |
| **11** | Sanctioning policy | Boolean | |
| **12** | Maintenance policy | Boolean | |
| **13** | M4W policy | Boolean | |
| **14** | HPMA policy | Integer | =1, =2 |
| **15** | New WP policy | Boolean | |
| **16** | Motivation | Integer | >=0, <=5 |
| **17** | Active? | Boolean | |
| **18** | Status information | Boolean | |
| **19** | Bank balance | Integer | >=0 |
| **20** | Mean 'relative budget' of its WUs | Integer | >=0 |
| **21** | Dependency of its WUs | List of integers | |
| **22** | Mean Dependency of its WUs | Integer | >=0 |
| **23** | Mobile | Boolean | |
| **24** | Preference for Mobile? | Boolean | |
| **25** | ID transferring 'noise' | Floating point | >=0, <=1 |
| **26** | Assessment requested? (If Status Information is False) | Boolean | |
| **27** | Request new WP? (requested If True) | Boolean | |
| **28** | Maintenance contract? (requested If True) | Boolean | |
| **29** | Monthly money collection? | Boolean | |
| **30** | WP Management knowledge level | Integer | >=0, <=2 |
| **31** | Request money collection support? | Boolean | |

The 20$^{th}$ variable indicates the mean of 'relative budgets' of WUs who are using water from the WUC's WP. The relative budget is discussed later more elaborately. If the relative budget is very low, the WUC can request the local government to help collecting money (variable 31) (Bey 2013b). Variable 22 'Mean dependency of WUC's WUs' is created so that the WUC can calculate whether a new WP needs to be requested (and eventually build) or not. This variable is only active if 'New WP policy' is implemented (variable 15).

The assumptions that are made in the model design for the WUC (and other interactors) can be read in appendix 9.7 and are summarized in appendix 9.11. Two examples of assumptions that are made in the model design are:

1. *The 'relative budget' of WUs, which is paid to a particular WUC, is calculated as follows:*
    - *Satisfaction of WU towards WUC= WSL (of x days ago).*
        - *The WSL is x days delayed before it influences the Satisfaction of WUs.*
        - *Satisfaction has a range between 0 and 5.*
    - *Dependency = Amount of WPs a WU has in its reach (3 km).*
        - *1 WP = 5, 2 WPs = 4 etc. 5 WPs = 1 and 6 WPs or more = 0*
    - *Knowledge level WUC= Amount of knowledge on managing a WP.*
        - *The range in-between 0 and 2*
    - *So, The relative budget is a floating point between 0 and 1.*
    - *Maximum Relative budget = 12/12 = 1*

$$\boldsymbol{Relative\ budget} = {Satisfaction}/{12} + {Knowledge\ level\ WUC}/{12} + {Dependency}^{24}/{12}$$

When the dependency of the WU, satisfaction on the WUC, knowledge level of the WUC are high, the relative budget the WUs want to give to the WUC is high.

2. *If the WP Management knowledge gets improved, it is assumed that the WP side gets better maintained* (Bey 2013b). *Therefore the Satisfaction of WUs gets updated after more knowledge is gained.*

**Model Formalization of the WUC – Water service basis phase**

The model formalization is the final step of this model design. Here the actions per time-unit step are described. Not just the actions are described, also the way how the actions are performed. In Table 8 a very small part of the 'water service basis phase' of the WUC's model narrative is shown.

Here it is explained how Table 8 can be read. On the top of the table it can be read that the 'Rules of WUC' have a theme, action/information stream and timing. Here the theme is 'Water service basis phase', which is the same as in the pattern of interaction example, Figure 25. One time-step in the model design is one day, so the actions that are described in Table 8 are executed once a time-step.

In this phase the WUC agent needs to check on information updates 'Check received *Status information* updates'. If there has been an update, the WUC's property needs to be updated (from functioning (True) to non-functioning (False) for example).

The next step in this phase is to 'Check the Status information'. If it turns out that the WP is functioning, the 'Assessment request?' needs to be checked and updated to 'False' if it was 'True'. The HPM has fixed the failure as the WP is functioning again. So, no failure assessment/repair is in the pipeline anymore for

[24] If a WU is dependent of 1 WP, the Dependency rate is 5. The Dependency rate has a range between 1 and 5. When a WU has 5 or more WP within 3 km distance, the rate is 1.

this WP. The WUs also need to be aware of this fact, as they can request a failure assessment from the HPM too (if the WUC does not become active during a WP failure).

**Table 8 Example of 'Rules of WUC'**

| Theme | Action/information | Timing |
|---|---|---|
| Water service basis phase | Check received *Status information* updates | 1x day |
| | ***If True***: | |
| | Update Status information | |
| | ***If False:*** | |
| | Go to *Check Status information* | |
| | | |
| | Check *Status information* | |
| | ***If False:*** | |
| | Check Error SMS | |
| | ***If True***: | |
| | Update *Assessment request* to False | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | ***If False***: | |
| | Go to **** | |
| | ***If (status information =) True:*** | |
| | *Check Assessment request*? | |
| | ***If False:*** | |
| | Go to **** | |
| | ***If True:*** | |
| | Update *Assessment request*? to False | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | Go to **** | |

The model formalization is an extensive story that comes down to generating a deeper understanding of what drives the WSL up or down under which circumstances. The model narrative looks like a conventional agent-based model narrative as there is:

- No pattern of interaction and evaluation criteria
- No distinction between memes shown
- No explicit reference to the three Darwinian principles
- No ADICO formalized institutions

However, this is just appearance as the conceptual framework is present in every action part of the model narrative, as:

- The model narrative is an extensive version of the pattern of interaction described in the system identification and decomposition section.
- The distinction between memes is not explicitly mentioned, however, the facts like 'Status information' is mentioned as fact in the property table of the interactor. The rules as mentioned

in Table 8 are the regulatory memes that are known and applied by the interactor (under certain circumstances).
- The interactors base their personal decisions on their personal priority[25], scope of memes[26] and conditions[27].
- The action arena is influenced by the environment (community, physical world and rules) as in the IAD framework.
- The Darwinian principles (heredity, selection and 'top down' variation) are incorporated, as far as currently understood, in the way interactors perform their actions.

## 4.3 Sub-conclusion

In this chapter the second research question is discussed - *How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case?*

This question is researched by answering two lacks of insight:

a. What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda?
b. How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda?

The first lack of insight is answered by identifying the key drivers of change concerning the water services delivery system. The change in this can be measured with the water service level (WSL). With help of the conceptual framework and interviews it is assumed that the key drivers of changing the water service level are:

1. The motivation of certain actors (mainly Water User Committee (WUC) and Hand Pump Mechanic (HPM)) (Nabunnya 2013; Bey 2013b).
2. The satisfaction of the water users (WU) with the WUC (as water users often do not trust the WUC) (Lieshout 2013).
3. The water users' dependency on a particular water point (Lieshout 2013). The dependency rate influences several WSL indicators, namely: distance to WP for a WU, quantity of water collected by WU and crowding at WP.
4. The water point's functionality (Schouten & Moriarty 2013). Functionality has an effect on the WSL indicator reliability of the WP.

The WSL is (directly or indirectly) related to the above summed up indicators.

In the initial hypothesis it is stated that the policies and knowledge as mentioned in Table 9 have an effect on the key drivers of the water services delivery system and affect the WSL. Here a proof of the model hypothesis is given as in the model design these policies have a (direct or indirect) effect on the WSL level (as well as the other key drivers). A completed agent-based model shows whether the policies'

[25] Represented as motivation
[26] Represented as knowledge level
[27] Represented as policies and thresholds

impact on the WSL is positive or not. Here is has not been said that, firstly, this model design proves that the list of key drivers is comprehensive and, secondly, the proposed policies have an effect on the WSL in the real world. These aspects need to be tested in a real world pilot.

**Table 9 Policy and knowledge (direct and indirect) effects**

| Policy: | Direct effects[28]: | Indirect effects: |
|---|---|---|
| **WP Management Knowledge** | Monthly payment (or incidental) request by WUCs, Relative budget of WUs, Maintenance contracts, Stock of spare parts | WSL, WUC motivation, Functionality |
| **WP Mechanic Knowledge** | Evaluation (sanction) | HPM motivation, WSL, Functionality |
| **Sanctioning policy** | Motivation of WUC/HPM | WSL, Monthly payment, Maintenance contract, Functionality |
| **M4W policy** | Conditional Grant proposal | Conditional Grant, WSL |
| **HPMA Policy** | Maintenance contracts, repair/installation of WP | WSL, Functionality |
| **Maintenance Policy** | Maintenance contract, WSL, Functionality | Satisfaction of WUs, Relative budget, WSL |
| **New WP policy** | Dependency | Relative budget, WSL |
| **WUC payment policy** | Motivation of WUC | WSL, Satisfaction of WUs |

This model design does not only describe the current water services delivery system but it also explores future states, by testing the effect of possible policies on the water service level. This understanding can educate people, as they can see how change is achieved (by small adaptations in their behavior patterns). In other words, the bottom up approach can empower people to do better in the future.

Section 4.2 has focused to answer the 2nd lack of insight - *How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda?* In this section the contribution of the conceptual framework is discussed in combination with the (first four) agent-based model design steps.

1. Problem formulation and actor identification: In this step the Ugandan context and water services delivery problem is researched. Interviews are conducted to gather more knowledge about the pattern of interaction in the water services delivery system. The interview questions are adjusted, but in line with the IAD framework questions as described by Ostrom and Polski (1999). The agent-based model development questions gave structure to the text in the 'problem formulation and actor identification chapter'.

   The initial hypothesis is also formulated in this section. The hypothesis is inspired by the knowledge that fact memes are guided by the institutions, which are in use in the action arena. The initial hypothesis requests a model in which different policies' effect on the emergent pattern can be analyzed.

[28] All terms are explained in chapter 9.7.1.

2. System identification and decomposition: The application of the conceptual framework in this part of the agent-based model designing process is:

    a) The pattern of interaction, as described in the IAD framework, identifies the different information flows within the action arena. The influence of the community, physical world and rules is explicitly implemented in the model design. The rules that are imposed by the environment on the model are the variety of policies (which the interactors can sometimes decide to accept or not in the model design). The physical world is not typified by natural disasters, drought etcetera in the model design as it is not the described problem in the water services delivery system. Here the physical world is characterized by the presence of spare parts/new water points. The influence of the community on the action arena is characterized by the input of means (for example the Conditional Grant) and knowledge.
    b) The division of regulatory memes and fact memes specify the content of the information that is exchanged. This division of memes is applied in the pattern of interaction and personal interaction maps of interactors.
    c) The model design is large, since the model design has a descriptive character. This makes testing generic mechanisms like variety (innovation and copy-errors) difficult. In the model design only 'top down' variation (from the environment) is implemented. Bottom-up variation (innovation and copy-errors) needs to be tested in a smaller model setup.
        - The institutional grammar and the four layer model are not tested, because the variation mechanism is not tested bottom up.
    d) Heredity contributes to the understanding where and when a pattern of interaction stagnates/continues. The core of the heredity principle is applied in the model design, as memes are requested and sent.
    e) Selection illuminates why a certain meme is transferred or not in the water services delivery system. The interactor's personal decisions in the model design are based on personal priorities (motivation), memeplex and conditions imposed by other memes. Furthermore, when a rather controversial policy[29] is implemented (by the environment) the interactors in the action arena can decide whether to adopt in their memeplex the new policy (regulatory meme) or not.

Strategic games are not explicitly included in the conceptual framework. However, regulatory memes do not exclude strategic games, as strategic games can be seen as shared strategies of interactors. Moreover, the pattern of interaction that the interviewees described did include a bit of strategic behavior. An example of incorporated strategic behavior is that DWOs can be influenced by lobby groups or not. Whether the DWO is influenced by this lobby or not is a property of the DWO in the model design. This property influences the regulatory meme selection.

3. Concept formalization and model formalization: The fact memes and personal priority are specified in the properties of the interactor. The rules, regulatory memes, are stated in the model narrative and quantified here. Every time-step interactors are influenced by: each other, the environment, their personal priority, known memes and new memes. These elements have an impact on the decision making of an interactor and the emergent behavior of the system.

[29] The M4W policy and the Sanctioning policy are both seen as rather controversial policies.

# Part IV: Validation, Conclusions, Discussion and Recommendations

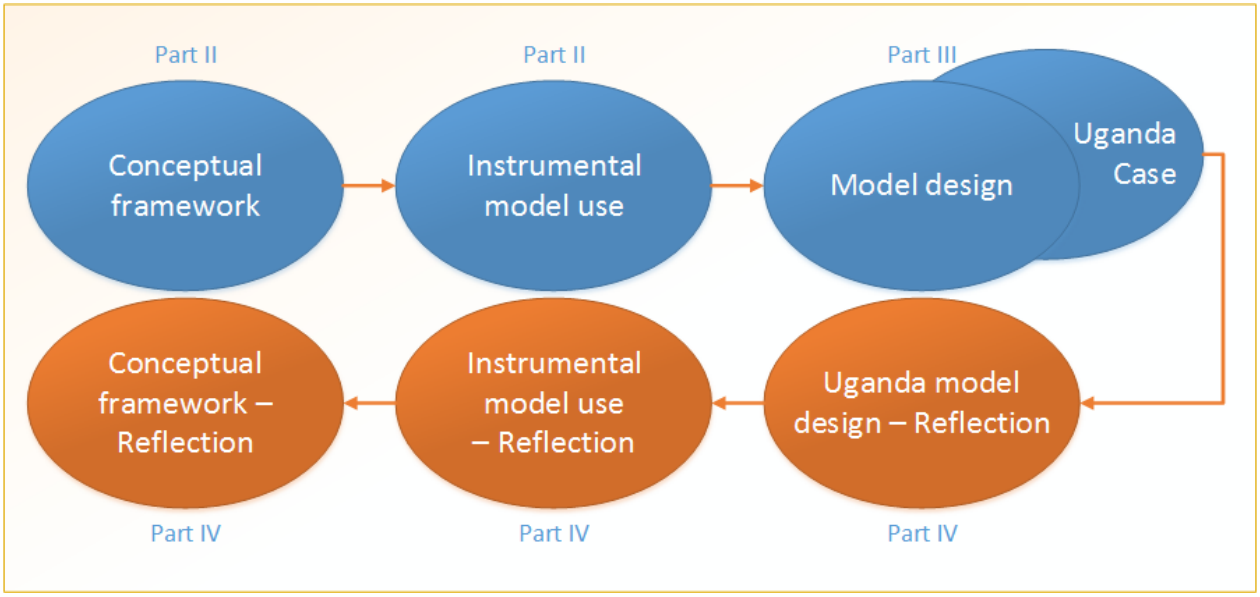


Figure 29 Reading guide 3

# 5. Validation

During the Master thesis research feedback and validations have been received from supervisors and Ugandan case experts. The feedback that has been given during this Master thesis research is valuable because it has given new insights.

In case of the model design feedback widens the modeler's tunnel vision, as the model designer puts his/her idea of the problem in a model design. Furthermore, it reflects upon the quality of the interpretation of the real world in the model design, as the design is once or twice removed from the real world. In this case the case information is twice removed from reality, as the gathered data, literature and interviews are itself already a (personal) interpretation of the world.

Overall, feedback gives the modeler a better sense of what is well translated in the model design and what needs more explanation or adaptation. Validation is a way to test whether the model design is:

- In line with the client's idea of the problem.
- In line with the current understanding of the Ugandan pattern of interaction.
- In line with the currently used set of memes.

Besides widening the tunnel vision, feedback stimulates a learning process. The model design and especially the conceptual framework has been adapted numerous times due to great input from supervisors and case experts, as feedback sharpens your thought.

Additionally, this research contains many assumptions regarding the conceptual framework and model design. Without solid feedback, assumptions, which have not been made explicit by the modeler, can stay hidden. Implicit assumptions are not good for the credibility of the model design or conceptual framework.

The model design that is presented in this Master thesis research is a descriptive design. The modeler is aware of the fact that big gaps between the real world and the model design can have a negative effect on the value of the model design, as people want to be able to 'recognize themselves' in a descriptive model. Therefore, a balance between adjusting the model in line with the received feedback or not needs to be found. As certain simplifications of the real world need to be made to be able to model the system. In appendix 9.10 it is explained which changes were made to harmonize the received feedback with the model design.

Decisions have been made concerning the retrieved information. Some data has influenced the model design largely and other data has been left out of the model design. An example is the role of means (personnel and money) in the model design. There is not a word about the lack of personnel the District Water Office is dealing with and on the other hand the relative budget of water users get a prominent place in the model design. Why and which information that has not been used in the model design is shown in appendix 9.11.

The readability and consistency of the model design has been tried to optimize as much as possible. However, it can still be difficult to quickly oversee and understand the whole model. This is worsened by the fact that the model design (pattern of interaction, network figures and model narrative) have different levels of detail. It can occur that an update of a particular property is mentioned in the model narrative and unfindable in the pattern of interaction. It is realized this can complicate the understanding of this model design for a reader of this report.

The quality of the agent-based model design is difficult to test, as the design could not be tested in an modeling program or with existing data. The feedback from the IRC employees who validated the model design is positive, see appendix 9.10. However, until it is programmed and tested there is no guarantee that there are no mistakes made in the model design. Furthermore, the descriptive character made it difficult to validate for the model designer and IRC employees, as the model narrative is almost 50 pages.

# 6. Discussion

In this chapter this research is critically reflected upon, see Figure 30.

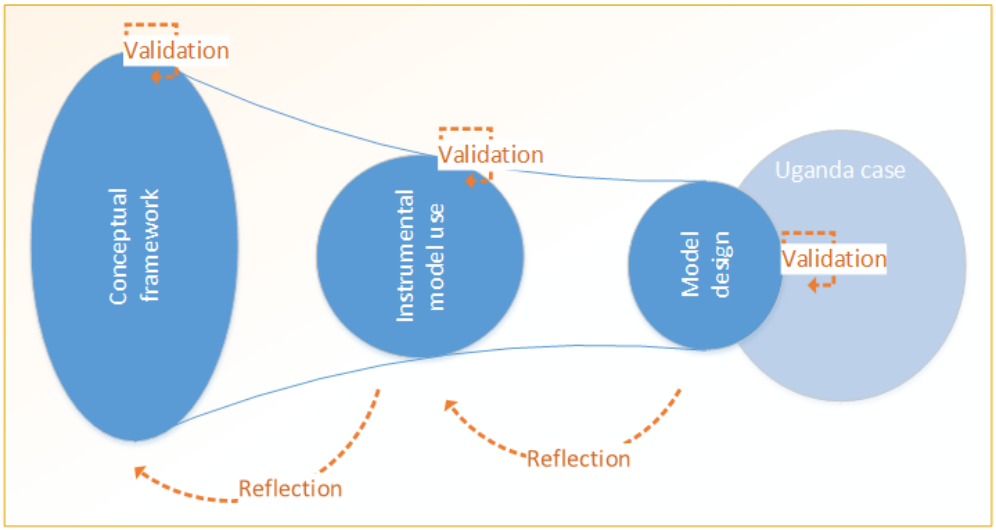


Figure 30 Discussion reading guide

*Conceptual framework – Universal Darwinism*

Universal Darwinism is chosen as starting position for the conceptual framework, despite the discussions, about the applicability of Universal Darwinism in a socio-technical system, that are currently going on (Mulder 2012; Buenstorf 2006; Nelson 2006; Foster 2011; Foster 1997). During the research it became clear that there are still many unknowns concerning the operationalization of Universal Darwinism, like for example the gene-like entity. This makes it difficult to translate the core principles of Universal Darwinism in an agent-based model design, as a model design cannot be programmed with 'nice' statements and suggestions of how the mechanisms function in the socio-technical system.

It is believed that the combination of Universal Darwinism[30] and institutional analyses is a step into the right direction because the theories overlap each other in many areas of both bodies of theory. The current value of the conceptual framework is reflected below.

*Conceptual framework – Variation, institutional grammar and 4-layer model*

The variation mechanism is not implemented as a bottom up mechanism. In other words, the interactors in the model design cannot innovate a meme. As long as this is the case, the value of institutional

[30] Memetics is an extension of Universal Darwinism, as Memetics is a theory of the variation, transmission, and selection of cultural items, such as ideas, fashions, and traditions. Universal Darwinism is seen here as an overarching theory of Memetics. The UD-institutional conceptual framework incorporates the thoughts of Memetics.

grammar and the four layer model is not proven as they are incorporated in the conceptual framework to assist the variation mechanism[31].

The overall value of the conceptual framework can increase when the variation mechanism is worked out in more detail, by determining how and what can be varied and under which circumstances. Here it is suggested to use a small, non-descriptive agent-based model for testing the variation mechanism, as such a model set up is less occupied describing the events correctly and more free to experiment with researching more general mechanisms, like the variation of memes.

*Conceptual framework - Heredity*

In the model design a first attempt is done to capture the heredity mechanism[32]. In the real world a person can copy a meme as he/she sees another person using a particular 'new' meme. However, in the model design it is chosen to simplify this process. Here the meme-scope of an interactor can be enlarged due to the input of water point management/mechanical knowledge and new policies. This simplification's advantage is that an approximation of the mechanism is modeled in the descriptive model design. The disadvantage, however, is that the richness of the heredity concept is not completely captured, as in the real world the adoption of a meme is inter alia dependent on the interactor's location within the interactor network (Christakis 2010).

*Conceptual framework – Selection*

In biology the selection mechanism is mainly guided by the fitness of a particular meme in a certain environment. In a socio-technical system there is also an internal selection process, namely personal priority (Polski & Ostrom 1999). In the model design the added value of the selection mechanism is shown, as it is implemented in respect to the current understanding of selection. This mechanism can, however, change in the future (when the variation mechanism is completely worked out), as it can become apparent that another element also affects the selection process.

*Conceptual framework – Meme definition*

The definition of memes that is used in this Master thesis research is 'Everything that is passed on from person to person is a meme (Blackmore 2000)'. Blackmore (1998) also states that not all information types are memes, as some memes are not passed on from person to person or are not imitated, for example:

- Instinctive imitation, which is for example yawning and laughing, is not true imitation because humans already knew how to laugh. People do not copy another person's laugh, as memes should be learned from another person.
- Classical conditioning is a method where the process is changed but not from person to person.

[31] The institutional grammar can then give an overview of which repetitive part of the (varied) meme changed/added and the four layer model can help to determine the variation rate of a meme.

[32] Heredity in this research is understood as imitating/passing/copying problem-solving or developmental information from one entity to another.

This view keeps memes away from the catching of yawns or all the many things we each learn ourselves, by ourselves, additionally, of "*anything that can be the subject of an instant of experience* (Blackmore 1998)".

This argument subscribes the connection between institutions and memes, however, it also suggests that the information that for example a water point gives a water user, that the water point is broken, is not in line with the definition of memes. As the water point is not a person and the information is not imitated, as it is about an instant experience.

However, in the Ugandan case, a water user can either call the hand pump mechanic or speak to this person in real life. Using a phone to contact the hand pump mechanic is a regulatory meme that can be imitated by a person. In the conceptual framework this meme would be classified as a regulation meme, because it tells a person how to execute a certain action. However, the person possibly imitating the regulation meme also needs to know the conditions under which this regulation meme is suitable/possible or not. For example, the water user needs to have a phone, know that the water point is broken, needs to have the personal priority to fix the water point, etcetera. These facts are comprehended as fact memes in the conceptual framework. In the example it is shown that facts form the conditions under which circumstances it is appropriate or common to select a particular regulation meme.

This argument supports the fact that facts and regulations go hand-in-hand. However, it should be considered to call fact memes simply 'facts', as facts can be 'an instant of experience'.

*Conceptual framework – Institutional Analysis and Development framework*

The value of the Institutional Analysis and Development (IAD) framework is that it describes the socio-technical system without excluding the Darwinian principles' mechanisms, as they can be placed in the framework.

*Agent-based modeling - Conceptual framework*

The added value of the conceptual framework in relation to the existing agent-based modeling steps is, firstly, the social structure[33] as agent-based modeling cannot explain many complex phenomena if social structures are absent (Conte et al., 2001). The conceptual framework helps to overcome the problem that social structures are either not considered or are modeled as part of the agents in agent-based modeling (Ghorbani 2013), due to the incorporation of IAD framework and the focus on (different types of) institutions.

It has not been said that the conceptual framework replaces the existing agent-based modeling steps. If a certain problem requires an approach that explores the evolution of the particular socio-technical system, then the conceptual framework contributes to existing agent-based model development steps. It helps the modeler to focus on the core principles of evolution, the gene-like entity and the gene-like

[33] The social context (cultures, norms and networks) allows agents to act accordingly and in turn affect/evolve the structures (Ghorbani 2013).

entity carrier of the socio-technical system. Furthermore, due to the focus these elements/mechanisms give it becomes easier for a modeler to filter useful information from the real world for the agent-based model (design).

The division of memes (fact and regulation) can be kept in the agent-based modeling tool, as the fact-memes have the role as property of an agent (together with personal priority) and regulation memes are the rules used by the agent.

The instrumental use of agent-based modeling is considered to be positive for this model design, as this tool facilitates the exploration of evolutionary behavior, due to the bottom up approach, open boundaries and non-stationarity/non-linearity assumptions of the modeling approach. However, these benefits also have a downside, as mentioned in the model design chapter, the modeler cannot validate and verify the model with traditional validation methods (Van Dam et al. 2012, p.127).

*Conceptual framework & modeling method – Fit with Ugandan case*

During the information gathering on the Ugandan case it became clear that the interviewees are familiar with:

- The pattern of interaction in the water services delivery system.
- The actors that play a (important) role in the provision of water services.
- The laws and initiatives to promote more sustainable water services.
- Key drivers of the (evolving) water service level.

However, (as Crawford and Ostrom also notified (1995, p.595)) they were not able to define specific norms, laws and shared strategies which are in use within the borders of the institutions (laws, norms and shared strategies). Due to the significant role of superstition in human action, laws cannot be enforced as intended. Additionally, people do not seem to think explicitly in institutions and facts and the questions seemed to be too direct for the Ugandan interviewees and too specific for the 'Western' interviewees. The Ugandan interviewees replayed to the interview questions by telling stories that contained much more specific and diverse information than formulated in the questions, so the questions were adapted to be more like cues to stimulate a story in a certain direction. The answers the 'Western' people gave were more focused on answering the exact question, but they generally found it more difficult to name the exact law/shared strategy that made people do a certain thing and therefore gave links to literature where the requested information could be found.

Due to adaptation of the interview questions the model is populated with inter alia institutional information. The formulation of the pattern of interaction and the model narrative also helped to extract the institutions from the interview data, as these steps ask a very detailed approach of the modeler.

The quality of the model design is validated by three IRC employees, see chapter 9.10. They think that the quality of the Ugandan model design is good, in line with the Ugandan situation and the described problem. However, the quality can only be proven when the model is programmed and tested. Furthermore, the model designer did not do research on how rules can be structured efficiently in an agent-based model narrative, this would have possibly enhanced the readability of the model design.

*Ugandan case - Information gathering to populate the model design*

There is much to read and know about Uganda. It has been tried to get an complete overview of the Ugandan case, the historical and current situation in Uganda. It is not suggested that neither all viewpoints nor all literature present is captured. It would have been best to go to Uganda to get a feeling with the country and the problem. Unfortunately the timing to go to Uganda was not ideal, as IRC employees, who could have introduced me to the District Water Office, hand pump mechanics etcetera, were either rounding off important projects or were on holiday (from mid-November till mid-January).

Instead, interviews are conducted with IRC case experts in the Netherlands and (via Skype) in Uganda. These interviews have had two purposes. First, to gather information about the problem and Ugandan context and, secondly, to reflect upon the usability of the model design. However, it is realized that:

- Three of the five interviewees have a 'Western' look on the Ugandan situation.
- The Ugandan interviewees are well educated people, who might not be able to represent the ideas and thinking of the local civilian/Water User Committee etcetera.
- For the reliability of the information it would have been better to do more interviews and with a more diverse group of people.

Despite of these drawbacks, this methodology is chosen because the IRC employees are very knowledgeable and know the situation from different perspectives and levels inside out, as they currently work or have worked closely with people at local level up to national level in Uganda.

*Conceptual framework – Usability outside the Ugandan case study*

The conceptual framework has the potential to generate a deeper understanding in other socio-technical systems then the Ugandan case. For example, a system that is going through a transition, like from the Community Based Maintenance System towards a Piped Scheme Management System. Such a transition can be analyzed with the conceptual framework because the transition theory, which describes a system in transition on a meta-level, is based upon the same principles as the conceptual framework (bottom up approach and on the principles of variation, selection and heredity) (Chappin 2011; Loorbach & Rotmans 2006; Geels 2002).

However, in case a modeler aims to explore/simulate extreme situations (with a high chance of a 'decision making error' (McKenzie 2003; Burns et al. 2013)), processes without regularity (no institutions) and/or a high increase of variety of memes, it is not advised to directly copy paste this conceptual framework. These situations are not yet well represented in the conceptual framework. The conceptual framework is, however, explanatory for problems that contain:

- Regularity, as otherwise there are not institutions guiding the behavior.
- People as they carry and replicate the memes.
- Variation of memes, as changes in decision behavior should be able to influence the problem.
- Interaction between people, as the memes are transferred from person to person.

# 7. Conclusion

The goal of this Master thesis research is to create a deeper understanding of evolving processes in socio-technical systems, which is tested in the water services delivery case in rural Uganda with an agent-based model design. Such a deeper understanding, which is captured in a conceptual framework, is interesting because it gives IRC International Water and Sanitation Centre the knowledge/capacity to explore and promote policies that fit the characteristics of the evolving system and which stimulates the evolution towards a more sustainable (water services delivery) system. The problem implies that there are two main challenges. Firstly, the formulation of the conceptual framework and, secondly, to make a first attempt describing the water services delivery system in Uganda, with the formulated conceptual framework, to provide IRC International Water and Sanitation an extensive description of the system and to test the current value of the conceptual framework. This problem description has led to the following research question: *What conceptual framework can generate a deeper understanding of evolving processes in socio-technical systems, applied to the water services delivery case in rural areas of Uganda?*

The questions that assist to answer the research question are:

1. How can evolution in a socio-technical system be formalized in a conceptual framework? (descriptive, meta- and operational-level)
    a. *How do processes in socio-technical systems evolve over time? (descriptive, meta-level)*
    b. *How can processes in socio-technical systems be formalized? (descriptive, operational-level)*
2. How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case? (empirical and design oriented)
    a. What are the drivers in the water services delivery system that cause a (changing) water service level in rural areas of Uganda? (empirical)
    b. How can the conceptual framework be applied to the water services delivery system in rural areas of Uganda? (design oriented)

**First the conceptual framework is described, answering the first sub-research question - *How can evolution in a socio-technical system be formalized in a conceptual framework?***

The starting point of this study is Universal Darwinism, see Figure 31, because this theory is the most 'simple' theory that can explain the process of natural selection and evolution. To apply this theory in a socio-technical system it is necessary to identify Darwin's principles (variation, selection and heredity), gene-like entity and gene-like entity carrier. The translation of the Darwinian principles (selection, heredity and variation) have been sought in the fields of, besides Universal Darwinism (related) theories, institutional analyses, see Figure 31 .

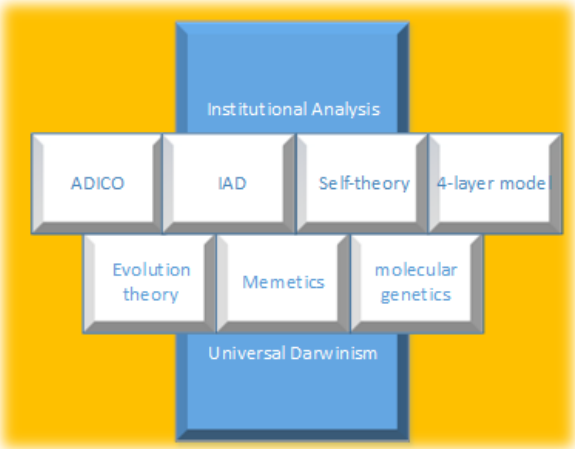


**Figure 31 Conceptual framework**

The link between Universal Darwinism (UD) and institutional analyses is made to operationalize UD in a socio-technical system. Institutional analyses contribute to the measurability and applicability of UD, as institutions structure socio-technical systems (Polski & Ostrom 1999).

In a socio-technical system is likely that memes are the gene-like entity (or generative replicator) (Blackmore 2000; Dennett 2007), as memes contain adaptive solutions to problems and guides the development of interactors (Stoelhorst & Huizing 2006). Memes is everything that is passed from person to person, like language and rituals.

In this research the analogy is made between molecular genetics (which describes genes) and memes, as the same distribution is chosen. In molecular genetics there are coding genes and regulatory genes. The coding gene stands for a particular property of the entity. The regulation gene governs the coding gene, by determining where and when the property is expressed (J.B. Reece & Urry 2010; Mesoudi et al. 2006). Accordingly to the gene distribution, memes are divided into coding (hence forth: fact) memes and regulation memes.

In line with the institutional body of theory, institutions (norms, values and shared strategies) are chosen to be the content of the regulatory memes. The reason for choosing institutions as content of regulatory memes is that, as stated above, institutions give structure to socio-technical systems, are relatively stable, durable and have a way to adapt to new situations which is transferred from interactor to interactor (Veblen 1899).

The Darwinian principles are interpreted as follows:

a. Selection of a particular meme depends on a human's personal priority, known memes and selection pressures (Bandura 2013; Polski & Ostrom 1999).
b. Heredity is conducted by imitation and information transfer (by for example writing a message) (Hodgson & Knudsen 2006).
c. Variety is executed in the conceptual framework by copy errors and innovation. The change rate of memes is guided by the four layer model of Williamson and tracked with the institutional grammar (Crawford & Ostrom 1995; Williamson 1998; Hodgson & Knudsen 2006).

These three mechanisms help to study how relative stable information is adapted to the changing environment. In Table 10 an overview of the UD concepts' interpretation is given.

**Table 10 Adapted UD concepts interpretation**

| Concept | Concept translation |
|---|---|
| **(possible) Generative replicator** | Fact and Regulatory memes |
| **Generative replicator carrier** | Interactor |
| **Variation** | Innovation and copy errors |
| **Heredity** | Information transfer and imitation |
| **Selection** | Personal priority and memes |
| **Environment** | Fact and Regulatory memes |

Agent-based modeling is instrumentally used to test the conceptual framework, as here different theories can be tested together (Gilbert 2004). This modeling method is chosen due to its bottom up approach, open boundaries and non-stationarity/non-linearity assumptions of the modeling approach, which inter alia enables simulating the emergent behavior of a socio-technical system (Van Dam et al. 2012). The downside of agent-based modeling is that the traditional validation methods cannot be used, as it is exploring possible future states (Van Dam et al. 2012, p.127). Unfortunately, there is no data confirming the likelihood of those states.

**Here the explanatory value of conceptual framework is discussed, answering the second sub-research question - *How can the conceptual framework be applied to generate a deeper understanding of evolving processes in the water services delivery case?***

The conceptual framework is a first attempt to combine the institutional analyses and UD theory. The combination of the institutional body of theory and the UD theory seem to have potential, as many areas of overlap between the two bodies of theory is identified:

- The 'gene-like entity' in the socio-technical system.
- The different foundation of the replicators.
- The different change rates of existing replicators.
- The network of interactors that (possibly) influences the replication of replicators.
- The human selection process of replicators.

The explanatory value of each element of the conceptual framework is discussed here.

The division between memes helped to understand processes, as a particular fact meme can stimulate the decision for a particular regulation meme. The chosen regulation meme can in turn 'guide' a the particular fact meme into a particular direction, which can change the fact meme.

Heredity is about the imitation/transfer of memes from person to person. In the conceptual framework heredity contributes to the understanding where and when a pattern of interaction stagnates or continues, as it gives a focus on the replication of memes.

- In the model design the meme-scope of the interactor determines which memes can be replicated or not. It would be more realistic if the interactors would have the possibility to imitate the behavior of his/her 'neighbor'.

The value of 'bottom up' variety in the model design is not well tested in the model design. The model design did not help to test the value of variation in combination with institutional analyses, due to the model design's descriptive character. Here it is difficult to test a generic mechanism that enlarges the complexity greatly.

- In the model design only 'top-down' variation (from the environment) is implemented, where the model user can influence the policy and knowledge input.
- The institutional grammar can give a clear overview of the used the regulation memes and show which repetitive elements of the institutions vary or stay constant during the process of variation. However, now that the variation mechanism is not yet incorporated fully, institutional grammar is kept out of the model design, as the added value of the (top down varied) regulation memes overview is too limited.
- Additionally, as soon as the 'bottom up' variation mechanism is implemented the four-layer model has the potential to guide the variation frequency of memes.

The selection mechanism contributes to the understanding why a certain meme is transferred or not. As the interactor's personal priority, known memes and conditions influence the decision making process of the interactor. Conditions are created by memes that have an influence on the attractiveness of a particular meme.

The value of the Institutional Analysis and Development (IAD) framework is its possibility to describe a socio-technical system with the possibility of incorporating the Darwinian principles' mechanisms. However, during the interviews, for the model design and conceptual framework reflection, it became clear that people find it difficult to define specific norms, laws and shared strategies which are in use, as people do not organize their knowledge within the borders of institution 'types' (norms, values and shared strategies).

**Besides conclusions concerning the conceptual framework there are also concluding remarks concerning the model design itself.**

Firstly, the Ugandan model design enables to test different policies, mechanisms, theories etcetera together, which is impossible in the real world and very elegantly performed with a finalized agent-based model.

Furthermore, the model design as presented in this Master thesis research is not only a description of the current system, but it also explores the effect on the water service level[34](WSL) of possible policies. Mainly because it is a descriptive model design, this model cannot only educate people of IRC

[34] The water service level is defined by IRC International Water and Sanitation Centre and its partners to be able to define different service levels, based on quantified 'service delivery indicators'(Moriarty et al. 2011; Fonseca et al. 2011).

International Water and Sanitation Centre, but also Ugandan policy makers and development partners, as people can recognize the situation and maybe even themselves in the model design.

In the Netherlands there is the slogan 'A betere wereld begint bij jezelf' (translation: A better world starts with you). Due to the bottom up approach of the model it can be seen that local 'normal' people can have an effect on the outcome of the system, by for example paying the water service provider. Showing this model design to these people can therefore also have an empowering effect on the local actors.

With help of the conceptual framework and interviews with case experts the suggestion is made that the key drivers of change, in the water services delivery system of rural areas of Uganda, are:

1. The motivation of certain actors (mainly Water User Committee (WUC) and Hand Pump Mechanic (HPM)) (Nabunnya 2013; Bey 2013b).
2. The satisfaction of the water users (WU) with the WUC (as water users often do not trust the WUC) (Lieshout 2013).
3. The water users' dependency on a particular water point (Lieshout 2013).
4. The water point's functionality (Schouten & Moriarty 2013).

In Figure 11 the model design is proven, as the initial hypothesis of the Ugandan case model design states that the policies and knowledge, as mentioned in Figure 11, have an effect on the key drivers of the water services delivery system and affect the water service level. In Figure 11 it is shown that in the model design these policies have a (direct or indirect) effect on the water service level (as well as the other key drivers). It should be tested whether the effects are positive or not in an agent-based model. Additionally, whether the list of key-drivers is comprehensive and truly affect the water service level should be proven with pilot in a rural area of Uganda.

**Table 11 Policy and knowledge (direct and indirect) effects**

| Policy: | Direct effects[35]: | Indirect effects: |
|---|---|---|
| **WP Management Knowledge** | Monthly payment (or incidental) request by WUCs, Relative budget of WUs, Maintenance contracts, Stock of spare parts | WSL, WUC motivation, Functionality |
| **WP Mechanic Knowledge** | Evaluation (sanction) | HPM motivation, WSL, Functionality |
| **Sanctioning policy** | Motivation of WUC/HPM | WSL, Monthly payment, Maintenance contract, Functionality |
| **M4W policy** | Conditional Grant proposal | Conditional Grant, WSL |
| **HPMA Policy** | Maintenance contracts, repair/installation of WP | WSL, Functionality |
| **Maintenance Policy** | Maintenance contract, WSL, Functionality | Satisfaction of WUs, Relative budget, WSL |
| **New WP policy** | Dependency | Relative budget, WSL |
| **WUC payment policy** | Motivation of WUC | WSL, Satisfaction of WUs |

[35] All terms are explained in chapter 9.7.1.

As a western researcher analyzing the current water services delivery system in Uganda it is striking to see that superstition has such an important role in the Ugandan culture. Due to superstition sanctions and evaluations are rarely given/done, as people, who are responsible for giving a sanction, are afraid that the affected person will send a bad spirit to them. So, maybe it can be said that laws (which contain a sanction) are more like norms (which do not contain a sanction) in the water services delivery system of rural Uganda.

Furthermore, the District Water and Sanitation Conditional Grant (DWSCG, hence forth: Conditional Grant) distribution rates that are adopted at the moment by district water office assigns a large chunk of the money to the investment in new water facilities, namely 70%. The jar of money for the rehabilitation of water points is only 8% of the total received grant. This affects the sustainability of water points negatively.

**Usability of the conceptual framework in other situations, than the Ugandan case, is reflected upon here.** The conceptual framework is helpful for problems that contain:

- Regularity, as otherwise there are not institutions guiding the behavior.
- Variation of memes, as changes in decision behavior should be able to influence the problem.
- People as they carry and replicate the memes.
- Interaction between people, as the memes are transferred from person to person.

Problems that entail extreme situations (with a high chance of a 'decision making error'), processes without regularity and/or a high increase of variety of memes are not advised to directly copy paste this conceptual framework, as these elements need more research.

The conceptual framework could for example also serve for generating a deeper understanding of a system that is going through a transition (from Community Based Maintenance System towards a Piped Scheme Management System for example), as the transition theory[36] has the same scientific basis and view on the emergence and adaptation of complex adaptive systems (Chappin 2011; Loorbach & Rotmans 2006; Geels 2002).

It should be realized that the interview questions, which are proposed (and used in this research) to populate a model design with case specific knowledge, potentially need some adaptation. Depending on the background interviewees, the interview questions should be more or less specific than stated in this research.

[36] It is realized that the transition theory has been mainly applied to the Dutch energy sector and still in the development phase (Chappin 2011).

# 8. Recommendations

In this Master thesis research a first effort is made to come closer to a conceptual framework and agent-based model design that gives a deeper understanding of the changes of processes in socio-technical systems.

**Design recommendations**

The combination of the institutional analyses and Universal Darwinism has the potential to explain some interesting mechanisms, like emergent human behavior. Here it has been tried to give a handle for future research. Future research should give attention to:

1. The further operationalization of the variation and heredity mechanism.
2. Proof of concept concerning the division of fact and regulation memes.
3. Application of the model design for a multi-problem situation.

1) Currently, most of the variety and heredity is in the hands of the environment. The aim should be to give the interactor the possibility to innovate a meme by itself, to make a copy-error and imitate the behavior of a 'neighbor'. It is of great value to explore the possibilities of variety and heredity of memes in agent-based models, as they are two of three key principles of evolution. The network theory can be a starting point for exploring the further operationalization of variation and heredity, as this body of theory has been working on the spread of memes within a system (Christakis 2010).

2) This study shows that the meme division is helpful in the model design, however, it is not proven that the regulatory and fact meme distribution is comprehensive. More research needs to be done to prove this distribution and to refute Blackmore's argument that not all types of information (for example facts about an event (Blackmore 1998)) are memes.

3) In the current model design, there is only one problem, namely the water services delivery failure. However, it would be interesting to see the possibilities of the conceptual framework in multi-problem situation. Currently the personal priority is simplified in the model design as motivation 'to solve the problem'. A possible solution to this is to implement several motivations in the individual's property.

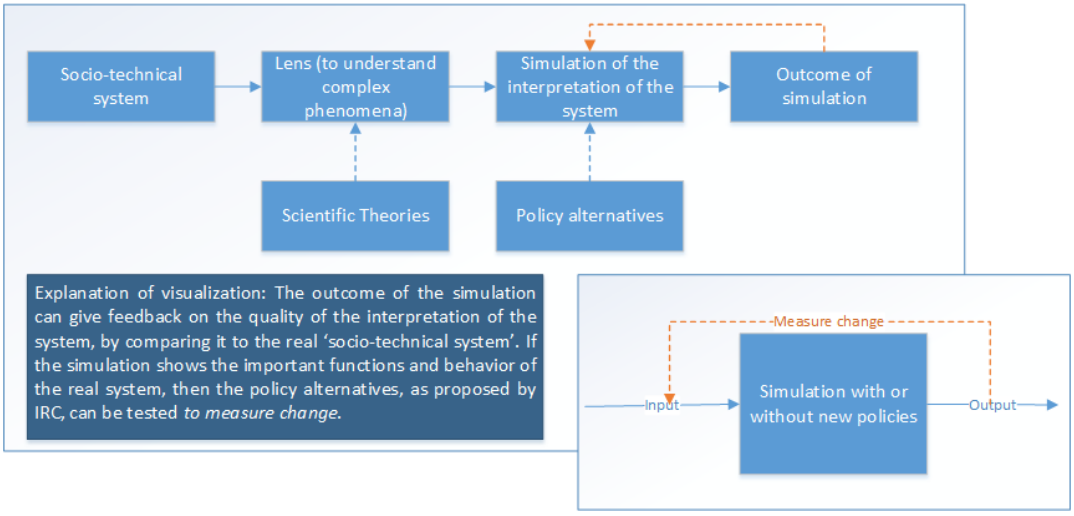


Figure 32 Future research: measuring change with implementing particular policies

In Figure 32 the step of testing the agent-based model design is shown. Changes of the model design can take place in this stage, as the outcomes can be compared with real data (with help of interviews (qualitative data) and if possible data from field research (quantitative data)). Before starting this stage the conceptual framework should be agreed upon. As soon as the model design is good enough to simulate the water services delivery system with, then it would be highly useful to study the effects of the different policy alternatives on the individuals and the system as a whole, Figure 32.

**Direct recommendations**

It is advised to IRC International Water and Sanitation Centre to choose between the two options given below:

Option 1. Develop the model design, as presented in the main text and appendix, further by programming the model design in an agent-based modeling program, like NetLogo. The main advantage of this option is that people can quickly test and see the influence of certain policies on the outcome of the water services delivery system, which can be very educative for local parties and development partners. The biggest disadvantage is that some of the conceptual framework's mechanisms are not functioning to its fullest extent, which currently reduces the value of the proposed conceptual framework.

Option 2. First develop a small agent-based model that has much less explanatory value, but is focused on the operationalization of the variation and heredity mechanisms (in combination of the institutional grammar and the other theories). The operationalization of the selection mechanism should be checked as soon as variation and heredity is well understood, as new insights concerning variation and heredity can affect the selection mechanism.

The main advantage of this option is that the scientific value of the conceptual framework is further explored and elaborated. In other words, as soon as these Darwinian principles are well translated in an agent-based model, the evolution of processes in socio-technical systems can modeled from within the action arena. The main disadvantage is that this option is less quick than the first.

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# Appendix

# 9. Appendices

## 9.1 Water services delivery ladder

IRC and its partners developed ladders for assessing and costing water services delivery (Moriarty et al. 2011). The concept of service levels is a structure to analyze data (Service Delivery Indicators) being collected in different countries and settings in terms of domestic services being received. The main phases of service delivery are initial capital investment, operation and minor maintenance, major repairs and upgrades. Besides phases, different aspects of service delivery are included in the water services delivery analysis, as the management of the water resource base, the provision of water infrastructure and the costs associated with the service (Moriarty et al. 2011; Moriarty 2010).

The water services delivery to people is defined by IRC as the quantity of water of a given quality accessible by users and the system (hardware and software) used to deliver it. In other words, it is the provision of access to water in a way that meets a set of key indicators (or norms) (Moriarty 2010).

The service level is a collection of different indicators. The exact interpretation of the water service level varies across countries. The factors are a combination of engineering, social and political factors. The most common Service Delivery Indicators (SDIs) against which the quality of water services can be assessed include:

1. **Quantity** (liters per capita per day (lpcd)
2. **Quality** (typically composed of one or more separate indicators looking at chemical and biological quality)
3. **Distance** (from household to a WP)
4. **Number of people** (crowding of WP)
5. **Reliability** (proportion of the time that it functions to its prescribed level)(Moriarty 2010)

In order to define service levels, values have to be used for monitoring service quality. For many indicators internationally accepted minimum standards exist, for example the Joint Monitoring Program (JMP) norms (Moriarty et al. 2011; Fonseca et al. 2011) and WHO norms for improved and unimproved sources(Moriarty et al. 2011).

Service ladder is a metaphor for the notion of incremental steps between service levels of different quality. The indicator levels are operationalized as shown below (Table 12 & Table 13).

> *An assumption of the service ladder is that the five service levels reflect the operational reality of an emerging water services delivery level.*

**Table 12 Service levels and indicators** (Moriarty 2010; Moriarty et al. 2011)

| | Quantity (l/c/d) | Quality | Accessibility (mpcd) | Reliability | Status |
|---|---|---|---|---|---|
| **High** | >60 | Good | <10 | Reliable/secure | Improved |
| **Intermediate** | >40 | Acceptable | 30 | | |
| **Basic (normative)** | >20 | Acceptable | 30 | | |
| **Sub-standard** | >5 | Acceptable | 60 | | |
| **No service** | <5 | Unacceptable | >60 | Unreliable/ insecure | Unimproved |

An acceptable level of service is one that meets agreed norms for each of the 5 key indicators. Turning the mix of indicator levels into one aggregate indicator can be complex. However, a simple rule that is advised by Moriarty (2010) is to say the level of service accessed by a person is set by the level of the lowest individual indicator.

**Table 13 Norms for service delivery** (Moriarty 2010)

| Indicator[2] | Mozambique | Ghana | Burkina Faso | India[3] |
|---|---|---|---|---|
| **Access** | **Distance**<br>No norm[4]<br><br>**Crowding**<br>< 500 people | **Distance**<br>< 500 m<br><br>**Crowding**<br>BH < 300 people<br>W < 150 people<br>SP < 300 people | **Distance**<br>PS <1000 m<br>SS <500 m<br><br>**Crowding**<br>SP < 300 people<br>BP < 10 people<br>PDC < 100 people<br>BF < 1000 people | **Distance**<br>< 1600m horizontal<br>< 100m vertical (in hilly area)<br><br>**Crowding**<br>HP/SP < 250[5] people.[6]<br><br>**Social exclusion**[7] |
| **Quantity** | 20 lpcd | PS - 20 lpcd<br><br>HC - 60 lpcd | PS - 20 lpcd<br><br>HC - 40-60 lpcd d | 40 lpcd<br>70 lpcd (with high live-stock density) |
| **Quality** | WHO guidelines | Ghana Standards | WHO guidelines | Bureau of Indian Standard (BIS Is:10500) |
| **Reliability** | Nothing defined | Rural – nothing defined<br>SS % time available >95% | Nothing defined | Security concept[8]<br>At least once in a day |

Translation Table 13: BH – borehole, W- well, PS – point source, HC – house connection, HP – hand pump, lpcd – liters per capita per day, SS – small system, SP – standpipe, BF – Borne Fountaine (a kind of public standpipe), PDC – poste d'eau communautaire (a group of stand-pipes, each dedicated to one family).

## 9.2 Complex Adaptive Systems

In this appendix Complex Adaptive Systems are further explained. Before elaborating on Complex Adaptive Systems (CAS), one should have an understanding of the systems perspective and complexity.

The systems perspective describes the properties of the system in a non-reductionist way. So, that the behavior of the whole is not made incomplete by separating the system into parts. The description of the whole should include an explanation of the relationships between parts and any additional information that is needed to describe the behavior of the entire system (Bar-Yam 2011).

The systems perspective shows the complexity of a situation. Mikulecky's definition of complexity is '*Complexity is the property of a real world system that is manifest in the inability of any one formalism being adequate to capture all its properties. It requires that we find distinctly different ways of interacting with systems. Distinctly different in the sense that when we make successful models, the formal systems needed to describe each distinct aspect are not derivable from each other*'. In other words, everything that is not simple nor complicated is complex (Mikulecky 2001).

The definition of CAS can be applied to many different systems. A more specific application of CAS is Complex Population System. This theory is developed for social and biological phenomena (Aldrich et al. 2008). A complex population system refers to populations: which consists of non-identical entities; who compete for local scarce resources; who have problems with survival; who store adaptive solutions; and pass on adaptive solutions to other entities. Additionally they include human entities, as long as humans may be regarded as cohesive entities having some capacity for the retention and replication of problem solutions (Aldrich et al. 2008).

## 9.3 Core Darwinian principles

To further understand the meta theory Universal Darwinism the three core principles are further elaborated:

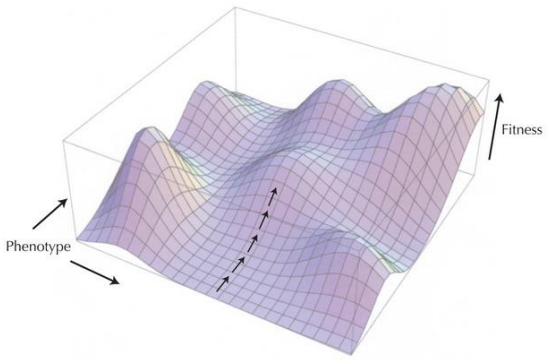
**Variety** in biological systems involve genetic recombination and rare mutations. However, there is no closely analogous mechanism in the evolution of social institutions (Aldrich et al. 2008). Innovation and copy-errors are the mechanisms which are closest to the biological systems (Mesoudi et al. 2006; Podos et al. 2004).

**Selection** pressures cause a set of entities, a population to 'gradually adapt in response to the criteria defined by an environmental factor (Aldrich et al. 2008)'. The ability to adapt makes that some entities are better adapted to the current environment than others and are more reproductive. For example, in a cold environment, the proportion of mammals with more fat or longer fur is likely to increase.

**Heredity** (or replication) refers to imitating/passing/copying of problem-solving or developmental information from one entity to another. In biology this mechanism involves genes and DNA. In social evolution, we may include the replication of customs, rules, routines and habits, all of which may carry the information to solve adaptive problems.

## 9.4 Fitness landscape

The design space of the evolutionary process can be represented with a fitness landscape. It is really a mental image that helps to think through how co-evolution works. The landscape is a result of individuals, environment and their interactions. It is not something that is designed.




If you affect one another within a specific environment, the combined fitness of a system would be higher or lower. Interactors are moving around the space, as they evolve and

adapt. The hills move around on their own, as the environment changes and adapts. The environment of the fitness landscape is shaped by the perspective that is adopted. Different perspectives cause a different landscape (hills and valleys).

**An example to explain the fitness landscape**
There are Lions and Gazelles. Imagine that Lions suddenly learn to cooperate, then the Gazelles are toast. The fitness of the Lions suddenly increases and the fitness of the Gazelles radically decreases because they are eaten more efficiently as it exhibits a pressure onto the Gazelles. Then Gazelles need to invent something new genetically, which then becomes learning to turn corners faster or evolving larger legs so that they can run quicker. Which then re-shifts the balance and reduces the fitness of the Lions. Now this is a simple 2-dimensional thing. An actual eco-system has multi-dimensions.

There is a constant shifting around, so one time Gazelles have productive success, because that is what fitness really is. The productive success is really high if you are making lots of offspring. And the more you are doing that, the more you are affecting everybody else's fitness, because (with lots of Gazelles) they are eating all the grass, thus reduces all the other prey and thus the Lions are suffering.

## 9.5 Consciousness and decision making error

In this appendix the reasoning of not adopting the theories of consciousness and decision making error in the conceptual framework.

**Consciousness**
Kroes (2009, p. 283) discusses whether '*the possibility of emergent features with causal powers of their own are taken seriously within engineering practice'.* Some scientist, like Blackmore (2003), say that consciousness is an illusion, a computer program, a purposive behavior (Dawkins 1976) or not of importance.

Dawkins states that consciousness is a philosophical thing that is treated in his book The Selfish Gene as purposiveness of humans and it is left open whether it exists or not (Dawkins 1976). The book states: '*The fundamental principle involved is called negative feedback, of which there are various different forms. In general what happens is this. The 'purpose machine', the machine or thing that behaves as if it had a conscious purpose, is equipped with some kind of measuring device which measures the discrepancy between the current state of things, and the 'desired' state. It is built in such a way that the larger this discrepancy is, the harder the machine works. In this way the machine will automatically tend to reduce the discrepancy—this is why it is called negative feedback—and it may actually come to rest if the 'desired' state is reached*.'

In the book 'Consciousness explained' Dannett (1991) shows that you do not have the authority over your consciousness the way we think we have. The reason for that is that your eyes give the suggestion that you are well aware of the things that are happening around you (Dennett 1991). The things of which you are aware of are only a small part of reality. Dannett suggests that your consciousness is a set of tricks. He states that people do not want to know/hear that their 'being' is just a bag of tricks (Dennett 1991).

On the other side, Searle (2003) states that the purposive view of consciousness excludes that certain behavior does not fill the gap between desired and current situation. For example, it is not the same to feel pain and show a behavior of pain (like screaming) (Searle, 2003). As feeling doesn't have by all means a purpose nor is reacted to purposefully. Searle (2003) states that consciousness consists of all those states of feeling, sensuous and awareness.

> *Here it is chosen to have the view of inter alia Blackmore and Dannett as the arguments of Searle are, for the sake of the researched system/problem, not relevant. As the included (purposeful) 'personal priority' can entail desires/feelings.*

**Decision making error**

Humans can take rational decisions, during 'normal' decisions. This means that you take one step back and analyze your resources, accumulated set of memes and personal priority. In an extreme situation or in a situation in which you have never been before, you can also act irrationally, which can be seen as a decision making error. Irrational behavior is an action or opinion which is given through an inadequate use of reason or cognitive failure (McKenzie 2003; Burns et al. 2013).

During the interviews it became clear that the situations which are apparent in the researched system are not as extreme as e.g. Burns and McKenzie describe in their articles. Therefore 'decision making errors' are left out of the research.

## 9.6 IRC's Water Services Delivery Expert Interviews

In this appendix the interview with the IRC experts are summarized. The summaries are checked by the interviewees themselves. First the setup of the interview is treated here. The interview is evaluated by Maartje E.D. van den Boogaard, who is a researcher at the Technical University in Delft and a teacher in interview techniques. As mentioned in the Methodology chapter, the interview has been performed on a semi-structured basis.

### Interview setup for IRC's Water Services Experts

Thank you for your time and for sharing your knowledge on water services delivery in Uganda. The interview will approximately take an hour. I appreciate the cooperation very much.

The information that you give during this interview will be used by IRC for the formalization of a simulation model. In the future, it is possible that this model will be published in a scientific magazine for scientific and policy formulation use.

**If you wish, your information can stay anonymous. The interview will be recorded, so that the interviewer can stay focused on the conversation.**

#### Purpose of research

In this paragraph an introduction of myself is given and the purpose of my research is explained. My name is Simone van Tongeren. I'm a Master student of the Technical, Policy and Management faculty at the Technical University of Delft and I'm performing my thesis research project for IRC International Water and Sanitation Centre in The Hague.

My thesis focusses on creating a deeper understanding on (changing) processes concerning the water services delivery in rural Uganda at district level. A deeper understanding of the evolution[37] of a socio-technical system[38] over time is interesting to IRC International Water and Sanitation Centre, because with this knowledge IRC can promote and explore policies that stimulate the evolution towards a more sustainable water services delivery system.

## Introduction of interview

In this introduction my vision on the water services delivery problem is given. *Please feel free to comment on this description.*

In rural areas of Uganda, reliable water flowing from safe sources is not a certainty. The reality is that water points often break down, services failure is frequent and often lasts for many days or weeks. Local people are then forced to drink from unreliable unprotected sources. The **problem** is that there is a water services delivery system within a region/sub national service area (district), which fails to deliver water services at a desired level of performance.

As mentioned in the *Purpose of research*, the **lack of insight** that is addressed in this research is the evolution of the water services delivery system in rural Uganda across the levels of water users, water service provision and water service authority (district). The **pattern** that is observed is that services fail to maintain/repair the water points. In other words, a relatively low percentage of water points, and thereby civilians, receive the desired level of water services (Schouten & Moriarty 2013).

The **desired pattern** is that there is a basic[39] level of service for all water users. The **initial hypothesis** for the (low) water service level in rural areas of Uganda is that because local civilians (with different roles) have different priorities, values, norms etcetera in relation to the desired pattern, they tend not to act in line with processes which are designed to improve and/or maintain the water service level. Instead, they develop different kinds of attitudes and perceptions, that influence their choice of actions/decisions about how to act (i.e. pay their water user fees, make a small repair, call a mechanic) towards water services delivery processes. In other words, the more the desired pattern, the basic level of water services, is aligned with personal priorities, norms etcetera, the more robust the system is. A small variation of a process will lead to the same result in a robust situation.

The **problem owner** is in this case IRC, as it wants to be an effective change manager. The **other actors** involved are the Water Service Authority, Water Service Provider and Water Service Consumer/User at district and village levels in Uganda, respectively: the District Water Officer, Water User Commission/Hand Pump Mechanic and the Water collector. The **role** of IRC in this research is to gain more information on how the water services delivery system functions, to later facilitate the desired change.

[37] The words 'evolution' and 'change' are used interchangeably and are seen as synonyms.

[38] Socio-technical systems are complex and consists of technical artifacts and heterogeneous decision making entities. These systems are guided by public policy in a multi-scale institutional context (Ghorbani 2013).

[39] An acceptable level of service is one that meets agreed norms for each of the 5 key indicators. An basic level indicates that the water is: reliable, the quality is acceptable, the quantity is more than 20 liters per capita per day and finally the crowding and distance is acceptable.

**The goal of this interview is**:

1. to identify outcomes of the water services delivery system
2. to identify pattern of interaction of the water services delivery system
3. to identify the range of possible decisions of the different actors
4. to identify personal priorities of the actors
5. to identify regulations in use: Laws, Norms & values and Shared strategies
6. to identify relevant facts about the delivery of water services
7. to identify relevant environmental influences (of physical world, community and rules)
8. to evaluate water services delivery criteria.

## Questionnaire

**Theme 1. Personal background**

The first few questions are about your personal background.

1. **What is your expertise?**
    a. How long have you been active in the WASH sector?
    b. What is your educational background?
2. **In which district(s) of Uganda have you been active?**

Please keep this/these districts(s) in mind while answering the questions.

**Theme 2. Outcome of the system**

To analyze the water services delivery in rural parts of Uganda, it is important to know what the current outcome of the system is and who participate in this system.

*(Outcome)*

3. **What are the outcomes of the system?**
4. **How do the observed outcomes of the water services delivery compare to the policy objectives (for the district(s) that you have been active in)?**
    a. Which of these outcomes of the current situation are satisfactory and which are not?
        - Who is involved, when, where?
        - Which outcomes are important?
5. (See appendix) Can you please evaluate the outcome of the water services delivery system taking the following criteria under consideration (please rate them from 1 to 10, 'not' to 'very much/high').

*(Heredity)*

6. Which elements change over a time scope of 10 years? (think of personal priorities, norms, values, laws, shared strategies)
7. What are the chances of success for a new twist? (do people adopt new ideas, or ways of doing things, quickly or are they conservative in their thinking and doing?)

**Theme 3. Actors**

This set of questions is about the actors, their interconnections and their motives.

**Stakeholders – Pattern of interaction**

8. What is the pattern of interaction in relation to water services delivery?
9. What is required to provide a water service?
    a. Physical resources
    b. Human resources
    c. Technologies
    d. Processes
10. What are the storage requirements and distribution channels?

**Participants**

**Water service authority**

11. **Who fulfils this role?** (DWO?)

12. **What are the actions that the Water Service Authority can take?**

13. Which main concerns are possible for an authority to have? (a focus on regulation and sanctioning of Provider's performance, personal power and status, personal financial gain, personal survival, knowledge gain)
    a. What are the personal priorities?
        - Think of health, power, status, money, time etcetera.

14. Which resources come with those types?

15. What are members' values and beliefs (maybe per 'type')? Which of them are popular?
16. What are laws that are in effect? Which of them are popular?
17. What are shared strategies that are in effect? Which of them are popular?

18. What information about the action situation is available to Water Service Authority?
        - in relation to health, technology, finance, water service provision
19. What influence do these actions, mentioned in Q11, have on the outcome of the system/other actors?
20. What costs and benefits do Water Service Authorities incur when they take action in this situation?

**Water service provider**

21. **Who fulfils this role?** (WUC&HPM (can be seen as one?!))

22. **What are the actions that the Water Service Provider can take?**

23. Which main concerns are possible for a provider to have? (a focus on water service level, personal power and status, personal financial gain, personal survival, knowledge gain)
    a. What are the personal priorities?
        - Think of health, power, status, money, time etcetera.

24. Which resources come those types?
25. What are the personal priorities?
        - in relation to health, time, money

26. What are members' values and beliefs (per type)? Which of them are popular?
27. What are laws that are in effect? Which of them are popular?
28. What are shared strategies that are in effect? Which of them are popular?

29. What information about the action situation is available to Water Services Provider?
        - in relation to health, technology, finance, water service provision
30. What influence do these actions, mentioned in Q21, have on the outcome of the system/other actors?
31. What costs and benefits do Water Service Providers incur when they take action in this situation?

**Water service user**

32. **Who fulfils this role?** (Water user)

**33. What are the actions that the water service user can take?**

34. Which main concerns are possible for a water service user to have? (a focus on received water service level, personal power and status, personal financial gain, personal survival, knowledge gain)
    a. What are the personal priorities?
        - Think of health, power, status, money, time etcetera.

35. Which resources come with those types?
36. What are the personal priorities of the water user (types)?
        - in relation to health, time, money

37. What are members' values and beliefs (per type)? Which of them are popular?
38. What are laws that are in effect? Which of them are popular?
39. What are shared strategies that are in effect? Which of them are popular?
40. What information about the action situation is available to the Water Services User?
        - in relation to health, technology, finance, water service provision
41. What influence do these actions, mentioned in Q32, have on the outcome of the system/other actors?
42. What costs and benefits do Water Service Users incur when they take action in this situation?

**Perception towards others**

43. What are members' beliefs about each other's main concerns, preferences and actions? (homogenous group of actors?)

**Environmental impact**

**44.** Which actors, resources from the environment have an influence on the outcome of the system? **In addition to the above, are there any other actors/resources of influence to the system?**

**Theme 4. Evaluation**

**Evaluation criteria**

45. Do you agree with the evaluation criteria for a water service?
    - Quantity (amount of controls, maintenance and repairs per year)
    - Quality (mean time between repair)
    - Price (total price of service per water point per year)

## Appendix

Evaluation current system

| Evaluation criteria | 1 (not) – 10 (very much/high) |
|---|---|
| Efficiency | |
| Fiscal Equivalence | |
| Distribution Equity | |
| Accountability | |
| Conformance to general morality | |
| Sustainability | |
| Adaptability | |

Evaluation criteria – Water services delivery (product)

- Quantity (amount of controls, maintenance and repairs per year)
- Quality (mean time between repair)
- Price (total price of service per water point per year)

## Report Interview with Valérie Bey

*12-12-2013*

### Personal background:

Valerie is a French woman that has been working for IRC since 3,5 years. She is a WASH engineer and worked in Malawi before she came to IRC. Between Malawi and IRC she did a Masters in social anthropology. At the moment Valerie supervises the data collection of the Service Delivery Indicators in Uganda for the Triple-S project.

The areas Valerie is familiar with are Kabarole and Lira.

### District information

#### Lira

Lira is dry and people have more difficulty to collect water. They often fetch water after working in the field, at around 2 pm (it is possible that this time is only correct in the rainy season (cross check with Robert Otim)). The water collection pattern is affected by the season (dry or wet) as shallow boreholes are not giving enough water during the dry season. The broad boreholes keep supplying the same amount of water. In Lira there are less water points than in Kabarole (VB).

#### Kabarole

Kabarole is a green area with many natural water sources. It is seen that the water services delivery level is not reached in Kabarole inter alia because the people do not need 20 liter per person a day from the protected water point. The people also collect water from for example the river. In Kabarole children collect water (as the water points are not far from each other). A children jerry can contains 10 liters and an adult size is 20 liters. These people tend to go to the water point in early morning. (VB)

#### SDIs

The Service Delivery Indicators that are monitored by IRC are: Quality, Quantity, Reliability and Access. 95% of the water points do not reach the level of basic water service delivery. Often the reliability is lacking and in Kabarole they do not reach the desired quantity. The quality has not been measured by IRC. A DWO from a district near Lira (Kidgum) measured the quality of the water from the well up to the point that is in the homes of the water users. The water gets contaminated more in the jerry cans. The perception of the people on the quality is that the water quality is fair. (VB)

#### Water Service Authority

The DWOs are open to opportunities, like the Mobiles for Water (M4W). They engage with the opportunities, so that they can get the monitoring done well. They are genuinely interested in improving the water services delivery system/technique. As they are engineers, they are very interest in the technique (information). (VB)

The DWO has information sharing moments with NGOs at a quarterly basis (DWSCC). (VB)

### HPM

At sub-county level there should be 2 HPMs. The HPMA are organized at district level. The DWO supports the HPMA to function properly (policy). With M4W the DWO gets an overview of the text messages and the DWO can stimulate the HPM or HPMA to be more reliable/quick. (VB)

### WUC

For Ugandan water points people need specialized tools and expertise to maintain/check the water point. The WUC cannot dismantle the water points themselves. The only check or maintenance a water user committee can perform is oiling some parts of the water point. So, if a water point breaks down they inform the HPM and ask him to make an assessment of the failure and costs. The money then needs to be collected by the water user commission. This is however a difficult step to take, as water users don't want to pay for their water (as politicians promise water for free) , don't necessarily trust the WUC or the WUC is not into collecting money (as it is an volunteer job). An estimate is that of the 180 water points that broke down and were assessed by an HPM during the M4W project in Kabarole and Lira, only 30 water points got repaired. (VB)

### Pattern of interaction

If a water point breaks a WUC/water user (leader) contacts the HPM and asks him to make an assessment of the costs. If the costs are above 250 euro or UGX 150,000 it is more a practice that repairs are beyond the means of the community, then the DWO is asked to pay for the repair and spare parts. The Water users are asked to pay for the repair when the water point repair costs less than 150.000 shillings. If the WUC succeeds to collect the necessary money, then the WUC pays a small share of the money at forehand, so that the HPM can buy spare parts. Then the HPM repairs the water point and the

Local Councilor 5 is elected by the people and can have an influence on distribution of the Conditional Grant (DWSCG). At a district level the LC5 and DWO compose a request for money, which is send to the ministry. The ministry sends a certain amount of money, which is less than asked for, to the district level. The DWO and LC5 then decide on the further distribution. The LC5 councilors can then influence the flow of the grant money. Some villages will get more money than other villages. (VB)

The grant money is linked to reporting, coverage etcetera and is given in phases. Often the grant should come in June and arrives in September (first part). The Conditional Grant should be spend is the following way:

- Investment in new water facilities: >= 70%
- Investment in software activities: <= 11%
- Rehabilitation of boreholes and piped water schemes: <= 8%
- Investment in Sanitation facilities: <= 6%
- Supervision, monitoring and DWO operational costs: <= 4% (2009/10 Water and Sanitation Sectorial Specific Schedules DWSCG)

The DWO office is often understaffed. In an office there should be at least 5 members, however, there are often just 2 people running the office. The DWO should look after 10-15 sub-counties (so around

1000-1500 water points. (See enclosed file “Kabarole” and “lira” from the Uganda Water Supply Atlas) The means and resources of the DWO are extremely limited. (VB)

### Local leader

The local leader in Uganda is often elected and has not as much power as a medicine man in Malawi. (VB)

### Additional resources/actors

CAOs is responsible for the district, NGO are playing an important role (depending per NGO and district). (VB)

### Evaluation criteria

- Ideas for the service evaluation criteria: (VB)
- Quantity -> report of problem-> # of days before assessment
- # of service providers last year, # of service providers which are dormant, # of service providers which are retrained.
- Last repair was crap, the water point is old, the users do not care about the water point: are all reason why the service can be lacking, which are not failures of the water service provider. (VB)
- See file “Draft Service Delivery Indicators for Rural Water Supplies 13 09 2013 – short”. In there, you have an overview (and definitions) of the different service delivery indicators we designed for Uganda. Some may provide some inspiration on the additional dimensions you would like to add in your analysis. Note this is not the latest version, it needs an update, but it will already give you a good idea. And will share the updated document as soon I have it.

### Report of failure by SMS; Numbers

- 230 SMS sent to 8888 since the beginning of the project, 151 since beginning of Phase 2 (sensitization of communities), with e.g. 75 problems reported in September 2013
- For 183 water points, an assessment was made
- 189 open, 35 solved, 6 suspended
- 34 fixed, 148 not fixed, 48 ?? (left blank, recorded neither as fixed or not fixed)
- Cost of repair (costs labor + materials) ranging from UGX 4,000 (eq. USD 1.6) to UGX 5,000,000 (eq. USD 1954)
- Average cost repair UGX 570,441 (eq. USD 223)
- Median cost repair UGX 144,000 (eq. USD 56)

## Report Interview with Rene van Lieshout

19-12-2013

### Personal background

Rene is a Civil WASH engineer. First he was more technical oriented while working in the WASH sector and now more process oriented. As IRC is more focused on process designs. At the moment he is a senior program manager and manages/works on a number of projects in Kenya, Uganda and Sierra Leone.

### Outcome of the system

The ambition of the rural water services delivery system is to achieve a basic level of water services delivery. The Quality is not measured in the field yet. The Quantity should be 20 liters per person per day. However, as soon people have to walk 15 minutes or more for water, they tend to live from 10 liters a day.

Most people live within 1 km distance from their water point. Water collection is often done by women and children.

The low water service level is a vicious cycle that is difficult to stop.

### DWO

The coverage is measured as: amount of water point*people capacity (e.g. 300, 50 families)/amount of people in the district.

The DWO does functional spot checks for the annual report. A water point is counted as functional when the water point is providing water, but also if the water point is broken but in the opinion of the DWO can be repaired. The spot checks are carried out at least once a year with the help of consultants that check the functionality of most water points for the DWO. The Functionality published in the annual sector review report is higher than in reality because of this way of counting. Also the Water User Committee functionality score is much higher than in reality. About 25% of the WUCs are actually functional.

Every quarter of the year the DWO is supposed to report to the ministry, so that they can receive the conditional grant. The DWO has an idea of the functionality of his water points and they monitor changes. There is no systematic routine of water point checks for the quarterly reports for the ministry.

The DWO is reactive to complaints and wants to overcome that by giving the HPMA the power to overlook the site when implementing a new water point. The DWO is proactive in stimulating this direction. The ministry however does not want to see that happen.

The HPM do not earn enough with repairing water points to live from. So, the DWO stimulates the HPMA to do more jobs (and bigger jobs, like building pipelines).

In the piped schemes, the Umbrella Organization (is association of Water Boards for piped schemes) staff pays a support visit every 3 month. The UO has taken away the burden for the piped schemes for the

DWO (but is for 95% paid by the DPs). The DWO hopes that the HPMA is going to have a similar impact for the support to the hand pumps.

The DWO has to monitor 1000 WUCs, which difficult to manage with such few employees.

The HPMs' personal priorities are water and financial gain. He has the drive to help the sector forward and the DWOs' function also opens doors to help him further in his carrier and income. The contractors always pay 10% of the value of the project to the contractor.

Repairs can take months, as the DWO has (15%) projects from the other financial year that still need to be fixed. The political lobby (Local Councilors) have an influence on the distribution of money, some sub counties receive more money than others.

M4W help to speed up the rehabilitation process.

The DWO has to divide the money per sub-county. They measure the distribution, but they do not do something with this measurement. The DWO would like to achieve a better water service level and if that is possible by doing it fair, then they would be willing to do so.

Measuring could be stimulating or repressing, depending on the policy

### Laws

De DWO has well defined tasks he should stick to and is evaluated on by the ministry (sanctions are possible here). The guidelines have a big influence on their job. E.g. the distribution of money.

The guidelines are not the reality. They often cut corners, so that they can achieve their goal quicker.

Resources are often well documented in the books, but often in reality there are a lot less resources available.

*Uganda has guidelines and laws for everything. The difficulty is how to make people follow them (with a lack of resources, capacity).*

### *Assumptions*

*The system is built from a community based responsibility perspective. In the 1980' people were told what to do from the central government. Now it is more community based responsibility. This perspective brings ownership, which doesn't work easily.*

*The central government doesn't have the capacity to take to responsibility of ownership.*

### Water Service Provider

People barely pay for their water and often there is no payment structure. However, if there is a payment structure (pay once a month) it is unclear who needs to pay, because the WUC should have a list of all the families who are using the water point, but often this list is lacking or has many mistakes.

If the point breaks then and there is no payment structure there is a problem, because there is no money. This is sometimes a reason to collect the money and people are willing to pay the money if they are in need of this pump.

### Sanction

The sanction often has a negative feeling, you can better work with incentives.

### Superstition

Often there is no rational explanation of why things happen. The superstition has an influence on the people ways of acting.

If you sanction somebody, then you are scared that this person will send a bad spirit into your direction or that you get bewitched.

*Yearly evaluations of employees is for this reason not probable.*

### Water User Committee

The WUC has the responsibility of ONE water point. Around 50 families and 300 people live from one water point.

When there is a strong need of water from that certain water point and there is an appreciation for the action to repair the water point, it is more easy to collect money.

The WUC that gets trained is reelected the next time too, as they are the only ones with knowledge. The main concern for a well-functioning WUC is the knowledge that should be in place.

Transparency of a WUC is very important for the success of an WUC. *An display of the income and expenditures for example can help a lot in building a trust relationship.*

Women are often treasurers, because they see the importance of clean drinking water. Men often do not recognize the importance of WUCs, do not see the priority of clean drinking water.

The main concern of the LC1 (chairman) of the WUC is power and status. The other members of the committee are often more concerned with water (safety), especially the women of the committee. The treasurer is a very serious position and gives status.

The main resource of the WUC is knowledge for the daily maintenance of the WUC committee, like small repair knowledge, accounting (simple) and management.

Small maintenance is keeping the ground around the water point clean, fixing a tap, oiling the system etc.

Other resources are a little bit of money (500 UGX/m/hh), a lot of time, but no money for big repairs.

The HPM are trained/chosen by the DWO/NGO. The HPM are chosen because they performed a technical profession. The change of HPMs in a district is quick, as they move a lot and go to places where

they think they can earn more money. Furthermore, they don't earn enough money with repairing water points to live from.

The HPMA helps to make the HPM profession more professional and entail bigger projects.

### Evaluation criteria

The time between action of the WUC and failure is a way to measure the quality of a WUC.

### HPMA

Transparency in pricing is an important achievement of the HPMA. The DWO helps them to earn more money and to become a more stable and reliable factor, as it is difficult to live from just water point repairs, by tendering for other bigger jobs. The ministry doesn't want HPM to do these jobs, because they will pay then less attention to fixing rural water points. The Ministry and the DWOs have therefore different views on the future role of the HPMAs.

### Culture

They are proud of the way they do their work and they are not willing to change very easily or radically. They don't like experiments, you have to know what the effects are before starting the project, otherwise you are a bit stupid.

### Water User

Reliability and dependency are main factors for water users.

It is not per se that people don't pay because they don't have money (see mobile expenditures). Problems with WUC: lack of internal transparency; lack basic skills; often don't represent the all water users; mistrust between e.g. WUC and HPM about pricing by HPM bad organization, bad trust relationship with WUC and HPM.

## Report Interview Jo Smet

*11-12-2013*

### Personal background:

Jo is a sanitation engineer from the TU Delft. First he has worked in Tanzania at an technical and medical center. Now, he has worked at IRC for 26 years. His field of expertise is technology and making technology sustainable. In 2006 he went to Uganda for 4,5 years. The main focus back then was the sanitation and accountability in the WASH sector at local up to governmental level.

*In his early days he already noticed that the governments' and politicians' attitudes and perceptions (at a local level) have great influence on outcomes of the system.*

The districts that he visited were: *the West Nile area (5 districts) and Kabarole area (4 districts).*

### Outcome of the system:

*See Sector Performance Report which quantifies the 11 golden indicators.* While reporting for the SPR there is *a tension* between 'under reporting of amount of water points' (as the coverage is an important

indicator for the National Grant distribution) and 'good results, like coverage, for career development and for a better salary of the DWO/assistant DWO'.

### Change

Communication is an important part of change. *People nowadays are more emailing, travelling, meeting each other in workshops*. During the workshops they learn about other districts, get new ideas, generate a larger network, get a good idea of their position within the WASH sector and finally they learn about possible bottlenecks.

Another key element of dynamics is the *drive to do better in the future*. Young dynamic CAO's (highest officials in a district) are chosen by (dynamic) councils and can do good things to make the water service system perform better.

### Actors:

#### *Water and politics (and authority)*

The local water users give their vote/trust during the local Councilor elections to the person that promises inter alia good water facilities/services. Water is an important problem for the water users. So, the local Councilor should prioritize the water issues of his or her district at district level and should make sure that the (national grant) funds are coming to his district.

The local Councilor is often not very well educated, the DWO however is at least Bachelors or Master in Engineering. So, the game that the DWO can play with Local Council is sophisticated. The DWO is interested in knowledge, (especially) money, status, water services delivery.

People their perception depends on politics, history, promises of politicians and African culture (clans, witch craft).

Water is politically attractive, because local people prioritize water. So, local politicians make promises concerning free/good quality/reliable water.

Every district has 1 or 2 counselors (LC5), that has influence on the amount of money/new water points/allocation of budgets at village level.

#### *WUC*

The hand pump is an standalone system that should be managed by the community-of-users. The community can organize itself by a committee (Water User Committee or Borehole Committee). They ask the Hand Pump Mechanic to repair the water point when it is broken. The WUC doesn't do official water point checks nor maintenance. The water point is just repaired or replaced if it is broken.

#### *HPM*

The HPM is a private worker who covers certain geographical area, for example a parish and sales a service. In principle the WUC should send the HPM away if they are not happy with the result. The WUC has a desire that can be fulfilled by the HPM. The HPMA can play an important role concerning the quality of the HPM.

### *HPMA*

The HPM Association can function as a central point for spare parts and information. The HPMA can also (in the future) rate/sanction the HPM on quality and mutual support (ideally!) (but they are also competitors!!)

### *Water user*

The water users are focused on surviving and are self-sustaining in poor districts. At the end of the month they have a cash income of about 5 euro's to spend on school/salt/clothes. Of this budget they also have to pay the monthly water charges. The influence on the water services delivery system by the water users is by voting for a Local Councilor that puts water issues and solutions forward during the elections.

## Initiative

Water sector professional, Mr. Paul van Beers, introduced the Blue Pump and Blue Zone concept. The locals pay a set amount of money every month and when the pump is broken the water point will be fixed a within a certain but short time frame. For poor rural Ugandan people this concept is difficult to understand and support.

## Laws & sanctioning

There are no rules concerning maintenance or checks that the DWO governs. The DWO should pay for a new water point if the water point breaks down (500/700 euro). In an ideal situation there should be someone who checks the WUC to be reliable and there should be conditions on how maintenance is performed. In some cases an advice is given by the DWO to maintain the water point better.

## Responsibilities

Responsibilities are often not clearly divided, due to unclear agreements. The ownership of the water points is vague. However, the water point is on loan by the WUC and is still belonging to the District Authorities during the loaning period.

## Additional information

NGOs, Dynamics in an village, good leaders (that are examples within their own and for other villages)(who don't work for their own benefit) have influence in the system.

## Evaluation criteria

The criteria seem to be from an managerial perspective, so the water service provider.

## Report interview Peter Magara

**Theme 1. Personal background**

Peter works for IRC as the Triple-S Uganda Learning Facilitator (national level). He is an expert in Project Management and Evaluation. The areas he geographically focusses on are Kabarole and Lira. The projects that he monitors, concerning learning, are inter alia Mobiles for Water (M4W), HPMA, Learning Alliances.

**Theme 2. Outcome of the system – pattern of interaction**

### Mobiles for water

Reporting breakdown is a big change in the outcome of the system since the Triple-S project started off. The WUC/WUs did not have contact information about the HPM in the area, so they would ask the sub-county to contact a HPM. Nowadays, people SMS the system to inform the HPM that they need assistance of a HPM. The collection of text messages can also be seen by the DWO. The M4W quickens the information flow.

Additionally, the HPM now knows which water points failed. This information helps with planning of rehabilitation for the DWO. The DWO cannot repair all the big failures of water points, as they do not have enough resources. Due to the M4W system they know the history, when the WP broke, location and they can prioritize.

### M4W – pattern of interaction

The water point breaks down; message is sent by the WUC/WU to the system (there is a ID and telephone number on the water point). The local HPM then makes an assessment and contacts the WUC, WU or DWO to pay for the repair. The DWO puts the last request last in line (first come, first get). If the pipeline is full of repairs, it can take a while before a particular water point gets repaired. The DWO also tries to balance the money flow geographically.

### LC5

The LC5 doesn't say that he will provide water for free, but that it should be for free, the government should provide it for free. There is a clear tension between the politicians and technocrats.

### Water users

Water users feel that they don't have a high water services delivery level if they have to walk very long distances to collect water. So, if the access is low and the alternatives are low, they are triggered to collect money to pay a rehabilitation of the water point.

If the quality of water is low there is zero chance that people will pay for the water, the water will get abandoned. The color and smell (odor) are characteristics that the water is evaluated on.

The Distance (access) is important to the water users (it is in relation to the amount of boreholes/rivers and trips they have to do to collect the necessary amount of water).

### Water Service Authority

The DWO is responsible for the big repairs and does planning and monitoring. The monitoring focusses on construction works.

### HPM is not a water service provider

The HPMs are no water service providers! They are just technical support. The people who may perform the task of WUC are chosen because they seem to be responsible and able to act. There are about two HPMs per district present.

### WUC

The Water User Committee receives a bit of recognition and respect. However, they want to get paid for the job, as time is money for them. The care keeper should be in every WUC and should sit next to the water point to ask for money and keep the water point well-functioning.

### Maintenance phase

The Maintenance that should be done regularly is oiling the different parts.

### Beliefs

There is no relation between beliefs and water services delivery.

## Report Interview Jane Nabunnya

19-12-2013

The functioning of the water services delivery system is measured with the Water Service Level indicators. Distance is an important SDI, because if the distance is large it can give insecurities for women.

Knowledge/the right information is important for the water services delivery system to function, people have to how to maintain, take care of a water point etcetera. There are many laws and by-laws that states how things should be done (all the laws are in place to make the system work). The government even defined what minor, medium and large repairs are and who should be responsible for it. However, it is difficult to make people follow the rules.

The WUC often doesn't get replaced after 3 years and if they leave/die they are not replaced. If the WUC is not functioning well, the water point is very difficult to maintain, as they are the ones that should collect fees. Fees are collected to pay spare parts and the HPM (if necessary).

So, in other words, if the water point has no WUC then there is no money, there is no HPM and the water point will not get repaired by the community.

The WUCs often lack accountability and transparency. The well-functioning WUCs go to village banks with their collected money, so that the treasurer (often a woman) doesn't get into contact with domestic violence (due to the fact that the man wants to spend the money for himself).

At the village bank they can borrow a bit of money when they need to spend a bit more than they have. With some interest they will pay the lend money back.

### Local Councilors

Village (neighborhoods)(LC1), Parish, Sub-County (LC3), County (LC4) and District (LC5). LC4 is often not present, it is actually nonexistent. This political system is important as all the information and money streams should go through these levels. So, this system is important for the spread of information and power. LC1 should be represented in the WUC.

### Fees

For one water point there should be 300 people who use the water point. Per households that pays the DWO is willing to pay 500 shilling per year.

The financial year starts in July and ends in June for the government. The DWO should predict how many repairs will take place in the next political year. Sometimes it is difficult to estimate and the money can be gone after the second month. In this case, repairs of many water points are pushed to the next financial year. Sometimes, when the need is very high, people go the NGOs or Ministry. To go to the Ministry, you should know the right people.

### Protected source

The water point can be in order, **but** if the site of the water point is not protected against dirt and animals, then the water is still not protected. The WUC is furthermore important as there should be a person to be held accountable for the status of the water point area.

In the area Jane comes from, they do not have a WUC, but they do keep the water point very clean. Every month all families should help physically or financially with the cleaning of the water point. In this area no WUC is needed.

'Lets come and slash' is an initiative to make the people aware of the importance of tidy water point areas.

People dip their jerry can into the water point, so the water point gets contaminated from the jerry cans' bacteria.

### DWO

If lucky, the District Water Office is staffed with two well educated men. They are responsible for the maintenance, monitoring, training and big repairs.

There is a strong motivation to do it better and there is the knowledge that it can be done better.

The Conditional Grant money that is most misused is the software money, that should organize meetings to share knowledge etcetera. These meetings are often not organized, because they don't find it important, do not have fulltime staff on the subject of water (at sub county level). If they have no fulltime staff for it, then the Secretary –assistant Community Development Officer or Health assistant is responsible, but it is not their first priority, so water often lacks behind in attention.

### WUC

The care takers should not do their job on a voluntary basis (a small salary is important).

People are now paid to come to knowledge sharing meetings like the District Water and Sanitation Coordination Committee and Sub County Water and Sanitation Coordination Committee. The payment is very low, but allows them to pay the trip to the meeting place.

### HPMA

In total there are 111 districts, of which 90 have an HPMA.

HPMA are not obliged to be formed, just stimulated. The aim is to stimulate O&M and functionality. The HPMAs that have existed for a longer period have been teaching the new HPMA how to set up such a business and how to get the HPMA functioning.

It is important to give the HPMA more confidence so that they can do things larger than just a water point. The NGOs now can hire HPMA for extending a piping system for example.

HPMA tries to come to one transparent policy/tariff.

HPMAs have contact with or have spare parts (shops). This makes it easier, quicker for HPM to get spare parts.

HPMAs want to choose their own leader (so no NGO leader) and have requirements for this leadership. The TSU helped the HPMA with information.

### Road conditions

The road conditions/traffic is not very well organized, so it takes a long period to go from one place to another, especially in remote rural areas.

## 9.7 Model design: system identification and decomposition

In this appendix the system identification and decomposition of the model design is shown, which is the first step of the agent-based model design steps (Van Dam et al. 2012). First an extensive overview of the current pattern of interaction is shown. This overview of the system is followed with a more detailed explanation of each interactor of the action arena, see 9.7.1. Here the actions and assumptions of a particular interactor are described. The same is done for the objects of the model design and the environment, see 0 and 9.7.3. The decisions that are made or need to be taken in a next step of the model design are described in section 9.7.4.

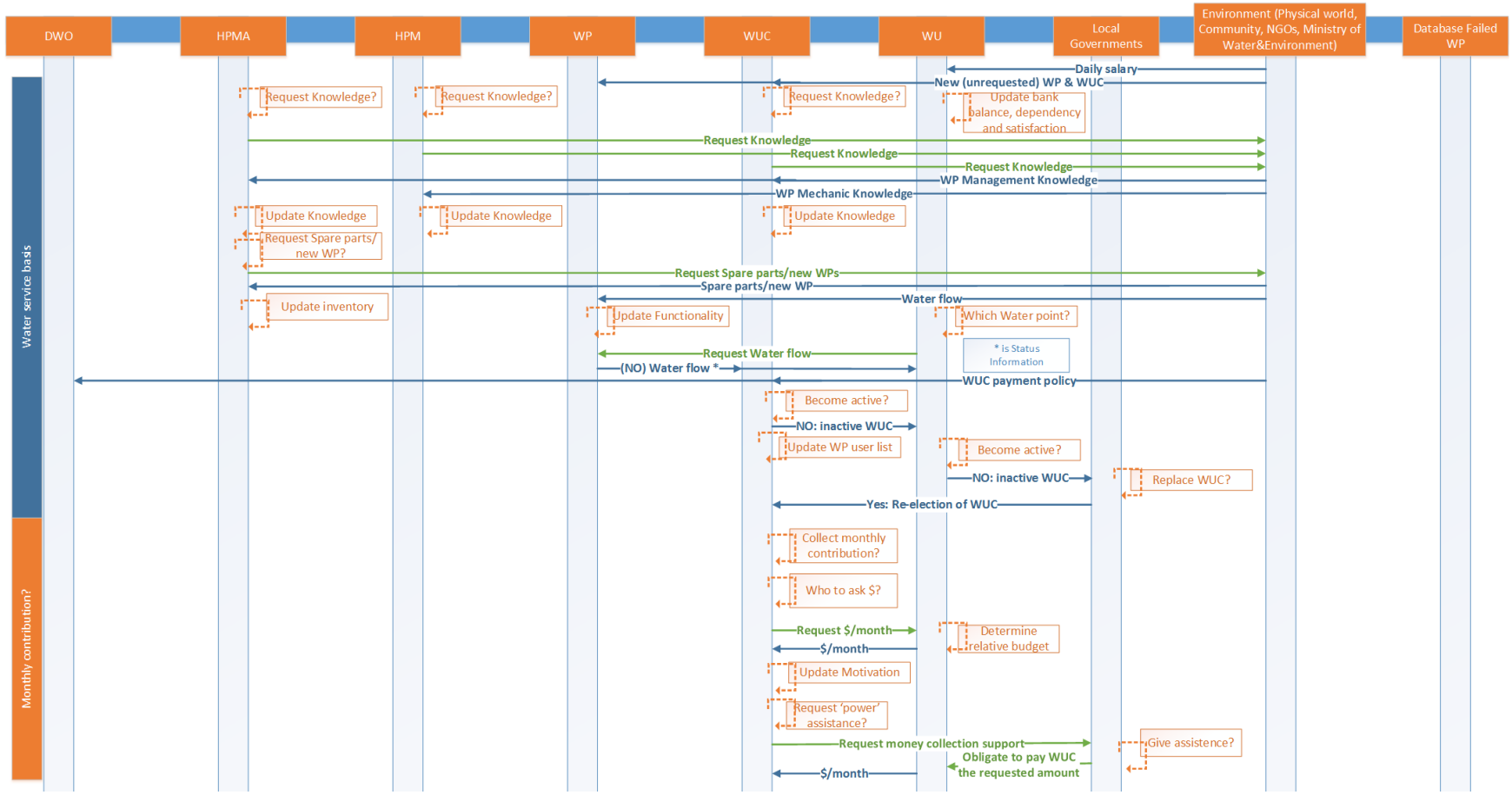



Figure 33 Pattern of interaction part 1

In the pattern of interaction there are three 'types' of information streams, see Figure 25 till Figure 38 The first stream is the information/means stream. This stream are visualized by blue arrows and represent fact memes. The second stream are actions. These are visualized by green arrows and are represent by regulatory memes. The third and final stream are the personal decisions/updates of fact memes. These streams are visualized by red square arrows.

The model design is divided into phases, so that the different parts of the system can be categorized. In this pattern of interaction the main interactions between actors are shown. In the model concept formalization the updates of actors and some interactions are a bit more extensive. Here in the pattern of interaction description the bank balance, for example, is not updated.

Relevant interactors are, as described above, who make decisions are: District Water Offices (DWOs), Hand Pump Mechanics (HPMs), Water User Committees (WUCs), Water Users (WUs), local government (LG). The Ministry of Water and Environment, NGO's, Technical Support Unit (TSU), the physical world and the community are embedded in the environment. Important objects are water points (WPs) and the database of failed water points. Each interactor is represented by a light blue trunk. The interactions which affect certain interactors are visualized by an arrow that touches the interactor's trunk with the front or back of the arrow. The interaction is initiated by the interactor that is touched by the back of the arrow. The square arrows represent a reconsideration or an update of the interactor.

The *Water Service Basis* (see Figure 25) is the first phase. In this phase it is or becomes apparent whether a water point is broken or not. Furthermore, the Water User Committee (WUC) decides to become active or not. There is a strong relationship between the WUC becoming active and her motivation to sustain the water point. When the WUC decides not to become active, the WU needs to decide to become active and the local government assigns a different WUC or not. Finally, in this phase the Hand Pump Mechanic (HPM), WUC and Hand Pump Mechanic Association (HPMA) can request for some more managerial or mechanical knowledge, depending on their motivation and the environments' 'generosity' in supplying knowledge.

This 'basis phase' of collecting water or not, is followed by the '*Monthly contribution? Phase'* (see Figure 33). This phase is apparent when the WUC did become active and has a certain motivation and Knowledge level. The knowledge level is needed, because it asks quite some financial and management education before a committee is capable of monthly money collection (Lieshout 2013; Nabunnya 2013).

The *DWO Grant Phase* and *Evaluation Phase* are two phases which are closely related to each other, see Figure 34. The environment (which entails the Ministry of Water and Environment) requests an update of the Conditional Grant 'proposal' every three months. For the DWO it is undoable to give an update on all the water points every three months, therefore the DWO requests the local government to help him with this job (Bey 2014). The local government collects the data except for the 'Failed WP database' files. These database files are justly accessible for the DWO, if the M4W policy is implemented. The DWO can produce a Conditional Grant proposal with the data of the local government and the Database files. Depending on the amount of people, water points functionalities etcetera, the environment gives a certain amount of money which is called 'the Conditional Grant $' in Figure 34.

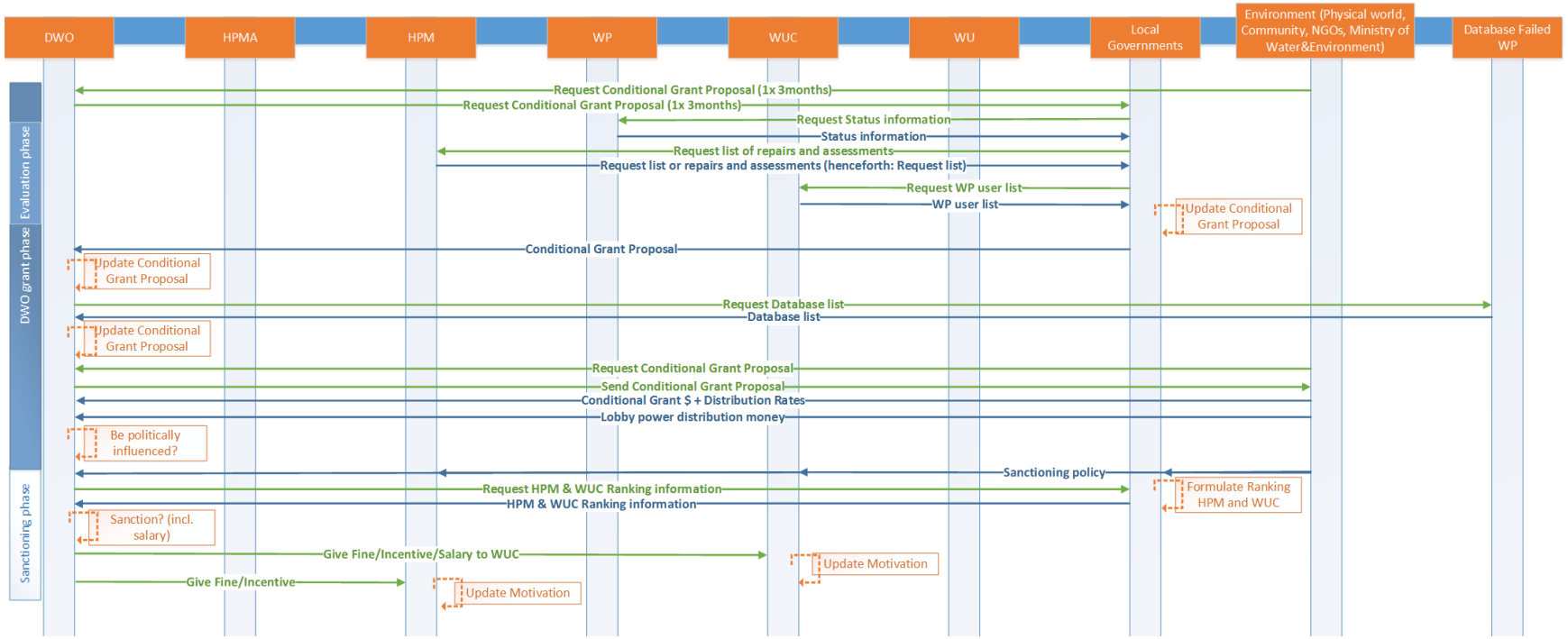



**Figure 34 Pattern of interaction part 2**

In the following phase *(Sanctioning Phase)* the DWO gets to decide to incentivize or fine the HPM and/or the WUC. Additionally, the WUC can receive salary from the DWO. These financial interactions are only possible if the right policies are implemented (Sanctioning policy and WUC payment policy). The motivation of a particular WUC and/or HPM is influenced (positively) if it receives a financial sanction (see Figure 34) (Lieshout 2013).

The following phase, the *Request Phase*, is shown in Figure 35. Here the water service provider (WUC or WU) requests an failure assessment to a particular HPM. This request of the service provider is executed 'live', so face-to-face, or via 'SMS'. The SMS function is only possible if:

- The Mobiles for Water (M4W) policy is implemented.
- The water service provider needs to have a mobile phone.
- The water service provider needs to prefer mobile above live contact.

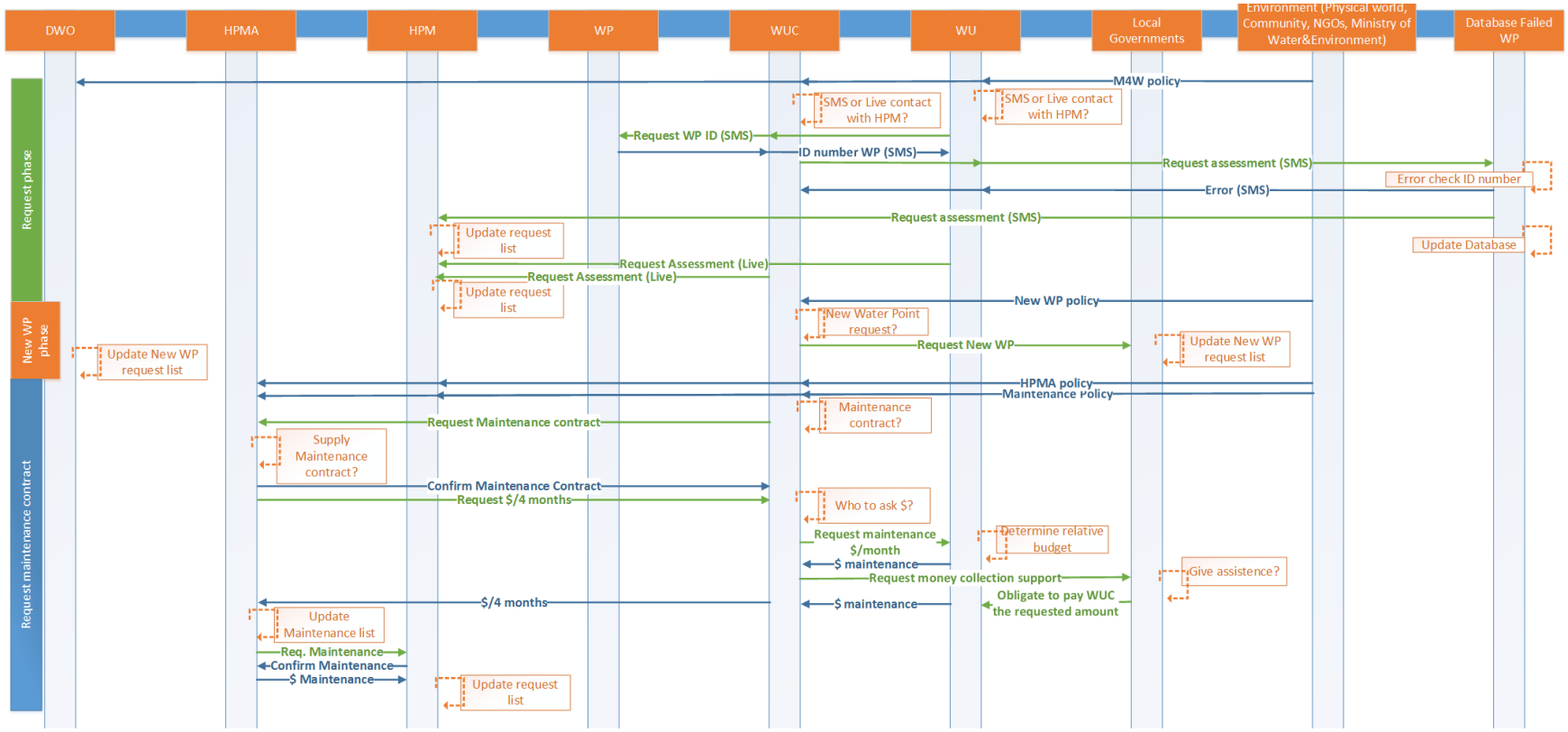



Figure 35 Pattern of interaction part 3

See Figure 35, the *New WP Phase* is a phase which is only apparent if the New WP policy is implemented. This means that the WUC can request a new water point, if the conditions are right, to the local government.

In the *Request maintenance contract phase* the WUC can request a Maintenance contract to the HPMA if the HPMA and the Maintenance policy are completely implemented and the motivation/Knowledge levels are above a certain threshold. If the contract is confirmed and the money collected, the HPM is requested to maintain a particular water point.

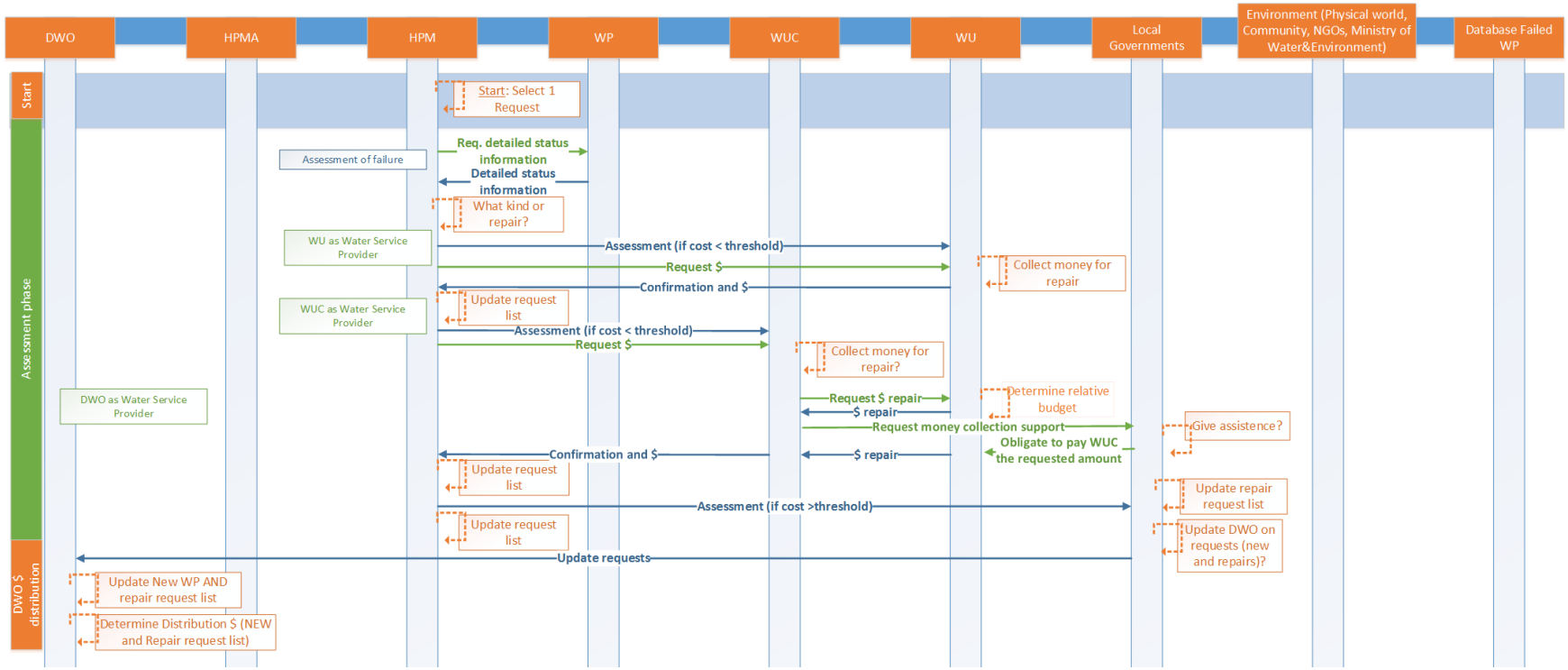



**Figure 36 Pattern of interaction part 4**

In the *Start Phase* (see Figure 36) the HPM decides whether it wants to work or not and if it decides to go to work he picks a job from the 'Request list'. There are several different jobs a HPM can perform, namely, he can make an assessment of a failed water point, repair or maintain a water point. If a repair seems to become more expensive than a certain threshold, the HPM sends the assessment of the failed water point to the local government, as some repairs are unaffordable for local civilians (Bey 2013b).

Once in a while the local government updates the DWO concerning repair and new water point requests. In the *DWO $ Distribution Phase* (see Figure 36) the DWO decides which request is granted. His decision can be influenced by lobby powers and is influenced by the Ministry's $ Distribution rules (Lieshout 2013). In Figure 38 the story line of the DWO will continue.

As described above, the HPM can also do maintenance or repairs, see Figure 37. To be able to repair a water point the HPM needs to request some spare parts of the HPMA. As soon as the spare parts are available the HPM repairs the particular WP and updates his request list. The water

point will have a higher functionality and Water Service Level after a repair job. These changes also need to be known by the WUs who are within a 3 km distance of the WP. If the water point gets maintained the reliability of the WP will be higher, so in the long run the Water Service Level will improve for the water users.

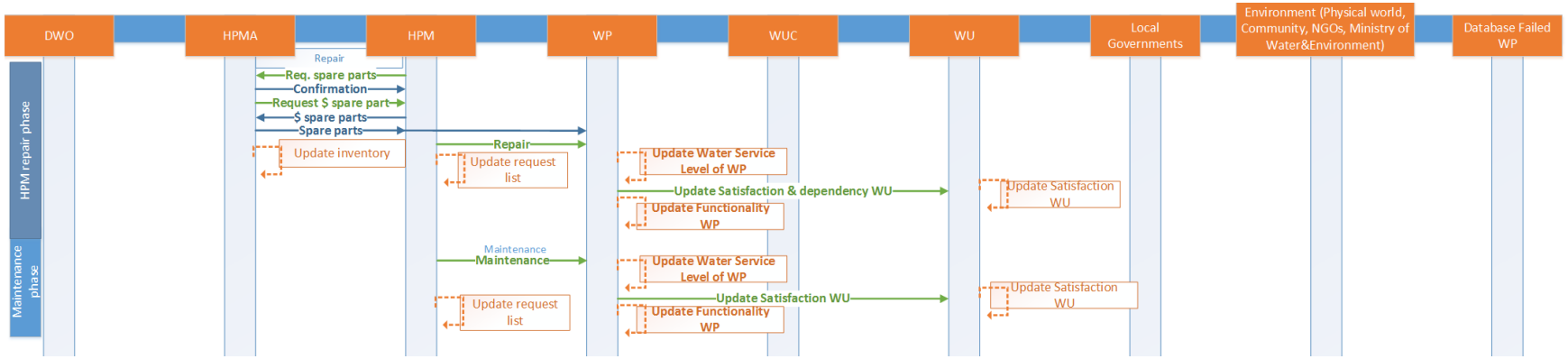



Figure 37 Pattern of interaction part 5

In the final *pattern of interaction* figure, Figure 38, the repair and installation jobs of the DWO are shown. Before a DWO can decide to spend money on a request from the 'Request list', the DWO needs to check whether this interactor has enough money on its bank balance. As mentioned above, the request that is chosen can be influenced by the ideas of the lobby group or not (Lieshout 2013).

As soon as a repair job is chosen, the DWO operates like a HPM, in the sense that it requests a New WP/Large repair to the HPMA and installs/repairs the water point. As soon as the water point is fixed/installed, the satisfaction/functionality etcetera is updated for the water users who live within 3 km distance.

> *People do not receive any water service if the WP is further away than 3 km* (Moriarty et al. 2011).

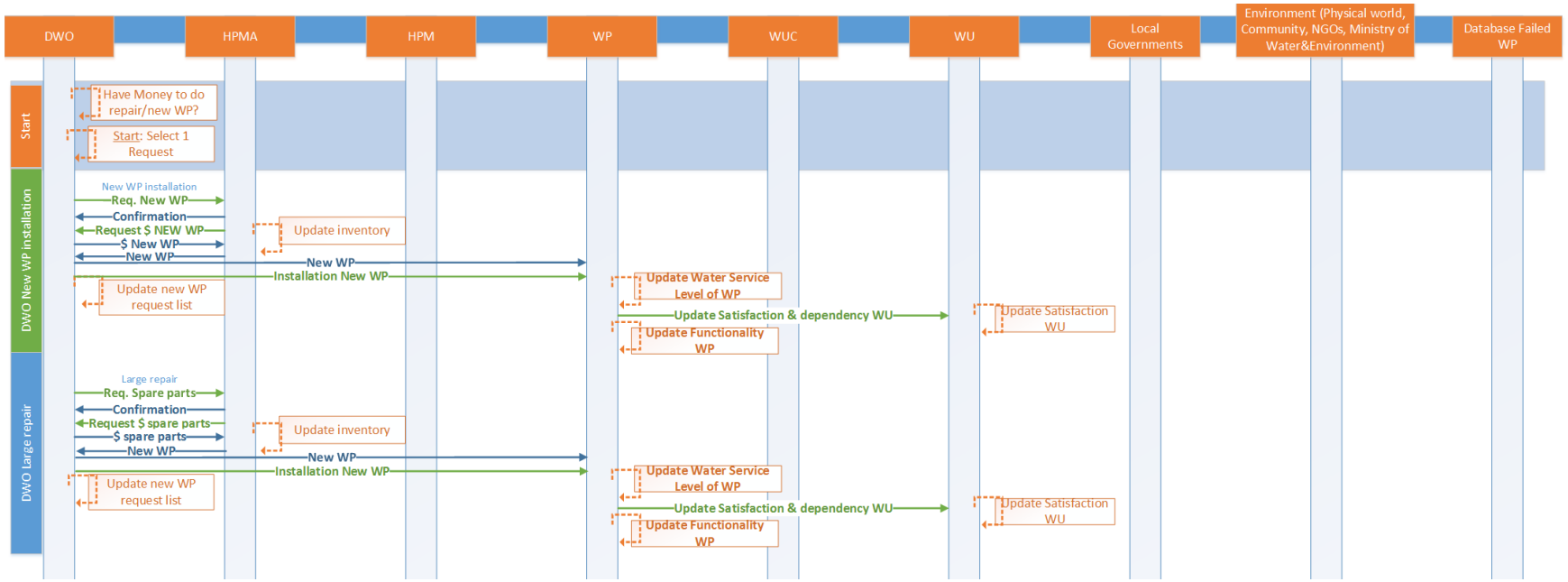



**Figure 38 Pattern of interaction part 6**

### 9.7.1 Interactors of the agent-based model design

This chapter describes the model conceptualization and formalization of the interactors. Normally the conceptualization and formalization are two separate chapters, however due to size of these parts per interactor/object it is chosen to give a complete overview per interactor/object. The model assumptions are summarized in appendix 9.11.

#### Overarching properties:

There should be a few overarching properties, known by all or several interactors, namely:

- IDs of the interactors' network
- ID of the interactor's district
- Policies which are implemented by the environment

The first interactor that is described in this chapter is the District Water Office (DWO).

> *The DWO, Hand Pump Mechanic Association (HPMA) and Water User Committee (WUC) are all actors which in reality are often presented by more than one person. Here it is assumed that the DWO, HPMA and WUC are individuals (with one personal priority, memeplex etcetera).*

#### *District Water Office (DWO)*

Per district there is one DWO, who is highest in hierarchy and decides on the distribution of the District Water and Sanitation Conditional Grant (DWSCG, hence forth: Conditional Grant). However, the distribution of money is influenced by ministerial policies and possibly by Local Councilors (who operate at level 5, which is district level). To be eligible for the Conditional Grant, the DWO has to give an extensive overview of the current failures, requests, plans etcetera to the ministry of Water and Environment. This overview is prepared at sub-county level and down, by sub-county staff and Parish leaders (hence forth: local government). Furthermore, he is responsible for big repairs and the installation of new WPs.

The DWO is in contact with district level Local Councilors (LC5) (who are in the environment of the model design). Depending on the DWO its properties, the DWO is either influenced by the opinion of the LC5 or not.

> *Because most DWOs are ambitious and want to have good relationships with his colleagues (Lieshout 2013), it is assumed that the percentage of DWOs who is influenced by LC5s' opinion is high.*

Furthermore, if the DWO needs to choose a request from the 'Request list', the DWO, that is influenced by the lobby, picks a WP that is high on the list of the 'Request list' and 'Lobby Distribution Preference' (Magara 2013). An uninfluenced DWO picks the request that has been waiting for a repair/new WP the longest (Magara 2013).

If the Sanctioning policy is in place, the DWO can fine or reward hand pump mechanics (HPMs) and water user committees (WUCs). The WUC can then also receive a salary (if the WUC payment policy is in place too).

*It is assumed that the salary and sanctions are all 7 USD[40], because that is the amount of money an average civilian in Uganda has left to spend after a month working* (Smet 2013).

It still needs to be researched how much a DWO receives from the Ministry of Water and Environment under which circumstances. This data is not known at the moment.

*However, the suggestion is made that the DWO has an income of 10.000 USD a year, so that the DWO can install around 4 new WPs and repair around 5 WPs* (Bey 2013b).

**Social network**: The DWO is in contact with the local government, HPMA, WUC, Database, Water Point (WP), Hand Pump Mechanic (HPM) and the environment (see Figure 39, Figure 40 & Figure 41). Figure 40 & Figure 41 are sketches of the interactions between interactors (Information and Actions flows) and in Figure 39 the updates or questions to itself of the DWO are showed. However, the rules have more detail than the overview figures (Figure 39, Figure 40 & Figure 41). *This will also be the case for the other interactors in the coming sections.*

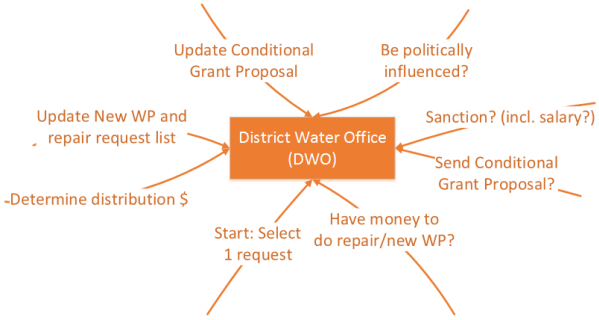



**Figure 39 Updates and decisions DWO**

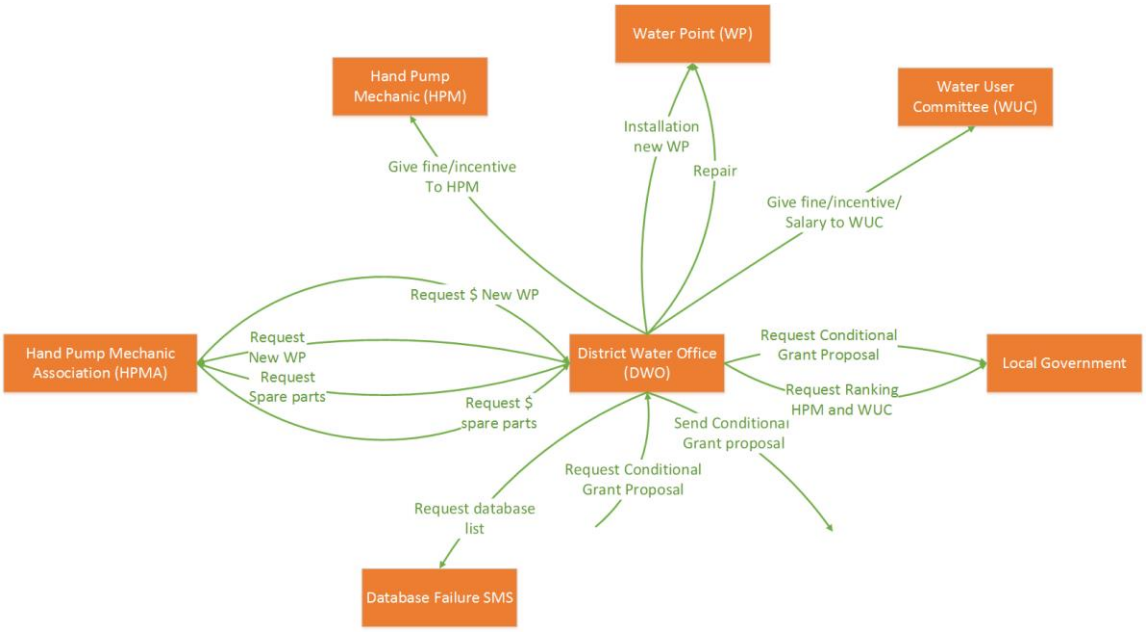



**Figure 40 Interactions (actions) DWO**

[40] Calculated with the exchange rate at 18-02-2014. The exact outcome is 6,87 USD for 5 Euro.

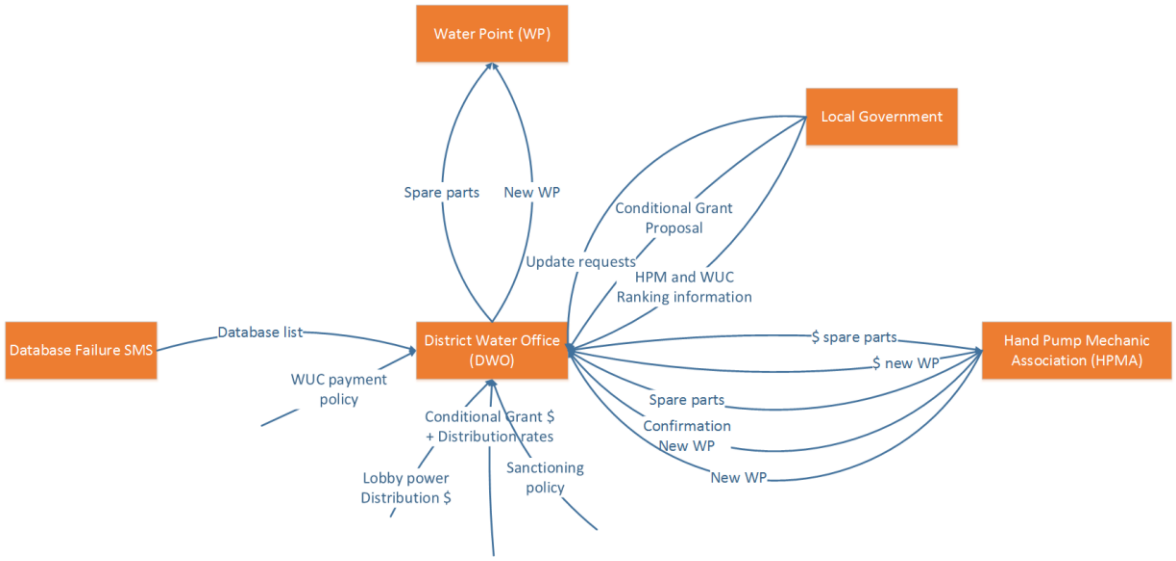



**Figure 41 Interactions (information) DWO**

In appendix 9.8.1 the properties and the model formalization of the DWO is shown. The following interactor that is described is the Hand Pump Mechanic Association.

### *Hand Pump Mechanic Association (HPMA)*

Of the 111 districts in Uganda, 90 of them have a HPMA (Nabunnya 2013). The ones that do not have a HPMA are often just created. Districts are often made, so that friends of high officials can have their 'own' district (Nabunnya 2013).

HPMAs are not obliged to be formed, just stimulated by the DWO/National government. The aim is to stimulate operations, maintenance and functionality. '*The HPMAs that existed for a longer period have been teaching the new HPMA how to set up such a business and how to get the HPMA functioning* (Nabunnya 2013)'.

In the model design the HPM Association functions as a central point for spare parts, which can also be the case in reality (Smet 2013; Magara 2013), and possibly a Maintenance contract provider. In reality, the HPMAs are also busy finding bigger installation jobs for their HPMs. This is not incorporated in the model, because it is outside our scope.

> *It is assumed that the HPMAs' motivation is:* $\frac{\sum Motivation\ (of\ HPMs\ of\ HPMAs'district)}{\#HPMs\ of\ HPMAs'district\ (which\ is\ 2)}$*. The reason for this average motivation is that the HPM together form the HPMA.*
>
> *In most districts a HPMA is present. It is assumed that the HPMA policy is always present and functions as a spare parts/new water points provider (policy level 1). If the HPMA is changed to level 2 (by the environment) the HPMA will also be able to compose a Maintenance contract.*
>
> *It is assumed that the environment has an inexhaustible amount of spare parts and new water points. It is chosen to bring the different types of spare parts back to two and for the water point types to one. Spare part 1 is for normal repairs (which is executed by the HPM) and spare part 2 is for a Large repair (which is executed by DWO).*

**Social network**

The HPMA the WUC, HPM, environment and DWO in its network, see Figure 43 & Figure 44. Besides a network the figures (including Figure 42) show personal updates and interactions between the interactions. In appendix 9.8.2 the properties and the concept formalization is shown for the HPMA.

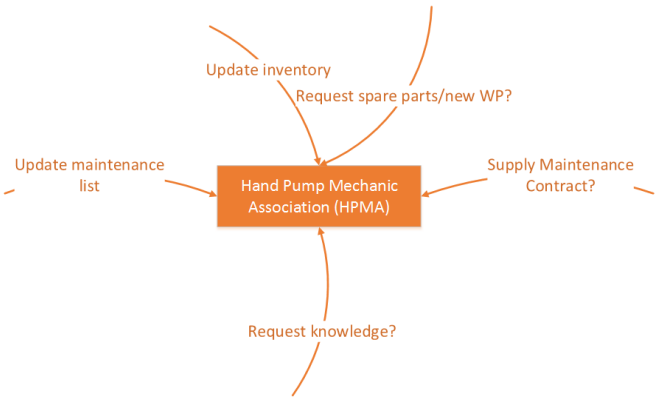



Figure 42 Updates and decisions HPMA

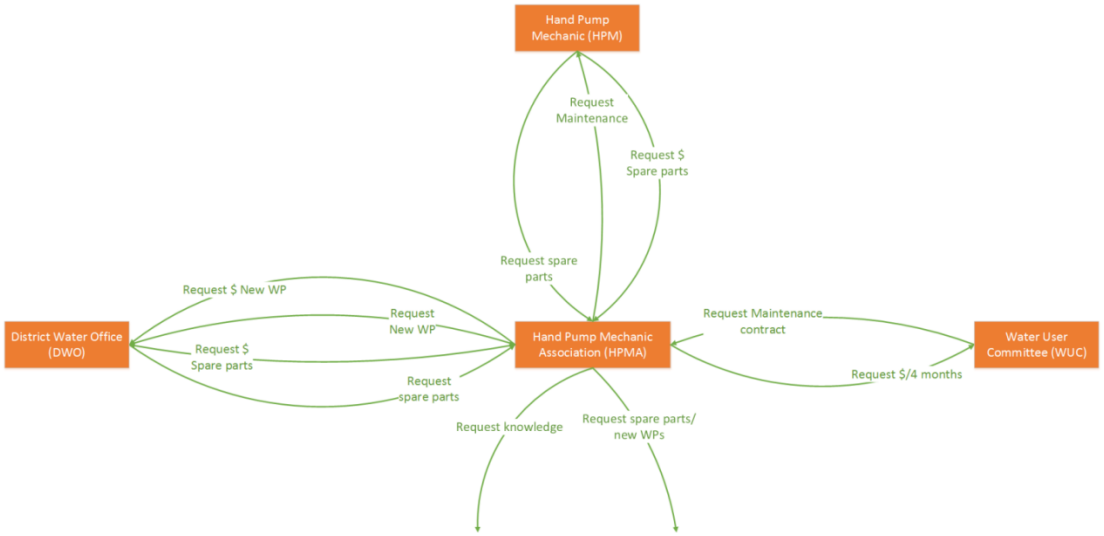



Figure 43 Interactions (actions) HPMA

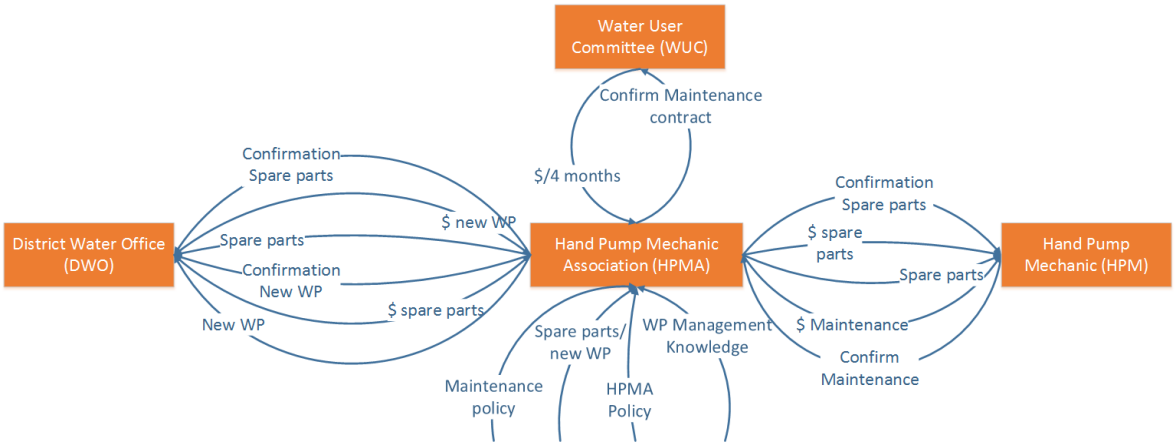



Figure 44 Interactions (information) HPMA

The next interactor whose daily story is 'told' is of the Hand Pump Mechanic.

### *Hand Pump Mechanic (HPM)*

The Hand Pump Mechanic is a private worker who can inter alia fix water points (Smet 2013). Here only the work generated by water points is taken into account for the model design.

The HPM works in a certain geographical area, for example in a few sub counties. In this area he sells his service (Smet 2013). '*Reporting breakdowns is a big change in the outcome of the system since the Triple-S project started off. The WUC/WUs did not have contact information on the HPM in the area, so they would ask the sub-county staff to contact a HPM. Nowadays people SMS the system to inform the HPM that they need assistance of a HPM. The collection of text messages can also be seen by the DWO. The M4W quickens the information flow* (Magara 2013)'.

Besides knowing whether an assessment is necessary for a certain water point or not, the HPM can also be motivated to do his job well or not. The motivation will show whether the HPMs' personal priority is to work hard and well or not for a more sustainable water services delivery system.

> *It is assumed that motivation influences whether the HPM works or not. Due to cultural influences*[41] *the WUC does not request the HPM to do his job better if he is not motivated* (Lieshout 2013).
>
> - *The DWO can give the HPM a fine every month, if the Sanctioning policy is in place and the HPMs' motivation is below a certain threshold.*
> - *A fine/incentive will lift the HPMs' motivation with 1 point (with a range of 0 to 5).*

At the moment there is no mechanism that lowers the motivation of the HPM, because his priority is to earn money and deliver a well-functioning water point (water) (Lieshout 2013). Furthermore, in reality HPMs can move to another district and the prices of repairs and maintenance are in reality not the same for every HPM. This is however not yet incorporated in the model design *(Magara 2013)*.

> *Finally, it is assumed that there is a constant amount of 2 HPMs per district (Magara 2013).*

**Social network**

The HPM's social network are the WUC, HPMA, the environment and the DWO, see Figure 46 & Figure 47. In the following figures it can be roughly seen what actions are taken/received by the HPM (Figure 46), which information is exchanged (Figure 47) and updates/decisions (Figure 45)are performed by the HPM.

[41] For Ugandan people, often there is no rational explanation of why things happen. The superstition has an influence on the people ways of acting. If you sanction somebody, then you are scared that this person will send a bad spirit into your direction or that you get bewitched. *Evaluations of HPMs is for this reason not probable* (Lieshout 2013).

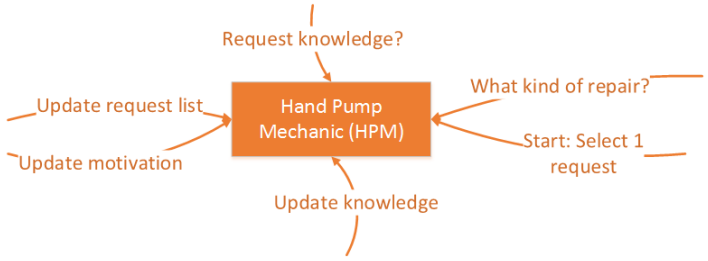



Figure 45 Updates and decisions HPMA

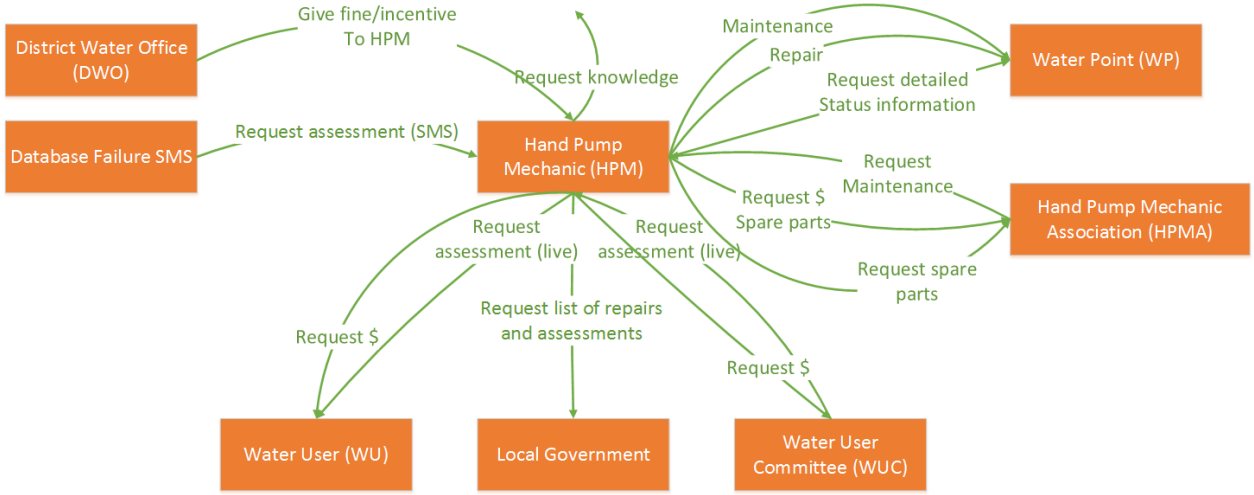



Figure 46 Interactions (actions) HPM

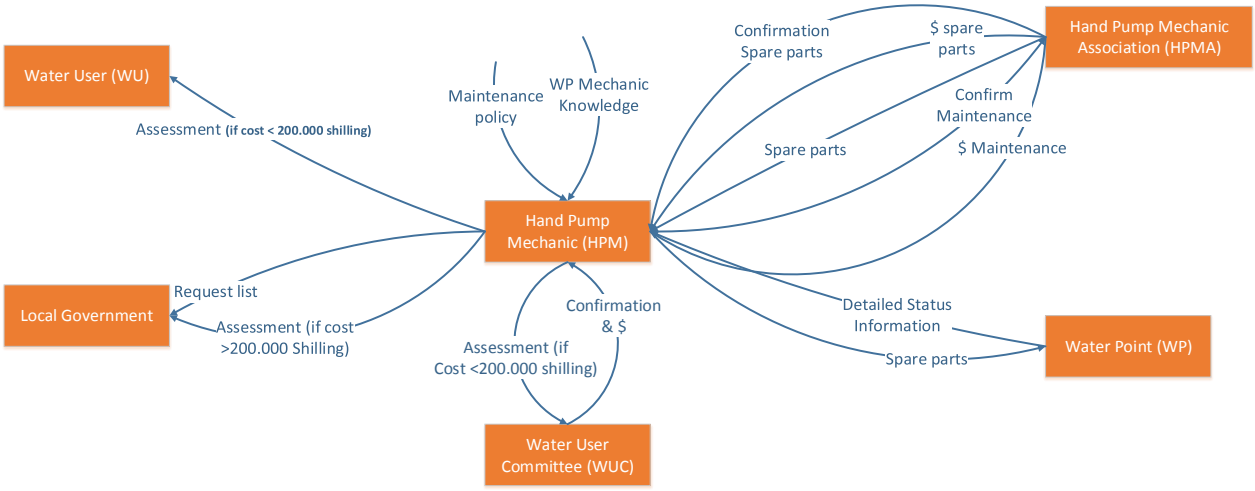



Figure 47 Interactions (information) HPM

In appendix 9.8.3 the properties and the concept formalization of the HPM is formulated. In the following section the Water User Committee is described.

### *Water User Committee (WUC)*

The WUC has the responsibility of one water point. Around 50 families and 300 people live off one water point (Lieshout 2013). When there is a strong need for water from that certain water point and there is an appreciation for the action to repair the water point, it is more easy to collect money (Lieshout 2013). In other words, when the Dependency of the WU, Satisfaction on the WUC, Knowledge level of the WUC are high, the relative budget of the WUs is higher. 'Relative budget' of WUs is calculated as follows:

- *Satisfaction of WU towards WUC= WSL (of x days ago).*
  - *The WSL is x days delayed before it influences the Satisfaction of WUs.*
  - *Satisfaction has a range between 0 and 5.*
- *Dependency = Amount of WPs a WU has in its reach (3 km).*
  - *1 WP = 5, 2 WPs = 4 etc. 5 WPs = 1 and 6 WPs or more = 0*
- *Knowledge level WUC= Amount of knowledge on managing a WP.*
  - *The range in-between 0 and 2*
- *So, The relative budget is a floating point between 0 and 1.*
- *Maximum Relative budget = 12/12 = 1*

$$\textbf{Relative budget} = {Satisfaction}/{12} + {Knowledge\ level\ WUC}/{12} + {Dependency}^{42}/{12}$$

*In the model design the WUC is not reelected because in reality. The WUC often gets reelected, for the current WUC has the most knowledge about WP management* (Lieshout 2013). *In the model design, the local government can, under certain conditions, assign a new WUC if inter alia the performance is too low. Zero motivation is chosen not to be possible when the WUC is just reelected.*

*There is a 0,01 chance that the local government replaces the current WUC. This percentage is chosen by the designer, not founded in literature, but it seems to be rare that a Local Government takes this action (Bey 2014).*

*If the WP Management knowledge gets improved, it is assumed that the WP side gets better maintained. Therefore the Satisfaction of WUs gets updated after more knowledge is gained.*

As mentioned in chapter 4.1, the Motivation of the WUC is important for the sustainability of a WP (Smet 2013).

*The motivation of the WUC can be influenced by several factors:*

1. '*Relative budget*' *WUs can demotivate the WUC. If the mean Relative budget is lower than 1/6 of the requested money, the motivation of the WUC will decrease with one point (motivation -1).*
   - *If there is a negative vicious cycle, of WUs not willing to give money and low WSLs, the WUC can break this negative cycle by asking backup of the local government.*

[42] If a WU is dependent of 1 WP, the Dependency rate is 5. The Dependency rate has a range between 1 and 5. When a WU has 5 or more WP within 3 km distance, the rate is 1.

*They will make the WUs pay the amount of money the WUC asks them to (Bey 2014).This will give a positive boost to the WUC's motivation (motivation +1).*

2. *The motivation of the WUC can also get influenced by a sanction/salary of the DWO (motivation +1).*

*The WUC becoming active or not depends on the WUC's Motivation, if the motivation of a WUC is 2 or lower (on a scale of 0 to 5), the WUC has a certain chance of becoming active. If the WUC has a higher motivation than 2, the WUC will always become active on that particular day.*

*If the Motivation of the WUC is 3 or higher (on a scale of 1 to 5), the WUC will request WP Management knowledge, which will increase the ability of the WUC to manage their WP well.*

If the Sanctioning policy and WUC payment policy is implemented, the WUC can also get paid for their work. As the payment of the WUC can only be done if there is some control of the performance of the WUCs by the local government (which is covered with the Sanctioning policy).

If a water point breaks, a WUC can ask a HPM (live or via SMS) to make an assessment of the costs. If the costs are above a certain amount of Dollars/Shilling then the DWO is asked to pay for the repair and spare parts (Bey 2013b; Bey 2013a).

> *In the model design it is assumed that if the WUC succeeds to collect the necessary money, the WUC pays the HPM the full amount of money before the repair is executed. In reality it is paid in phases* (Bey 2013b; Bey 2013a).

Furthermore, the WUC can either actively collect money for a repair/maintenance job or not, depending on its Motivation. The way a WUC collects money (monthly or indecently) depends on its WP Management knowledge, as the WP management knowledge level determines the WUC's ability to manage the WP.

The network and interactions with itself and others are roughly shown below:


**Figure 48 Updates and Decisions WUC**

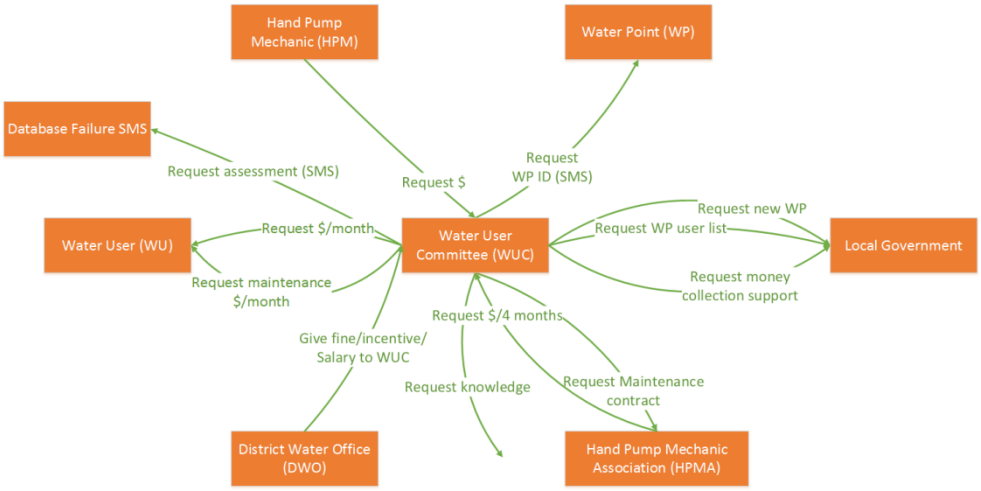



**Figure 49 Interactions (actions) of WUC**

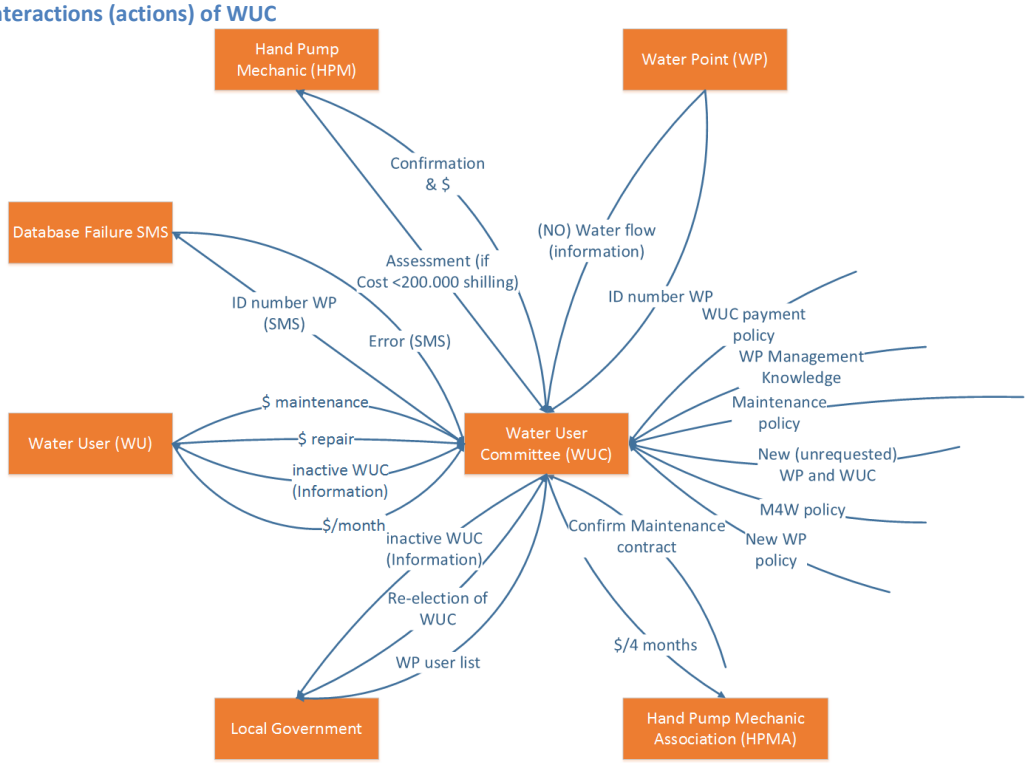



**Figure 50 Interactions (information) of WUC**

In appendix 9.8.4 the properties and the concept formalization of the WUC is represented. In the next section the WU will be described.

### *Water User*

The water user requests water at the water point. In the model design, requesting water by the water user is written down as 'requesting status information', which also shows whether the water point is functional or not. A water user collects water once a day. The amount of water a water user is dependent on is related to the distance between the water point (with the highest WSL) and a water user's home.

As mentioned in the WUC description: the 'Relative budget' of the WU is calculated as follows:

- *Satisfaction of WU towards WUC= WSL (of x days ago).*
  - *The WSL is x days delayed before it influences the Satisfaction of WUs.*
  - *Satisfaction has a range between 0 and 5.*
- *Dependency = Amount of WPs a WU has in its reach (3 km).*
  - *1 WP = 5, 2 WPs = 4 etc. 5 WPs = 1 and 6 WPs or more = 0*
- *Knowledge level WUC= Amount of knowledge on managing a WP.*
  - *The range in-between 0 and 2*
- *So, the relative budget is a floating point between 0 and 1.*
- *Maximum Relative budget = 12/12 = 1*

$$\boldsymbol{Relative\ budget} = {Satisfaction}/{12} + {Knowledge\ level\ WUC}/{12} + {Dependency}^{43}/{12}$$

The relative budget is a floating point between 0 and 1. If the relative budget is 1, the WU will pay the exact amount the water service providers asks for. The WU can pay, because it receives a salary of the environment.

The 'WP user list' gets updated by the WP as soon a WU requests water from the WP. The user list is often not up to date in reality (Lieshout 2013). However, it is chosen not to do anything with this fact, as it is also related to the ability of the WUC to manage their WP well. The relative budget does become higher if the ability (knowledge level) of the WUC is high(er).

If a WU needs water (which is once a day) he/she goes to the WP with the highest WSL (from his WPs list). As soon one WP has been chosen, water is requested to the WP. The WU receives information from the WP as soon a WP changes of Status information ((un)functional) or WSL.

The WUC can become active or not. If the WUC does not become active, the WU is notified. The WU then needs to decide whether to become active or not. There is a small chance a WU becomes active. In reality a village leader sometimes becomes active if the WP is broken and no action is taken (Bey 2013b). If the WUs stay inactive, the local government is informed about the inactive WUC and WUs (Bey 2014).

> *It is assumed that if a WU becomes active and requests money for a repair to WUs from the WP users list, that all the WUs he asks it to will pay their share, as it is often the village leader who takes action* (Bey 2013b).

Depending on the mean Relative budget WUs spend on the WUC repair/maintenance money request, the local government can be asked to put pressure on the WUs to pay the full amount to the WUC (Bey 2014).

[43] If a WU is dependent of 1 WP, the Dependency rate is 5. The Dependency rate has a range between 1 and 5. When a WU has 5 or more WPs within 3 km distance, the rate is 1.

As soon as the WP's Status Information is False, an active WU can make a request of an assessment to the HPM (live or via SMS). As mentioned earlier, the identification of the WP ID is not always easy, therefore the WU can receive an 'Error SMS' if the WP ID was not written correctly.

Finally, the *Assessment request?* Property is known by the WUC of the particular WP, so that no double repair requests are send to the HPM.

In Figure 51**,** Figure 52 & Figure 53 the interactions between other interactors and with itself are shown. In appendix 9.8.5 the properties and the model formalization are shown of the WU.

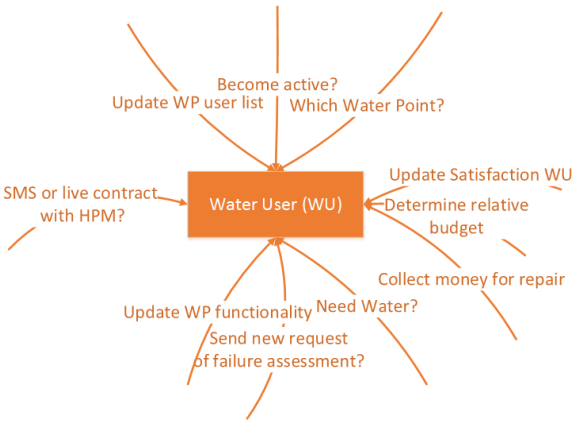



**Figure 51 Updates and Decisions WUs**

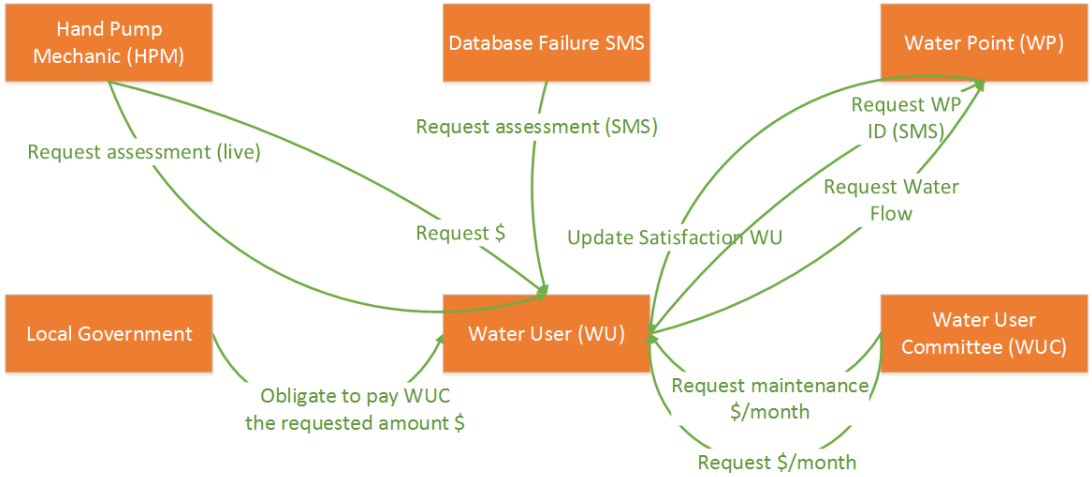



**Figure 52 Interactions (actions) Wus**

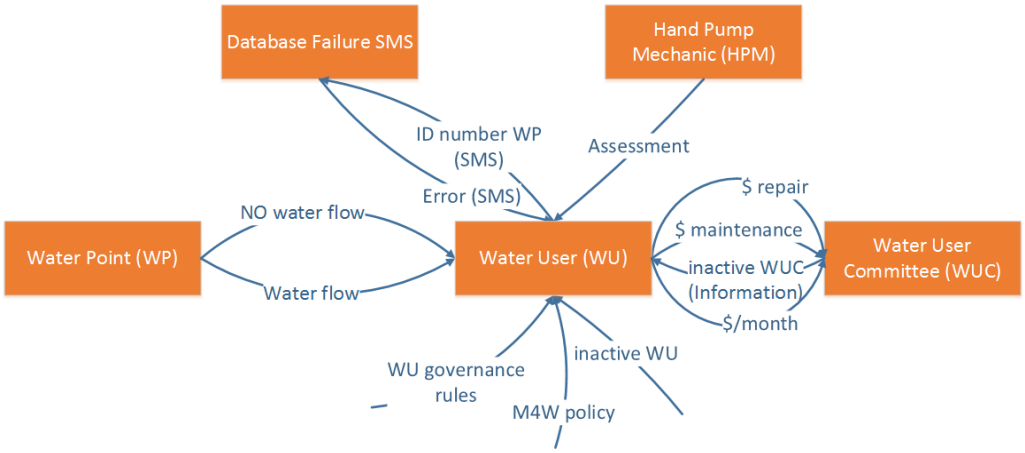



**Figure 53 Interactions (information) WUs**

The following interactor that is described is the local government.

### *Local government*

The local government are Parish leaders, Local Councils (at sub-county level) that inter alia prepare the Conditional Grant proposal and HPM and WUC ranking for the DWO and it has contact with WUCs concerning new WP requests, can help WUCs collecting money. Furthermore, it can replace a WUC if WUC is inactive and unmotivated.

> *In reality the local government makes a selection of New WP requests that go to the DWO or not. This is chosen not to put that in the model design, as there are already many obstacles (Motivation rate and Knowledge level) before a WUC can request a new WP* (Bey 2014).

The requests for Large repairs and new WPs are sent once in a while to the DWO.

> *'WUC and HPM ranking' orders the WUCs and HPMs their Motivation and Knowledge level from low to high.*

In the following figures (see Figure 54, Figure 55 and Figure 56) a rough description of the interaction between the local government and other interactors/environment is described. The local government is in contact with the HPM, WU, DWO, WUC, WP and Database of Failed WPs. In appendix 9.8.6 the personal properties and the concept formalization are represented.

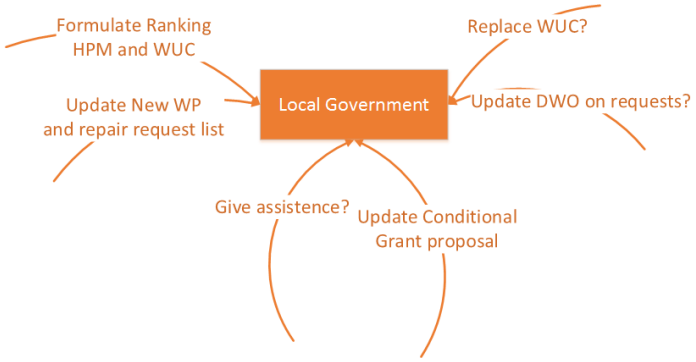



**Figure 54 Updates and decisions local government**

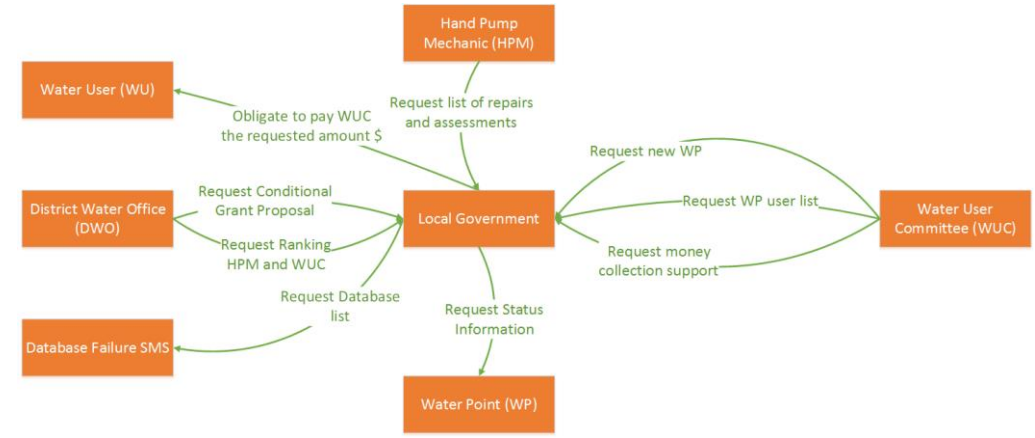



Figure 55 Interactions (actions) local government

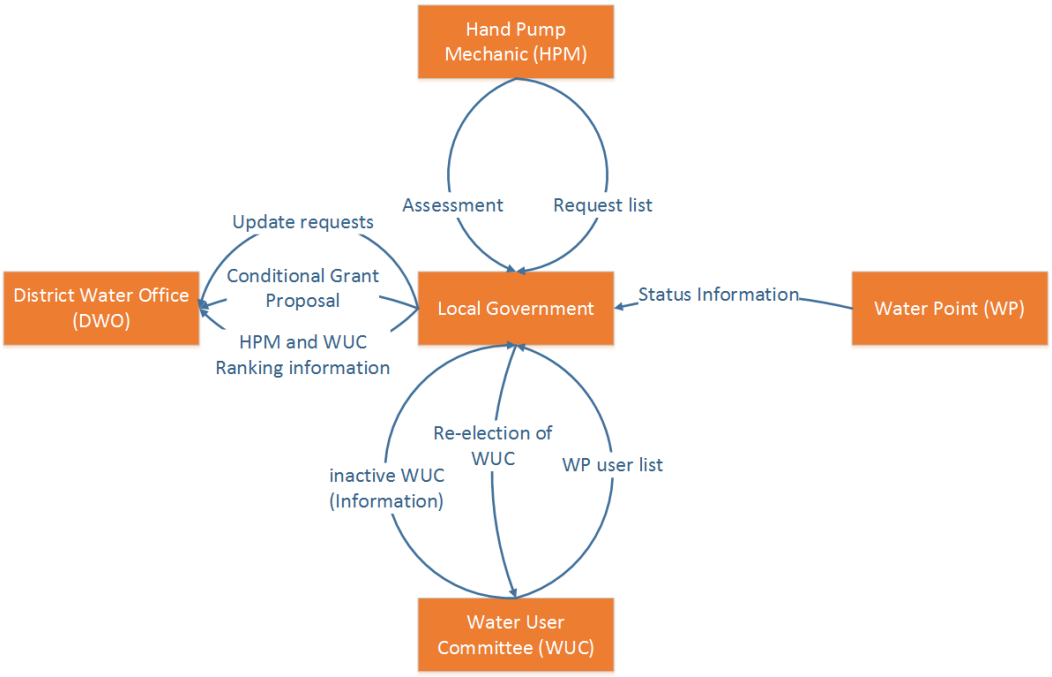



Figure 56 Interactions (information) local government

### 9.7.2 Objects of the agent-based model design

Besides interactors, which are representations of living things, there are also objects included in the model design.

#### *Water Point*

As mentioned above, the hand pump is a standalone system that should be managed by the community-of-users. The WUC doesn't do official water point checks nor maintenance (Smet 2013; Lieshout 2013; Bey 2013b).

Small maintenance is keeping the ground around the water point clean, fixing a tap, oiling the system etcetera (Bey 2013b). This kind of maintenance is not directly included in the model design.

> *The knowledge level is assumed to go hand in hand with the level of proper care of the WP. However, it is assumed that the knowledge level of the WUC is taken into account for determining the relative budget.*

The Water Point (WP) in Uganda needs specialized tools and expertise to maintain/check the water point. The WUC cannot dismantle the water points themselves. In one district there are around 10-15 sub-counties with a total of 1000 to 1500 WPs. For one water point there should be around 300 people who use the water point (Smet 2013; Lieshout 2013; Bey 2013b).

> *It is assumed that in Uganda there are just WPs with WUCs. These WUCs can be however active or inactive.*
>
> *Furthermore, there is no distinction made between protected and unprotected WPs, because unprotected water sources, just like protected ones, can have dirty water, can be crowded etc. So, the unprotected WPs get a Water Service Level, just like the protected WPs.*

The WSL is determined at the object Water Point. The WSL information is up to date and known by the WUs, who are within a certain distance. The WU chooses the WP with the highest WSL. The WSL can change over time discretely. The WSL is determined by the Service Delivery Indicator that scores lowest (Schouten & Moriarty 2013), see for an explanation of the WSL page 67. IRC and its partners normally determine the WSL from the WU point of view (Moriarty 2010).

> *Here it is assumed that it is possible to calculate the WSL of a WP (for a set group of WUs).*
>
> *It is assumed that people stay alive, even though the WSL is 0. In a later stage of the designing process it should be decided if it has additional value, if agents can die.*

The Reliability, Crowding and Dependency can change over time. First, the Dependency and Crowding is proposed to be calculated, by:

*Total families= WUs within 1,5 km (group 1) + WUs within 3 km (group 2)= **A** families*

$$Dependency\ mean = \frac{\sum Dependency\ WP\ if\ WSL\ is \geq 2 (of\ \boldsymbol{A}\ families)}{\boldsymbol{A}\ families}$$

*The WSL of other WPs are taken into account while determining the WSL of a particular WP, as Crowding is related to the WSLs of WPs, which have overlapping WUs. So, determining the Dependency mean, WPs with a WSL of 2 or higher are taken into account.*

*The Quality, Quantity and Distance are determined with the setup of the model and static afterwards, as group 1 and 2 stay the same.*

*IF Dependency mean= 4 WPs and **A** families= 90 families*

$$Crowding = \frac{90\ families}{4\ dependency\ mean} = 23\ families$$

*Taking the number of Crowding, the Service Level for group 1 and 2 can be determined in Table A, see* Table 14.

**Table 14 Crowding Service Level Determining table A** (Bey 2013b; Ministry of Water and Environment 2013)

| **Amount of families -> Service Level for Crowding** | | | | |
|---|---|---|---|---|
| **>=80** | 79-60 | 59-40 | 39-20 | 19-1 |
| **1** | 2 | 3 | 4 | 5 |

The Reliability Service Level is determined by calculating the Mean Time Between Failures (MTBF) with the help of the '*Dates of failures and repairs list'* (henceforth: FR list). With the MTBF, the Reliability Service Level can be determined in Table B, see Table 15.

**Table 15 Reliability Service Level Determining table B**

| **Reliability, Mean Time Between Failure (in days)** | | | | |
|---|---|---|---|---|
| **1-300** | 301-600 | 601 - 1000 | 1001 - 1400 | 1401< |
| **1** | 2 | 3 | 4 | 5 |

*These MTBF numbers are chosen in* Table 15*, because it is assumed that WPs most often break down after two years.*

Every day there is a small decrease in the Functionality of the WP. If the Functionality is below a certain point (Functionality threshold), then there is no flow of water coming from the WP. The Functionality of the WP can be upgraded by maintenance or a repair (Large or Normal).

Information on the water flow is shared (Status Information) with the WUs and WUC who are assigned to the WP. If the WP breaks down, the new WSL (level 0) is shared with the same WUs and WUCs as who receive the Status Information. As soon as a water point gets repaired, installed or maintained, the WSL, the level of Functionality of the WP, Satisfaction and (possibly) the Dependency of the WUs is updated. The Satisfaction and Dependency of WUs is updated when a new WP is installed. The Satisfaction is updated when there is a change concerning the WSL.

The WUC or WU can request the WP's ID number, so that they can send a message if the WP broke down. These water service providers will only request the ID number if the M4W policy is implemented.

The ID number is a long number and often not clearly visible. So, the number is transferred from WP to WUC or WU with the possibility of a mistake (ID transferring 'noise'). This mistake will be later notified by the Database of Failed WPs.

> *Due to the relatively short period of ten years that the model will be running, it is assumed that WPs can be fixed. So, the new WPs are only requested if there the crowding at/dependency of the WP is too high.*

The network, interactions and updates of the WP is roughly as follows (see Figure 57, Figure 58 and Figure 59):

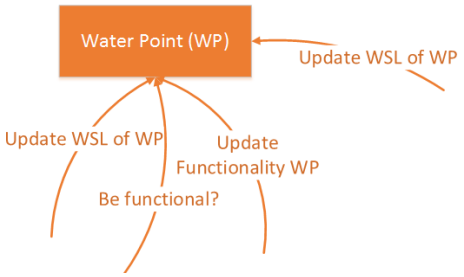



**Figure 57 Updates and decisions WP**

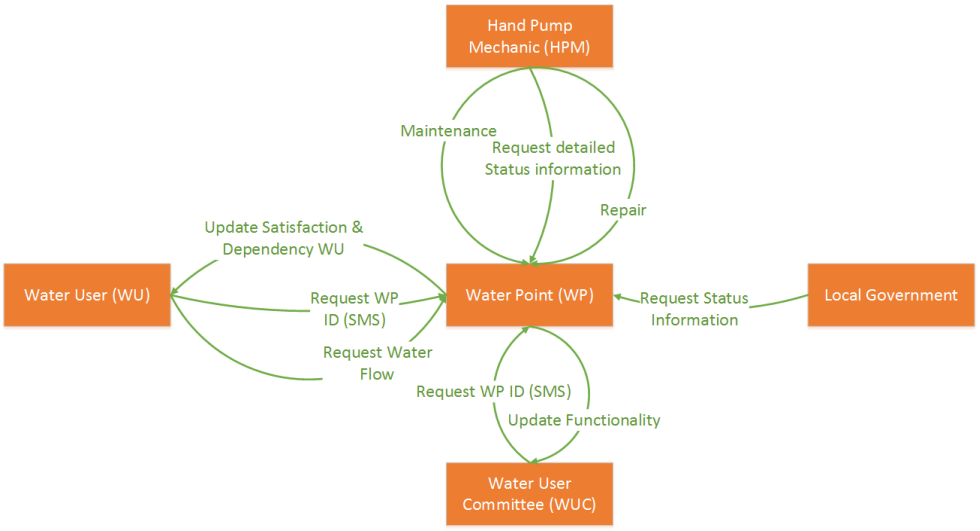



**Figure 58 Interactions (actions) WP**

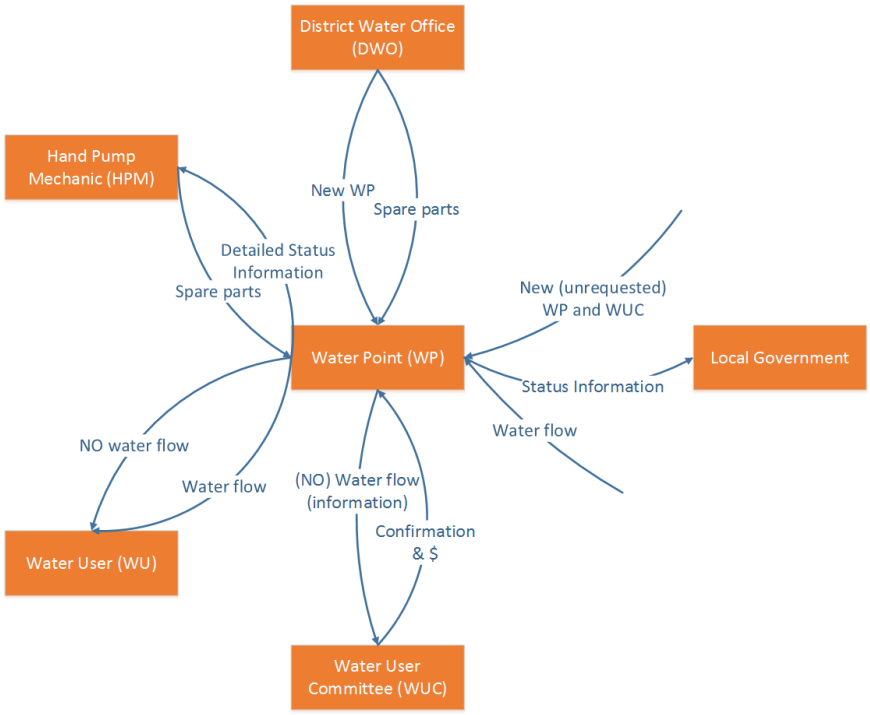



Figure 59 Interactions (information) WP

In appendix 9.9.1 the properties and the concept formalization are presented. The next object that is described is the Database of failed WPs.

### *Database of failed WPs*

If the M4W policy is implemented, the Database of failed WPs becomes active. The Database helps the water service provider to contact a HPM quicker. Furthermore, the DWO has up to date information on the current state of the WPs in his district.

The pattern of interaction for this object is relatively easy, see Figure 60, Figure 61 and Figure 62. The properties and concept formalization can be found in appendix 9.9.2.

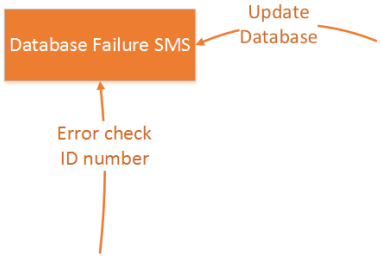



Figure 60 Updates and decisions of Database

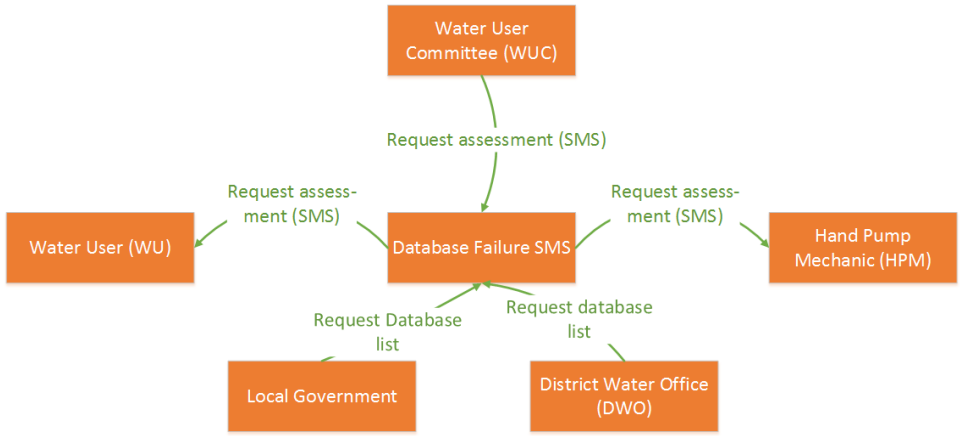



Figure 61 Interactions (actions) of Database

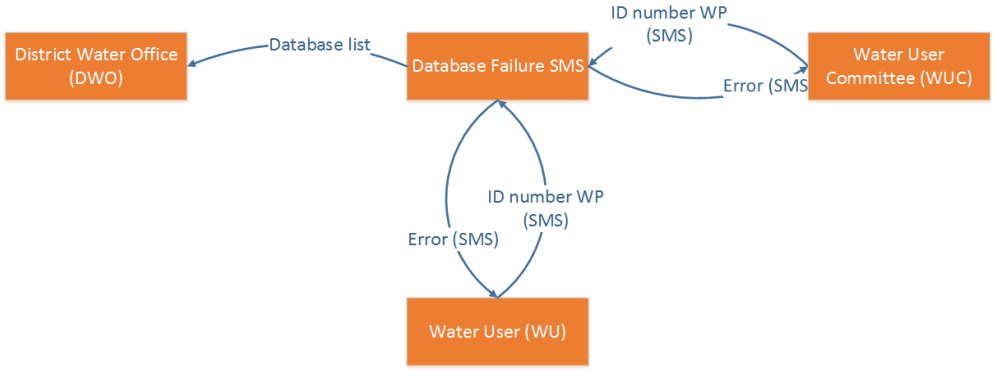



Figure 62 Interactions (information) of Database

### 9.7.3 The environment of the agent-based model design

The environment entails all the interactors who are not explicitly included in the model design, as they are out of the scope (actors at District level and lower). The environment supplies institutions (policies), money (salary and Conditional Grant money), Lobby power, WP mechanic and management knowledge, spare parts and new WPs.

**Spare parts and new WPs**

The environment supplies spare parts and new WPs. As mentioned earlier, it is assumed that *the environment has an inexhaustible amount of spare parts and new water points. Furthermore, the different types of spare parts is brought back to two and for the water point types to one.*

> *The amount of water (flow) that is received from the environment is assumed inexhaustible at the moment, because this model doesn't describe the natural drought problem, to be but the water services delivery problem.*

**Conditional grant money and distribution rates**

The Conditional Grant money is linked to reporting, coverage etcetera and is given in phases. Often the yearly Conditional Grant should come in June but arrives in September (Bey 2013a; Bey 2013b). The Distribution Rates policy is as follows:

- Investment in new water facilities: <= 70%
- Rehabilitation of boreholes and piped water schemes: <= 8%
- Others: <= 22% (Bey 2013a; Bey 2013b).

It is striking to see how little money is assigned for the Large repairs (rehabilitation).

Four times a year the Ministry (which is put in the environment) requests a Request Conditional Grant Proposal from each DWO. Depending on the data the DWO delivers, the Ministry sends a certain amount of Conditional Grant.

**Lobby power**

The environment (Local Councilors at level 5) are in contact with DWOs. They try to influence the DWO by requesting him to give the Conditional Grant money to a certain District. The model user has to decide which Districts are 'preferred' by the environment.

**Ratio Conditional grant – Sent data**

How much is received by the DWO, after a certain amount of failures is communicated with the Ministry, is still unknown. This ratio still needs some more research.

**Important setting up decisions**

Many policies are either on or off. The person who sets up the model can decide several things, see Table 16.

Table 16 Decisions at the beginning of a model run.

| Variables | Suggestion |
|---|---|
| **Amount of WPs per District** | 1000 WPs (Bey 2013b) |
| **Amount of Districts** | 4 districts |
| **Amount of WUs per District** | 15.000 families[44] |
| **Chance that the HPM and WUC become active if its Motivation is low.** | no suggestion |
| **Knowledge requests are always answered with a certain amount of knowledge, however the amount of (WP mechanic/management) knowledge needs to be set at 0 or 1 (or fluctuating).** | Depends on purpose of run (with triple-S project, 1) |
| **The Sanctioning policy, M4W policy, WUC payment policy are either on or off.** | Depends on purpose of run |
| **The amount of unrequested WPs put in a District.** | Depends on purpose of run (with triple-S project, 0) |
| **The salary a WU receives per month.** | 7 USD (Smet 2013) |
| **HPMA policy has policy level 1 or 2[45]** | Depends on purpose of run |
| **Salary of WUCs** | 7 USD [46] |

[44] For this suggestion it is assumed that an average Dependency of WUs is around **3 to 4 WPs** and 50 families are assigned to one WP. So, 50families/WP*1000WP=50.000 families, 50.000families/3-4 dependency= around 15.000 families

[45] For the HPMA policy the policy is not just turned on or off. When it is turned on: it has two phases. *As in most districts a HPMA is present* (Nabunnya 2013)*, it is assumed that the HPMA policy is always present and functions as a spare parts/new water points provider (policy level 1). If the HPMA is changed to level 2 (by the environment) the HPMA will also be able to compose a Maintenance contract.*

| | |
|---|---|
| **Price for repair (Normal)** | 56 USD (Bey 2013b) |
| **Price for repair (Large)** | 200 USD (Bey 2013b) |
| **Maintenance** | 1,6 USD[47] |
| **New installations (WPs)** | 2000 USD (Bey 2013b) |
| **Amount of days (ticks) between an WSL update & Satisfaction update.** | 14 days, 14 ticks |
| **Sanctioning amount (fine or incentive)** | 7 USD (needs checking) |
| **Conditional Grant proposal data** | Data of failures/repairs and requests. |

### 9.7.4 Model design decisions

In this section several decisions are made explicit in Table 17 and Table 18. In the first table, Table 17, the thresholds that need to be decided upon are put together in one table and suggestions of thresholds are made. Unfortunately there are no sources found to underpin the suggested thresholds.

**Table 17 Threshold suggestions**

| Variables | Suggested threshold [48] |
|---|---|
| **HPMAs' inventory for spare parts (type 1 and 2) and new WPs.** | Triangle (max 3, deviation (+&-)3) |
| **Threshold of the DWO: point of WUC's and/or HPM's their motivation is low 'enough' to fine the particular interactor.** | 2 (out of 5) or lower |
| **Threshold of the DWO: point of WUC's and/or HPM's motivation is high enough to incentivize the particular interactor.** | 4 (out of 5) or higher |
| **Threshold of the local government: point that WUC's motivation is low 'enough' to re-elect.** | 1 (out of 5) or lower |
| **Functionality threshold: below is a dysfunctional WP** | 30 % functionality |
| **ID noise threshold determines when a ID Error SMS is sent or not.** | 0,01[49] (out of range 0-1) |

As soon as the model is programmed, several decisions (setting-up decisions) need to be made, see Table 18. To make a realistic start of the model several interactors will need to have some starting capital and chance distributions need to be confirmed.

[46] If they earn 7 USD, it is the same amount as water users earn.
[47] 1,6 USD is the price for a very small repair (Bey 2013b).
[48] No sources for thresholds!
[49] As soon one letter/number is spelled wrong, the WP ID number needs to be rewritten/checked.

Table 18 Setting up decisions

| Variables | Suggested value (ranges)[50] |
|---|---|
| Starting capital of HPMs | 80 USD (able to pay one spare part) (Bey 2013b) |
| Start capital HPMAs | 300 USD (able to pay a small inventory) (Bey 2013b) |
| Start capital DWOs | 10.000 USD (shortly after payment) (Bey 2013b) |
| Start capital WUs | 7 USD (just received salary)(Smet 2013) |
| Ranking HPM and WUC should be calculated | Depends on motivations |
| IDs of WUCs, WPs, DWOs, WUs, HPMAs, local governments | Numbers >0, WUC1, WUC2 etc. |
| Distribution of WUs per WP, per distance (group 1 and 2), per district, per local governments (Dependency) | # Families/WP = Normal distribution with mean of 50 families per WP (Bey 2013b) |
| Chance WUC becomes active if the motivation is <=2 | 50 %, because the pressure of water users can stimulate the WUC. |
| Distribution of WSLs (Satisfaction) while starting up the model | Chance distribution (level->%)<br>0,1,2,3,4,5 (level) ->30, 40, 25, 3, 1, 1(%) because 95% of the water points do not reach the level of basic water services delivery (Bey 2013b). |
| Start Functionality per WP (distribution of Functionality rates) | *Chance distribution (functionality -> %) 1-20, 20-40, 40-60, 60-80, 80-100 (functionality) -> 30, 20, 20, 20, 5, 5(%) (Schouten & Moriarty 2013) |
| Chance distribution between large/normal repair: to determine when a repair is a repair that can be fixed by a HPM or only by the DWO. | 40 % Large, 60 % Normal repair |
| Start WP user list per WP | Normal distribution around 50 families |
| Start of Water Service Indicators: Quality [51] | Needs to be researched |
| Start of Water Service Indicators: Reliability | Needs to be researched |
| 'Money collection support' (yes or no per local governments) | It is suggested that they do support, so True (Bey 2014). |
| Status information (distribution broken/functioning) | Depends on functioning %, see * |
| Mobile distribution (percentage of WUs/WUCs who have mobile) | 60% (fast increasing number, needs to be checked) |
| Distribution of WUC/WUs who prefer using a mobile instead of trying to contact the HPM live. | 20% (mobile just for status and family calls (Smet 2013)) |
| Amount of DWOs who are sensitive to 'Lobby power' | 80% as people want to stay friends with prominent people . |
| Motivation distribution for the WUCs, HPMs. | Chance distribution (level->%)<br>0,1,2,3,4,5 (level) ->30, 20, 20, 20, 5, 5(%) |
| (WP mechanic/management) knowledge distribution for the WUCs, HPMAs and HPMs. | Each level of knowledge (0,1,2)-> (40, 40, 20) % |
| Percentage of HPMAs who are motivated to supply a Maintenance contract. | Depends on knowledge level and the Motivation level of HPMs |
| ID transferring 'noise' distribution (how many ID are incorrect transferred from WP to WUC/WU) | At the moment 50 per cent of the messages fail (Bey 2013b) |
| Starting request lists of the HPM and DWO(/local government) should be decided upon. | Needs to be researched |

[50] Numbers need checking by experts, some sources are found, not for all.
[51] The other indicators are related to the WP group, WP User list and amount of WPs within 3 km distance.

## 9.8 Model design: interactor properties and model formalization

In this appendix the properties and model formalization per interactor are shown.

### 9.8.1 DWO

**Fact memes (states)**

The states specify and describe the DWO and define the DWO. The first block in Table 19 shows the DWO's network and location. The second block are the policies the DWO is involved with. The other lists/thresholds etcetera that are important for decisions that the DWO needs to make.

**Table 19 Properties of DWO**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | District | Integer | >=0 |
| **2** | WPs in district | List of integers (IDs) | |
| **3** | WUC in district | List of integers (IDs) | |
| **4** | HPM in district | List of integers (IDs) | |
| **5** | HPMA in district | Integer (ID) | >=0 |
| **6** | Local Government in district | Integer (ID) | >=0 |
| **7** | DWO ID | Integer (ID) | >=0 |
| **8** | Sanctioning policy? | Boolean | |
| **9** | M4W policy | Boolean | |
| **10** | WUC payment policy | Boolean | |
| **11** | Fine threshold - motivation | Integer | >=0 |
| **12** | Reward threshold - motivation | Integer | >=0 |
| **13** | Sanctioning amount (-/+$) | Integer | >=0 |
| **14** | Salary WUC | Integer | >=0 |
| **15** | Lobby sensitivity? | Boolean | |
| **16** | Lobby distribution preference | List of strings | |
| **17** | Have money to repair/new WP? | Boolean | |
| **18** | Account Balance New WP | Floating point | >=0 |
| **19** | Account Balance repairs | Floating point | >=0 |
| **20** | Account Balance 'others' | Floating point | >=0 |
| **21** | 'Request New WP' list | List of integers[52] | |
| **22** | 'Request repair WP' list | List of integers[53] | |
| **23** | 'Distribution Conditional Grant' | Floating point | >= 0 and <= 1 |
| **24** | Conditional Grant proposal | List of strings | |
| **25** | Specific WP requested? | Boolean | |
| **26** | Specific spare part requested? | Boolean | |

[52] Dates of when latest maintenance job was done.
[53] Dates of when latest maintenance job was done.

**Rules**

During each time step the DWO has to go through the following steps, see Table 20. These steps are an elaboration on the pattern of interaction as shown in appendix 9.7.1.

During the DWO grant phase the DWO checks whether he needs to update the environment (DWD) on the current situation or not. To update the DWD the DWO needs an updated Conditional Grant proposal. This proposal is conducted by the local governments.

In the Start phase the DWO decides whether to repair/build a WP or not. This decision is strongly influenced by the amount of money the DWO has. Which repair/instalment the DWO is going to pick depends on the influence the Local Council has on him. The 'DWO new WP phase and 'DWO large repair phase' are about the installation/repair of a water point (WP).

The Sanctioning phase describes when and how the DWO sanctions a HPM and or WUC.

**Table 20 Rules of DWO**

| **Theme** | **Action/information** | **Timing** |
|---|---|---|
| **DWO grant phase** | Check received request for *Conditional Grant update*[54] | 1x day |
| | | |
| | ***If False***: | |
| | Go to *Check Conditional Grant (money)* | |
| | ***If True***: | |
| | Request *Conditional Grant proposal*[55] | |
| | Receive *Conditional Grant proposal* | |
| | Update *Conditional Grant proposal* | |
| | | |
| | *M4W policy in place?* | |
| | ***If False***: | |
| | Go to *Send Conditional Grant proposal* | |
| | ***If True***: | |
| | Request *Database list* | |
| | Receive *Database list* | |
| | | |
| | Send *Conditional Grant proposal* | |
| | | |
| | Check received *Conditional Grant (money)* & *'Distribution Conditional Grant' policy*[56] | |
| | | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |

[54] From the Environment (Ministry of Water and Environment)
[55] From the Local Government
[56] The amount that the DWO receives is a percentage of the requested amount of money. The data of the Conditional Grant proposal, like amount of requests of repair and WSL of WPs affect the amount of money granted by the environment (Ministry of Water and Environment).

| | | |
|---|---|---|
| | Update *'Distribution Conditional Grant'* | |
| | Update *bank balances (all three)*[57] | |
| | | |
| **Start phase** | Start *Selection phase* | 1x day |
| | Check request for *request lists*[58] | |
| | ***If False***: | |
| | Go to *Check bank balances (new WP & repair)* | |
| | ***If True***: | |
| | Send *request list* | |
| | | |
| **(1 request a day)** | Check *bank balances (new WP & repair)* | |
| | ***If False***[59]: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check '*lobby sensitivity*'[60] | |
| | ***If False***: | |
| | Select request from new WP & repair request list, which is '*working on request x*' OR otherwise first in line, update to (*working on request x*). | |
| | | |
| | | |
| | ***If True***: | |
| | Select request from new WP & repair request list, which is '*working on request x*' OR otherwise which is first in line with *Lobby distribution preference*, and update (*working on request x*). | |
| | | |
| | | |
| | | |
| | | |
| | | |
| **DWO new WP phase** | Check *'Specific WP requested?*' | ***(Start if selected in Start phase)*** |
| | ***If True:*** | |
| | Go to Check received *… new WP* | |
| | ***If False:*** | |
| | Request new WP | |
| | Update '*Specific WP requested?*' to True | |
| | | |
| | Check received *Confirmation* & *Request $ new WP* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Send money for *new WP* | |
| | Update *bank balance New WP*[61] | |
| | Receive *new WP* | |
| | Update '*Specific WP requested?*' to False | |
| | Send *new WP (mean)*[62] | |

[57] Distribution Conditional Grant determines which percentage of the money goes to which bank account.
[58] Each Local Government can send a update of request list (new and repair)
[59] If false, the bank balance is < the cost of a repair/new WP
[60] If Lobby Sensitive is 'True', the 'Select request' equation gets influenced by the *Lobby power distribution money.*
[61] Bank balance New WP – *Request $ new WP* (which is received from the HPMA)

| | | |
|---|---|---|
| | Send *installation (action) of new WP* | |
| | Send update *Request new WP?* (False)[63] | |
| | Update *request list*[64] | |
| | | |
| **DWO Large repair phase** | Check '*Specific spare part requested?*' | ***Start if selected in Start phase)*** |
| | ***If True:*** | |
| | Go to ** | |
| | ***If False:*** | |
| | Request *spare part (type 2)* | |
| | Update '*Specific WP requested?*' to True | |
| | | |
| | **Check received *Confirmation* & *Request $ spare part* | |
| | | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Send money for *spare part*[65] | |
| | Update *bank balance spare part*[66] | |
| | Receive *spare part* | |
| | Update '*Specific spare part requested?*' to False | |
| | Send *spare part (mean)*[67] | |
| | Send *repair (action) of spare part* | |
| | Update *request list*[68] | |
| | | |
| **Sanctioning phase** | Check received *Sanctioning policy?* | 1x month |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Request *'WUC and HPM ranking'*[69] | |
| | Receive *'WUC and HPM ranking'* | |
| | Is WUC/HPM performance below *fine threshold*? | |
| | ***If False***: | |
| | Go to Is performance…*reward threshold*? | |
| | ***If True***: | |
| | Check *Sanctioning amount (- $)* | |
| (direct debit, up to the bank balance allows it) | Update *bank balance 'others'* [70] | |
| | Is performance above *reward threshold*? | |

[62] During this action a new WUC and properties of WP has to be created.
[63] To particular WUC
[64] Delete New WP request from the request list.
[65] To HPMA
[66] Current bank balance - *$ spare part* (which is received from the HPMA)
[67] To WP
[68] Delete request from the request list.
[69] From Local Government (see Figure 40)
[70] Bank balance 'others' + sanctioning money (-$)

| | | |
|---|---|---|
| | ***If False***: | |
| | Go to *WUC payment … in place*? | |
| | ***If True***: | |
| | Check *Sanctioning amount (+ $)* | |
| (direct debit, up to the bank balance allows it) | Update *bank balance 'others'* [71] | |
| | | |
| | WUC payment policy in place? | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check *Salary WUC* | |
| (direct debit, up to the bank balance allows it) | Update *bank balance 'others'*[72] | |
| | | |
| **END phase** | | |

The following interactor that is described is the Hand Pump Mechanic Association.

### 9.8.2 HPMA

In Table 21 first the network and location are described, followed by the policies that have an effect on (some) decisions of the HPMA. The third block shows the knowledge level the HPMA has. The fourth block shows the motivation of the HPMA. This motivation of the HPMA is composed of the HPMs' motivations which work in the HPMA's district. If the motivation of the HPMA is too low, the HPMA will not want to close a maintenance contract (if requested by a WUC).

The other properties are about the supply of maintenance, spare parts and new WPs. 'Date of last maintenance' (which is in the Maintenance list) is the same as the tick number of that particular moment.

**Table 21 Properties of HPMA**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | District | List of integers (IDs) | |
| **2** | WPs in district | List of integers (IDs) | |
| **3** | WUC in district | List of integers (IDs) | |
| **4** | HPM in district | List of integers (IDs) | |
| **5** | HPMA ID | Integer (ID) | >=0 |
| **6** | DWO ID | Integer (ID) | >=0 |
| **7** | Maintenance policy | Boolean | |
| **8** | HPMA policy level | Integer | >=1, <=2 |
| **9** | Management knowledge level | Integer | >=0, <=2 |
| **10** | Motivation[73] | Integer | >=0, <=5 |
| **11** | New WP price | Floating point | >=0 |
| **12** | Spare part 1 price[74] | Floating point | >=0 |

[71] Bank balance 'others' – Sanctioning money (+$)
[72] Bank balance 'others' – WUC salary
[73] Which is the mean Motivation of the HPMs in that certain district.
[74] Part for Normal repair

| | | | |
|---|---|---|---|
| **13** | Spare part 2 price[75] | Floating point | >=0 |
| **14** | Maintenance price | Floating point | >=0 |
| **15** | Supply Maintenance Contract? | Boolean | |
| **16** | Bank balance[76] | Floating point | >=0 |
| **17** | Maintenance list | List of integer[77] | |
| **18** | # Spare parts 1 @inventory | Integer | >=0 |
| **19** | # Spare parts 2 @inventory | Integer | >=0 |
| **20** | # New WP @inventory | Integer | >=0 |
| **21** | Threshold spare parts, WPs @inventory | Integer | >=0 |

The rules that are known by the HPMA depends on the implemented policies and knowledge level. The theme that is described first in Table 22 are about the supply of spare parts/new WPs.

In the Water service basis phase (part 1) the motivation is calculated and the property to close a maintenance contract or not is possibly adjusted. In the following phase 'Request maintenance contract phase' the HPMA checks whether it is time to execute a maintenance job or not. In the 'Maintenance phase' the HPMA will request a HPM to execute a particular maintenance job.

The second part of the 'Water service basis phase' is only entered if the HPMA does not supply a maintenance contract. Here the HPMA's knowledge level and inventory threshold is adjusted.

**Table 22 Rules of HPMA**

| **Theme** | **Action/information** | **Timing** |
|---|---|---|
| WPs/spare parts supply | Start processing WP/spare parts requests | 1xday |
| *present in phase:* | Check availability requested *new WP, 1&2 in inventory* | |
| **HPM repair phase** | ***If False***: | |
| **DWO repair phase** | Request *new WPs, spare parts 1&2* | |
| **DWO new WP installation phase** | Receive *new WP, spare parts 1&2* | |
| | Update *bank balance (direct debit)* | |
| | Confirm *availability WP, spare parts 1&2* | |
| | Update *inventory* | |
| | ***If True***: | |
| | Confirm availability *new WP, spare parts 1&2* | |
| | | |
| | Request money for *WP, spare parts 1&2* | |
| | Update *Inventory* (*request reserved*) | |
| | | |
| | Check received *money for WP, spare parts 1&2?* | |
| | ***If False***: | |
| | Go to *next request or phase* | |
| | ***If True***: | |
| | Update *bank balance* | |

[75] Part for Large repair
[76] While setting up the model, every HPMA should get some starting capital.
[77] Dates of when latest maintenance job was done.

| | | |
|---|---|---|
| | Send requested *WP, spare parts 1&2* | |
| | Update *inventory* | |
| | | |
| **Water service basis** | Request Motivations of HPMs in HPMAs' district | 1x day |
| **phase part 1** | | |
| | Check received HPM Motivation | |
| | ***If False:*** | |
| | Go to '*Check if … than threshold*' | |
| | ***If True:*** | |
| | Calculate *Motivation mean of HPMAs' HPMs* | |
| | ***If < = 2:*** | |
| | Update *Supply Maintenance Contract? to False* | |
| | ***If >2 & <=5:*** | |
| | Update *Supply Maintenance Contract? to True* | |
| | | |
| | Check if *inventory is = or > than threshold* | |
| | ***If True***: | |
| | Go to *next phase* | |
| | ***If False***: | |
| | Request *(threshold – inventory) parts/WPs* | |
| (direct debit) | Update *bank balance* | |
| | Receive *requested inventory* | |
| | Update *inventory* | |
| | | |
| **Request maintenance** | Start checking conditions maintenance contract: | 1xday |
| **contract phase** | Check *HPMA policy* | |
| | ***If HPMA policy = 1:*** | |
| | Go to *Check Management Knowledge level*[78] | |
| | ***If HPMA policy = 2:*** | |
| | Check *Maintenance policy* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | *Check Supply maintenance contract?* | |
| | ***If False:*** | |
| | Go to *Water service basis phase (part 2*) | |
| | ***If True:*** | |
| | Check received *requests for Maintenance contract* | |
| | Send confirmation *Maintenance contract* | |
| | Send *request $ (for maintenance)* | |
| | Update *Maintenance list* (add maintenance +*Waiting for payment)* | |
| | | |
| | Check *Maintenance list* (# ticks = 120 + *date of last maintenance*[79]*)* | |

[78] Water service basis phase part 2.

[79] Date of last maintenance is the same as the tick number of that particular moment.

| | | |
|---|---|---|
| | ***If False:*** | |
| | Go to *Check received… 4 months* | |
| | ***If True:*** | |
| | Send request for *$ per 4 months* | |
| | Update *Maintenance list* (*Waiting for payment)* | |
| | | |
| | Check received *$ per 4 months* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Update *Maintenance list* (*Paid maintenance*) | |
| | Update *bank balance* | |
| | | |
| ***Maintenance phase*** | Check Maintenance list for *Paid maintenance* | |
| | ***If False***: | |
| | Go to *END phase* | |
| | ***If True***: | |
| | Request *Maintenance job* | |
| | Send salary for *Maintenance job* | |
| (direct debit) | Update *bank balance* | |
| | Update *Maintenance list* (*update date of last maintenance (x tick)*) | |
| | Skip next phase, go to *END phase* | |
| | | |
| **Water service basis** | Request *WP Management knowledge* | 1xday |
| **phase part 2** | Update WP *Management knowledge* | |
| | Check *WP Management knowledge level* | |
| | ***If level is 2:*** | |
| | Change '*supply maintenance contract?*' to True | |
| | ***If level is =<1:*** | |
| | Go to the next phase | |
| | | |
| | Check *Management knowledge level* | |
| | ***If level is 2:*** | |
| | Check *motivation* | |
| | ***If <4:*** | |
| | Go to *END phase* | |
| | ***If >= 4:*** | |
| | Update *(Threshold spare parts and WPs @inventory) +1* | |
| **END phase** | | |

The next interactor whose daily story is shown of the Hand Pump Mechanic.

### 9.8.3 HPM

The states, which specify and describe the agent, are summed up in Table 23. The first box shows the location and network of the HPM. The second box gives an overview of the policies which can affect the HPM. The personal motivation or personal priority is shown in the third box. The fourth box has the knowledge level of the HPM. The rest of the HPM's properties are based on the repairs and assessments the HPM does.

**Table 23 Properties HPM**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | District | List of integers (IDs) | |
| **2** | WPs in district | List of integers (IDs) | |
| **3** | WUC in district | List of integers (IDs) | |
| **4** | Local Government ID | Integer (ID) | >=0 |
| **5** | HPMA ID | Integer (ID) | >=0 |
| **6** | Maintenance policy | Boolean | |
| **7** | Sanctioning policy | Boolean | |
| **8** | Motivation | Integer | >=0, <=5 |
| **9** | WP Mechanic Knowledge level | Integer | >=0, <=2 |
| **10** | Repair price 1 | Floating point | >=0 |
| **11** | Repair price 2 | Floating point | >=0 |
| **12** | Account Balance[80] | Floating point | >=0 |
| **13** | Request list of assessments and repairs | List of integers[81] | |

**Rules:**

The HPM is active in several phases, see Table 24. In the 'Water service basis phase' the HPM decides whether to request more knowledge or not. In the 'Evaluation phase' the HPM needs to inform the local government on its motivation and knowledge level. Depending on how the HPM is evaluated the HPM can be sanctioned in the 'Sanctioning phase' or not.

The 'Requesting phase' and 'Request Maintenance contract phase' are both designed to handle the request of an assessment/maintenance job. From the 'Start phase' onward the focus is on the repair/assessment/maintenance of WPs.

**Table 24 Rules of HPM**

| **Theme** | **Action/information** | **Timing** |
|---|---|---|
| **Water service basis** | Check *WP Mechanic Knowledge level* | 1x day |
| **phase** | ***If level is 2:*** | |
| | Go to *next phase* | |
| | ***If level is <2:*** | |
| | Check *Motivation* | |
| | ***If Motivation is <3*** | |
| | Go to *next phase* | |

[80] While setting up the model, every HPM should get some starting capital.
[81] from HPM.

| | | |
|---|---|---|
| | ***If Motivation is >=3*** | |
| | Request *WP Mechanic Knowledge* | |
| | Receive *WP Mechanic Knowledge* | |
| | Update *WP Mechanic Knowledge level* | |
| | | |
| **Evaluation phase** | Check request for *Request list*[82] | 1x day |
| | ***If True***: | |
| | Go to *Check for … level request* | |
| | ***If False***: | |
| | Send *request list* | |
| | | |
| | Check for *Motivation and Knowledge level request*[83] | |
| | ***If True:*** | |
| | Send *Motivation and Knowledge level* | |
| | ***If False:*** | |
| | Go to the *next phase* | |
| | | |
| **Sanctioning phase** | Check status of *Sanction policy* | 1x day |
| | ***If False***: | |
| | Go to the *next phase* | |
| | ***If True***: | |
| | Check *Fine or Incentive* | |
| | ***If False***: | |
| | Go to the *next phase* | |
| | ***If True***: | |
| | Update *Motivation (Motivation+1)* | |
| **(direct debit)** | Update *Bank Balance*[84] | |
| | | |
| **Requesting phase** | Start updating *request list for assessment* | 1x day |
| | Check *Request for assessment via SMS/live* | |
| | ***If False***: | |
| | Go to *Check Confirmation …repair/maintenance* | |
| | ***If True***: | |
| | Update *Request list* | |
| | Check *Confirmation & $ for Normal repair/maintenance* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Update *Request list* (*repair request X* or Maintenance X) | |
| **(direct debit)** | Update *bank balance* | |
| | | |
| **Request Maintenance** | Check request for *Motivation update*[85] | 1x day |

[82] To the local government
[83] By the local government
[84] Bank balance + Fine or Incentive
[85] From the HPMA

| | | |
|---|---|---|
| **Contract phase** | ***If False***: | |
| | Go to *Check confirmation …for repair* | |
| | ***If True***: | |
| | Send *Motivation (information)* | |
| | | |
| | Check received *confirmation and $ for repair* | |
| | ***If False***: | |
| | Go to *Check received Maintenance policy* | |
| | ***If True***: | |
| | Update *bank balance* | |
| | Update *Request list (WP x & Paid (repair))* | |
| | | |
| | Check received *Maintenance policy* | |
| | ***If False***: | |
| | Go to the *next phase* | |
| | ***If True***: | |
| | Check request for *maintenance + $ maintenance* | |
| | ***If False***: | |
| | Go to the *next phase* | |
| | ***If True***: | |
| | Update *Request list* (WP X & Paid (maintenance)) | |
| | Update *bank balance* | |
| | | |
| **Start phase** | Start *Selection phase* | 1x day |
| **(1 request a day)** | Check *Motivation* | |
| | ***If Motivation = 1 or 2:*** | |
| | Make decision to work or not (Y[86]% chance, Boolean) | |
| | ***If False***: | |
| | Go to END phase | |
| | ***If True***: | |
| | Go to * | |
| | ***If Motivation >=3:*** | |
| | * Select request from request list 'working on request X' or first in line (update to *working on request* X) | |
| | | |
| | | |
| **Assessment phase** | Request detailed *status information* | *(Start if selected in Start phase)* |
| | Receive detailed *status information*[87] | |
| | ***If repair is Large:*** | |
| | Send assessment[88] | |
| | Update request list (*delete WP X*) | |
| | Go to END phase | |
| | ***If Normal:*** | |
| | Send assessment[89] | |

[86] Percentage needs to be chosen during the setting up of the model by the model user.
[87] The WP has determined whether the WP needs an large or normal repair.
[88] Large (and therefore costly) repair assessments are send to the local government.

| | | |
|---|---|---|
| | Send *request $ and confirmation* | |
| | Update *request list* (*waiting for confirmation WP X* & $) | |
| | | |
| **HPM repair phase** | Request *Spare part type 1* | *Start if selected in Start phase)* |
| | Receive *confirmation of availability* | |
| | Receive *request $ spare parts* | |
| (direct debit) | Update *bank balance* [90] | |
| | Receive *spare parts type 1* | |
| | Send *spare parts*[91] | |
| | Send *repair* | |
| | Update *request list* (*delete WP X*) | |
| | | |
| **Maintenance phase** | Perform Maintenance | *Start if selected in Start phase)* |
| | Update request list (*delete WP X*) | |
| | | |
| **END phase** | | |

In the following section the Water User Committee is described.

[89] Normal repairs are send to the applicant, who can be a certain WUC or a particular WU. It is important to stick the ID of the applicant to the request for assessment in the request list.
[90] Bank balance – cost spare part type 1
[91] To particular WP

### 9.8.4 WUC

The WUC has, like any other interactor, properties that characterize the WUC, see Table 25. The properties are started off with an overview of ID's and location related fact memes. It can be seen that many have a possible influence on the decision making process of the WUC. The motivation and knowledge level of the WUC are put in the third and fourth box.

**Table 25 Properties of WUC**

| nr. | Variable | Type | Range |
|---|---|---|---|
| **1** | District | Integer | >=0 |
| **2** | WPs in district | List of integers (IDs) | |
| **3** | WUC | Integer | >=0 |
| **4** | DWO ID | Integer (ID) | >=0 |
| **5** | Local Government ID | Integer (ID) | >=0 |
| **6** | HPMA ID | Integer (ID) | >=0 |
| **7** | WUs in district | List of integers (IDs) | |
| **8** | HPM in district | List of integers (IDs) | |
| **9** | WP user list | List of integers (IDs) | |
| **10** | WUC payment policy | Boolean | |
| **11** | Sanctioning policy | Boolean | |
| **12** | Maintenance policy | Boolean | |
| **13** | M4W policy | Boolean | |
| **14** | HPMA policy | Integer | =1, =2 |
| **15** | New WP policy | Boolean | |
| **16** | Motivation | Integer | >=0, <=5 |
| **17** | WP Management knowledge level | Integer | >=0, <=2 |
| **18** | Active? | Boolean | |
| **19** | Status information | Boolean | |
| **20** | Bank balance | Integer | >=0 |
| **21** | Mean 'relative budget' of its WUs | Integer | >=0 |
| **22** | Dependency of its WUs | List of integers | |
| **23** | Mean Dependency of its WUs | Integer | >=0 |
| **24** | Mobile | Boolean | |
| **25** | Preference for Mobile? | Boolean | |
| **26** | ID transferring 'noise' | Floating point | >=0, <=1 |
| **27** | Assessment requested? (If Status Information is False) | Boolean | |
| **28** | Request new WP? (requested If True) | Boolean | |
| **29** | Maintenance contract? (requested If True) | Boolean | |
| **30** | Monthly money collection? | Boolean | |
| **31** | Request money collection support? | Boolean | |

**Rules**

The rules of the WUC are described in Table 26. In the 'Water service basis phase' some updates of properties are executed and under certain conditions the knowledge level is adapted. Here the WUC also needs to decide to become active or not. The activity of a WUC is related to the motivation of the WUC. During 'Evaluation phase' the WUC is asked to inform the local government on its personal motivation

and knowledge level. Depending on the evaluation, the WUC is sanctioned in the 'Sanctioning phase' or not.

In the 'Request phase' the WUC notices that the WP broke down and requests the HPM to make an assessment of the failure. In the 'New WP phase' the WUC calculates whether there are too many people using a certain amount of WPs or not.

Under certain conditions the WUC asks the HPMA for a maintenance contract. This process is described in the 'Maintenance phase'. The final phase the WUC participates in is the 'Assessment phase'. Here the WUC needs to collect money for repair of the WP.

**Table 26 Rules of WUC**

| Theme | Action/information | Timing |
|---|---|---|
| **Water service basis phase** | New WUC created by local government or DP[92](environment)?[93] | 1x day |
| | ***If False:*** | |
| | Go to *Check received… WP? Update* | |
| | ***If True:*** | |
| | Create *new WUC agent* | |
| | | |
| | Check received *Request new WP?* Update | |
| | ***If False:*** | |
| | Go to the *Send request…its WUs* | |
| | ***If True:*** | |
| | Update *Request new WP? (to False)* | |
| | | |
| | Send request *Dependency of its WUs* | |
| | | |
| | Check received *Dependency of its WUs* | |
| | ***If False:*** | |
| | Go to *Update WP… Status Information* | |
| | ***If True:*** | |
| | Update *Dependency of its WUs* | |
| | Update mean *Dependency of its WUs* | |
| | | |
| | Check received *WP user list* updates | |
| | ***If True***: | |
| | Update *WP user list* | |
| | ***If False***: | |
| | Go to *Check received … information updates* | |
| | | |
| | Check received *Status information* updates | |
| | ***If True***: | |
| | Update Status information | |

[92] Development Partner
[93] Only one WUC should have the property to check this question and to create another WUC.

| | | |
|---|---|---|
| | ***If False:*** | |
| | Go to *Check Status information* | |
| | | |
| | Check *Status information*[94] | |
| | ***If False:*** | |
| | Check *Error SMS*[95] | |
| | ***If True***: | |
| | Update *Assessment request* to False | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | ***If False***: | |
| | Go to *Check WP …knowledge level* | |
| | ***If (status information =) True:*** | |
| | *Check Assessment request*? | |
| | ***If False:*** | |
| | Go to *Check WP …knowledge level* | |
| | ***If True:*** | |
| | Update *Assessment request*? to False | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | Go to *Check WP …knowledge level* | |
| | | |
| | Check *WP Management knowledge level* | |
| | ***If =2:*** | |
| | Go to * | |
| | ***If <2:*** | |
| | Check *Motivation* | |
| | ***If <4:*** | |
| | Go to * | |
| | ***If >=4:*** | |
| | Request *WP Management knowledge* | |
| | Receive *WP Management knowledge* | |
| | Update *WP Management knowledge* | |
| | Send Update *WP Management knowledge*[96] | |
| | | |
| | Check received *WUC replacement message*[97] | |
| | ***If True***: | |
| | Update *Motivation* (20% of 1/2/3/4/5)[98] | |
| | ***If False***: | |
| | Go to * | |
| | | |
| | *Start: *become active?* | |

[94] Whether the WP is broken or not.
[95] From Database of failed WPs
[96] If the WP Management knowledge gets improved, it is assumed that the WP side gets better maintained. Therefore the Satisfaction of WUs gets updated after more knowledge is gained.
[97] Send by the Local government
[98] Zero motivation is chosen not to be possible when the WUC is just reelected.

| | | |
|---|---|---|
| | Check *Motivation:* | |
| | ***If >=3:*** | |
| | Send & Update *'Become active?*[99] (WUC active? = True) | |
| | Go to ** | |
| | ***If <=2:*** | |
| | Make decision to become *active or not (% chance, Boolean*[100]*)* | |
| | ***If True***: | |
| | Update & Send update *activeness (WUC active? = True)* | |
| | Go to the *next phase* | |
| | ***If False***: | |
| | Update & Send *update activeness (WUC active? = False)* | |
| | Go to the *END phase* | |
| | | |
| | ** Start monthly money collection: | |
| | Check *Motivation* | |
| | ***If <3:*** | |
| | Update *Monthly money collection?* (to False) | |
| | Go to *next phase* | |
| | ***If >=3:*** | |
| | Check *WP Management level* | |
| | ***If <2:*** | |
| | Update *Monthly money collection?* (to False) | |
| | Go to *next phase* | |
| | ***If =2:*** | |
| | Update *Monthly money collection?* (to True) | |
| | Check *WP user list* | |
| | Request *$/month*[101] | |
| | Receive *$/month*[102] | |
| | Update *bank balance* | |
| | Go to *** | |
| | | |
| | ***Check mean relative budget (received$/requested$) | |
| | ***If relative budget mean is >=1/6*** | |
| | Go to *next phase* | |
| | ***If relative budget mean is <1/6*** | |
| | Update *Motivation (*current Motivation -1)[103] | |
| | Decide to ask *collection support*[104] (40% chance[105]) | |

[99] When WUC does (not) become active, then he updates the WUs of his WP on this fact.
[100] See Table 18
[101] To WUs of the WP users list.
[102] When programming the model it is important that the WUs can react on a request for money right away. If that is not possible, the WUC needs to 'check for received money' after the request for money. This note is applicable for money requests which are monthly or incidental.
[103] It is chosen that the motivation of the WUC only negatively influenced when the relative budget for a **repair/monthly collection is =<1/6, so not in case of a Maintenance money request, because the relative budget for the Maintenance and Repair will be the same at a certain moment.**

| | | |
|---|---|---|
| | ***If False:*** | |
| | Go to the *next phase* | |
| | ***If True:*** | |
| | Receive *Requested $/month* | |
| (direct debit) | Update *bank balance* | |
| | Update *Motivation* (current Motivation +1) | |
| | | |
| **Evaluation phase** | Check request for *WP user list* | 1x day |
| | ***If False***: | |
| | Go to *Check for… level request* | |
| | ***If True***: | |
| | Send *WP user list* | |
| | | |
| | Check for *Motivation and Knowledge level request*[106] | |
| | ***If True:*** | |
| | Send *Motivation and Knowledge level* | |
| | ***If False:*** | |
| | Go to the *next phase* | |
| | | |
| **Sanctioning phase** | Check *Fine/Incentive/Salary* | 1x day |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Update *bank balance* | |
| | Update *Motivation* (current Motivation + 1) | |
| | | |
| **Request Phase** | Check *Status Information* | 1x day |
| | ***If True***: | |
| | Go to *next phase* | |
| | ***If False***: | |
| | Check *Assessment requested* | |
| | ***If True***: | |
| | Go to *next phase* | |
| | ***If False***: | |
| | Check *M4W policy* | |
| | ***If False***: | |
| | Send request for *failure assessment (live)* | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | ***If True***: | |
| | Check *mobile* | |
| | ***If False***: | |
| | Send request for *failure assessment (live)* | |

[104] This is requested to the Local Government.
[105] This percentage is chosen by the designer.
[106] By the local government

| | | |
|---|---|---|
| | Update *Assessment requested* to True | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | ***If True***: | |
| | Check *mobile preference?* | |
| | ***If False***: | |
| | Send request for failure assessment (live) | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | ***If True***: | |
| | Request *ID information*[107] | |
| | Receive *ID information + ID transferring noise* | |
| | Send request for *failure assessment+ ID +ID noise*[108] | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? Update to WUs of WP user list* | |
| | | |
| **New WP Phase** | Check *new WP policy* | 1x day |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check *Request new WP*?[109] | |
| | ***If True***: | |
| | Go to *next phase* | |
| | ***If False***: | |
| | Check *mean Dependency of Group 1 and 2* | |
| | ***If <4:*** | |
| | Go to *next phase* | |
| | ***If >=4:*** | |
| | Check *WP Management knowledge* | |
| | ***If =2:*** | |
| | Update *Request new WP*? (to True) | |
| | Send *Request new WP*[110] | |
| | ***If <2:*** | |
| | Go to *next phase* | |
| | | |
| **Maintenance phase** | Check received *Maintenance policy and HPMA policy* | 1x day |
| | ***If False***: | |
| | Go to *Check Maintenance… HPMA policy* | |
| | ***If True***: | |
| | Update *Maintenance and or HPMA policy* | |
| | | |
| | Check *Maintenance policy and HPMA policy (True, 2)* | |
| | ***If False***: | |

[107] To particular WP
[108] To Database of failed WPs
[109] If true, the WUC can make the calculation that is necessary for requesting a new WP.
[110] To Local Government

| | | |
|---|---|---|
| | Go to *next phase* | |
| | ***If True***: | |
| | Check *Maintenance contract*?[111] | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Go to Check received … *$/4 months* | |
| | ***If False***: | |
| | Check *Motivation* | |
| | ***If <3:*** | |
| | Go to the *next phase* | |
| | ***If >=3:*** | |
| | Check *WP Management knowledge level* | |
| | ***If <2:*** | |
| | Go to the *next phase* | |
| | ***If =2:*** | |
| | Request *Maintenance contract* | |
| | | |
| | Check received *confirmation of Maintenance contract* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Update *Maintenance contract?* To True | |
| | Go to Check received … *$/4 months* | |
| | | |
| | Check received *request for $/4 months* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check *bank balance*: | |
| | ***If >= $/4 months:*** | |
| | Update *bank balance (-$/4 months)* | |
| | ***If < $/4 months:*** | |
| | Request *$/4months*[112] | |
| | Receive *$/4months* | |
| | Update *bank balance* | |
| | Check *bank balance >= $/4 months* | |
| | ***If False:*** | |
| | Go to *Check mean relative budget* | |
| | ***If True:*** | |
| | Send *$/4 months* | |
| | Update *bank balance (-$/4 months)* | |
| | | |

[111] This is a property of the WUC that shows whether the WUC to wants to invest time in maintenance or not.
[112] To WUs of the WP users list.

| | | |
|---|---|---|
| | Check *mean relative budget* (received$/requested$) | |
| | ***If relative budget mean is >=1/6*** | |
| | Go to *next phase* | |
| | ***If relative budget mean is <1/6*** | |
| | Decide to ask *collection support*[113] (40% chance[114]) | |
| | ***If False:*** | |
| | Go to the *next phase* | |
| | ***If True:*** | |
| (direct debit) | Receive Requested *$/4months* | |
| | Update *bank balance* | |
| | Send *$/ 4 months* | |
| | Update *bank balance* | |
| | Update *Motivation* (current Motivation +1) | |
| | | |
| **Assessment Phase** | Check received *Assessment + Request $ repair* | 1x day |
| | ***If False***: | |
| | Go to *END phase* | |
| | ***If True***: | |
| | Check *bank balance*: | |
| | ***If >$ repair:*** | |
| | Update *bank balance (-$ repair)* | |
| | Send *$ repair money and confirmation* | |
| | ***If < $ repair:*** | |
| | Request *$ repair*[115] | |
| | Receive *$ repair* | |
| | Update *bank balance* | |
| | Check *bank balance >= $ repair* | |
| | ***If False:*** | |
| | Go to *Check mean relative budget*[116] | |
| | ***If True:*** | |
| | Send *$ repair* | |
| | Update *bank balance (-$ repair)* | |
| | | |
| | Check mean relative budget (received$/requested$) | |
| | ***If relative budget mean is >= 1/6*** | |
| | Go to next phase | |
| | ***If relative budget mean is <1/6*** | |
| | Update Motivation (current Motivation -1)[117] | |

[113] This is requested to the Local Government.

[114] This percentage is chosen by the designer.

[115] To WUs of the WP users list

[116] **As long as a $/information request is not granted, the request remains until the point that the request has been granted.**

[117] It is chosen that the motivation of the WUC only negatively influenced when the relative budget for a repair/monthly collection is =<0,49, so not in case of a Maintenance money request, because the relative budget for the Maintenance and Repair will be the same at a certain moment.

| | | |
|---|---|---|
| | Decide to ask *collection support*[118] (40% chance[119]) | |
| | ***If False:*** | |
| | Go to the END phase | |
| | ***If True:*** | |
| | Receive *Requested $ repair* | |
| | Update *bank balance (+$ repair)* | |
| | Send *$ repair + confirmation* | |
| | Update *bank balance(-$ repair)* | |
| | Update *Motivation* (current Motivation +1) | |
| | | |
| **END phase** | | |

In the next section the water user will be described.

[118] This is requested to the Local Government.
[119] This percentage is chosen by the designer.

### 9.8.5 WU

The properties of the WUs are described in Table 27. First the location and network of the WUs is shown in the first box. The second box shows the policy that affects the decision making process of the WU (when implemented). The other properties come down to determining the WSL/dependency/satisfaction rate of the WU and activeness of the WU in case the WUC is inactive.

**Table 27 Properties of WU**

| | Variable | Type | Range |
|---|---|---|---|
| 1 | District | Integer | >=0 |
| 2 | WPs within 3 km (group A) list | List of integers (IDs) | |
| 3 | WPs within 1,5 km (group B) list | List of integers (IDs) | |
| 4 | WSLs of group A and B | List of integers (IDs) | |
| 5 | WUCs in group A and B | List of integers (IDs) | |
| 6 | HPMs in District | List of integers (IDs) | |
| 7 | WP user list | List of integers (IDs) | |
| 8 | Local Government ID | Integer | >=0 |
| 9 | M4W policy | Boolean | |
| 10 | Status information of group A and B list | List of integers | |
| 11 | Bank balance | Integer | >=0 |
| 12 | WUC Active? | Boolean | |
| 13 | Active? | Boolean | |
| 14 | Mobile | Boolean | |
| 15 | Preference for Mobile? | Boolean | |
| 16 | Assessment requested? (If Status Information is False) | Boolean | |
| 17 | Dependency | List of integers | |
| 18 | WSLs of group A and B list | List of integers | |
| 19 | Satisfaction towards WUC | List of integers | |
| 20 | Knowledge level WUC list | List of integers | |
| 21 | ID transferring 'noise' | Floating point | >=0, <=1 |
| 22 | Dependency increase (if Status information= False) | Integer | 1 |
| 23 | Dependency decrease (if Status information= True) | Integer | 1 |
| 24 | Knowledge level WUCs | List of integers | |

**Rules**

During the 'Water service basis phase' the WU sends requested information and updates inter alia its dependency rate, see Table 28. The second phase comes down to choosing the WP that has the highest WSL. The third part of the water service basis level gives a detailed description of how the WU chooses a WP if there is one or if there are more than one with the highest WSL.

If the WUC did not become active while the WP is broken, the WU can request the HPM to assess the failure. In the 'Assessment phase' the HPM asks the (active) WU to pay for the repair.

Table 28 Rules of WU

| Theme | Action/information | Timing |
|---|---|---|
| **Water service basis** | Check request *Dependency of its WUs* | 1x day |
| **phase PART 1** | ***If False:*** | |
| | Go to *Check received …. Knowledge level* | |
| | ***If True:*** | |
| | Send *Dependency (information)* | |
| | | |
| | Check received updates WUCs' WP Management knowledge level | |
| | | |
| | ***If False:*** | |
| | Go to *Check received … request? Updates* | |
| | ***If True:*** | |
| | Update *Knowledge level WUCs* | |
| | | |
| | Check received *Assessment request?* Updates | |
| | ***If False:*** | |
| | Go to *Check received… km list* | |
| | ***If True:*** | |
| | Update *Assessment request?* | |
| | | |
| | Check received NEW *WPs within 3 km list* (group 2 of WP) | |
| | ***If False***: | |
| | Go to * | |
| | ***If True***: | |
| | Update *Dependency* (Dependency+ received *Dependency decrease*) | |
| | | |
| | Update received *WSLs of group B list* | |
| | Update received *Status information of group B list* | |
| | Update Satisfaction (=WSL after x days) | |
| | | |
| | *Check received NEW *WPs within 1,5 km list* (group 1 WP) | |
| | ***If False***: | |
| | Go to ** | |
| | ***If True***: | |
| | Update *Dependency* (Dependency+ received *Dependency decrease*) | |
| | Update received *WSLs of group A list* | |
| | Update received *Status information of group A list* | |
| | Update Satisfaction (=WSL after x days) | |
| | | |
| **Water service basis** | **Check *received WSLs group A and B and Status information* | |
| **phase PART 2** | ***If False:*** | |
| **&** | Go to *Check received.. Dependency WU* | |
| **DWO New WP phase** | ***If True*:** | |
| & | Update *WSLs of group A and B and Status information* | |

| | | |
|---|---|---|
| **DWO large repair** | | |
| & | Check received *updates Satisfaction and Dependency WU* | |
| **Maintenance phase** | ***If True***: | |
| **&** | Update particular *Satisfaction* (increase after installation new WP, Large/Normal repair, Maintenance) | |
| **HPM repair phase** | | |
| | Update received *Dependency* (decrease after installation new WP, Large/Normal repair OR increase after if received Status information is False). | |
| | | |
| | | |
| | ***If False***: | |
| | Go to the '*Select highest… and Status*' | |
| | | |
| **Water service basis** | Select highest WSL and Status (= True) | |
| **phase PART 3** | ***If 1 with highest WSL:*** | |
| | Request *Status Information* (is equal to requesting water) | |
| | | |
| | Check received *Status Information* of particular WP | |
| | ***If True*** (water is coming out): | |
| | Go to next phase | |
| | ***If False*** (water point is broken): | |
| | Update *Status information of group A and B list* | |
| | Check *Assessment request?*[120] | |
| | ***If True:*** | |
| | Go back to ** | |
| | ***If False:*** | |
| | Check received *update WUC Active?* | |
| | ***If True***: | |
| | Go back to ** | |
| | ***If False***: | |
| | Become *Active? (0,01%, Boolean)* | |
| | Update *Active* | |
| | Go back to ** | |
| | | |
| | ***If >1 with highest WSL:*** | |
| | Select random WP (with highest WSL) | |
| | Request *Status Information* | |
| | Check *Status Information* of particular WP | |
| | ***If True***: | |
| | Go to next phase | |
| | ***If False***: | |
| | Send update *Status information of group A and B list* | |
| | Check *Assessment request?* | |
| | ***If True:*** | |
| | Go to ** | |
| | ***If False:*** | |

[120] If the Assessment request is true, the HPM is informed about the breakdown.

| | | |
|---|---|---|
| | Check received *update WUC Active?* | |
| | ***If True***: | |
| | Go back to ** | |
| | ***If False***: | |
| | Become *Active? (0,01%, Boolean)*[121] | |
| | Update *Active* | |
| | Go back to ** | |
| | | |
| **Monthly contribution** | Check received *request $/month* | 1x day |
| **phase** | ***If False***: | |
| | Go to *Check received Obligation… $/month* | |
| | ***If True***: | |
| | Determine *Relative budget* | |
| | Determine *$/month*[122] | |
| | Send *$/month* | |
| | Update *bank balance* | |
| | | |
| | Check received *Obligation to pay WUC the requested $/month* | |
| | ***If False***: | |
| | Go to the next phase | |
| | ***If True***: | |
| | Send $/month | |
| | Update bank balance | |
| | | |
| **Request phase** | Check *Active?* | 1x day |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check *Status Information* | |
| | ***If True***: | |
| | Go to *Assessment phase* | |
| | ***If False***: | |
| | Check *Assessment requested?* | |
| | ***If True***: | |
| | Go to *** | |
| | ***If False***: | |
| | Check *M4W policy* | |
| | ***If False***: | |
| | Send request for *failure assessment*[123] (live) | |
| | Update *Assessment requested?* to True | |
| | Send *Assessment request? update to WUs of WP user list* & WUC | |
| | | |
| | ***If True***: | |

[121] It needs to be sought out what happens if two water users become active with the same WP.
[122] Requested money * relative budget
[123] To HPM

| | | |
|---|---|---|
| | Check *mobile* | |
| | ***If False***: | |
| | Send request for failure assessment (live) | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? update to WUs of WP user list* & WUC | |
| | | |
| | ***If True***: | |
| | Check *Mobile preference?* | |
| | ***If False:*** | |
| | Send request for *failure assessment (live)* | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? update to WUs of WP user list* & WUC | |
| | | |
| | ***If True***: | |
| | Request *ID information* | |
| | Receive *ID information* | |
| | Send request for *failure assessment +ID +ID noise* [124](M4W) | |
| | Update *Assessment requested* to True | |
| | Send *Assessment request? update to WUs of WP user list* & WUC | |
| | | |
| | | |
| | ***Check *Error SMS* | |
| | ***If True***: | |
| | Update *Assessment request?* To False | |
| | Send *Assessment request? update to WUs of WP user list* & WUC | |
| | | |
| | ***If False***: | |
| | Go to *next phase* | |
| | | |
| **Assessment Phase** | Check received *Assessment + Request $ repair* | 1x day |
| | ***If False***: | |
| | Go to Check *received … request repair* | |
| | ***If True***: | |
| | Check *WP user list* | |
| | Request *$ repair*[125] | |
| | Receive *$ repair*[126] | |
| | Update *bank balance (- $ repair)* | |
| | Send *$ repair and Confirmation* | |
| | Update *bank balance* | |
| | | |
| | Check *received $ request repair* | |
| | ***If False***: | |
| | Go to Check received … *requested repair $* | |

[124] To Database of failed WPs
[125] To WUs of the WP users list
[126] It is assumed that all the WUs will pay their contribution if it is started by a WU.

| | | |
|---|---|---|
| | ***If True***: | |
| | Determine *Relative budget* | |
| | Determine *$ repair* | |
| | Send *$ repair* | |
| | Update *bank balance* | |
| | | |
| | Check received *Obligation to pay WUC the requested repair $* | |
| | ***If False***: | |
| | Go to the *END phase* | |
| | ***If True***: | |
| | Send *$ repair* | |
| | Update *bank balance* | |
| | | |
| **END phase** | | |
| | | |

The following interactor that is described is the Local Government.

### 9.8.6 Local government

In Table 29 the location and network of the local government is shown. In the second box the policy that affects the decision making process of the local government is shown. The other properties are important for the evaluations and Conditional Grant proposals.

**Table 29 Properties of local government**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | District | Integer | >=0 |
| **2** | WUCs in district | List of integers (IDs) | |
| **3** | WPs in district | List of integers (IDs) | |
| **4** | WUs in district | List of integers (IDs) | |
| **5** | HPMs in District | List of integers (IDs) | |
| **6** | Local Government ID | Integer | >=0 |
| **7** | Sanctioning policy? | Boolean | |
| **8** | Status information | List of integers | |
| **9** | WP user list | List of integers | |
| **10** | Request list (of repairs and assessments) | List of integers | |
| **11** | Conditional Grant proposal | List of integers | |
| **12** | Motivation threshold of replacing WUC | Integer | >=0 |
| **13** | Replace WUC? | Boolean | |
| **14** | Ranking HPM and WUC | List of integers | |
| **15** | New WP request list | List of integers | |
| **16** | Large repair request list | List of integers | |
| **17** | Update DWO on requests? | List of integers | |
| **18** | Motivation WUCs | List of integers | |

**Rules**

In Table 30 the first theme is the 'Water service basis phase' this phase entails potentially replacing the current WUC. The second phase describes that the local government can be asked to assist in the money collection for the repair/maintenance of a WP. The remaining four phases describe how the local government informs the DWO on the new WP requests/large repairs and the Conditional Grant proposal.

**Table 30 Rules of local government**

| Theme | Action/information | Timing |
|---|---|---|
| **Water service basis** | Check received '*inactive WUC*' information | 1x day |
| **phase** | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Check if particular *WUC Motivation< Motivation threshold* | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Determine to *replace WUC or not (1% chance*[127]) | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Send *WUC replacement information* | |
| | | |
| **Monthly contribution** | Check received request *money collection support* | 1x day |
| **phase** | ***If False***: | |
| **& Request** | Go to the *next phase* | |
| **Maintenance phase** | ***If True***: | |
| **& Assessment phase** | Check *WP user list* | |
| | Send *Obligation to pay WUC the requested amount* | |
| | | |
| **Evaluation & DWO** | Check received request for *Conditional Grant proposal* | 1x day |
| **grant phase** | ***If True***: | |
| | Send *Conditional Grant proposal* | |
| | ***If False***: | |
| | Request *Status Information* | |
| | Request *List of Repairs and Assessments*[128] | |
| | Request *WP user list* | |
| | | |
| | Check Received *List of Repairs and Assessments*[129]*, Status Information*[130]*, WP user list*[131] | |

[127] This percentage is chosen by the designer, not founded in literature, but it seems to be rare that a Local Government takes this action (Bey 2014).
[128] Request 'request list (of repairs and assessments)' from the HPM
[129] Of the two HPMs
[130] Of the districts' WPs

| | | |
|---|---|---|
| | ***If False***: | |
| | Go to *Sanctioning policy?* | |
| | ***If True***: | |
| | Update *Conditional Grant Proposal* | |
| | | |
| | Sanctioning policy? | |
| | ***If False***: | |
| | Go to next phase | |
| | ***If True***: | |
| | Request WUC and HPM their Motivation and Knowledge level | |
| | Receive WUC and HPM their Motivation and Knowledge level | |
| | Update *WUC and HPM ranking* | |
| | Send *WUC and HPM ranking* | |
| | | |
| **New WP Phase** | Check received *requests New WP* | 1x day |
| | ***If True***: | |
| | Update *New WP request list* | |
| | ***If False***: | |
| | Go to the next phase | |
| | | |
| **Assessment phase** | Check received *requests Large Repair* | 1x day |
| | ***If True***: | |
| | Update *repair request list* | |
| | ***If False***: | |
| | Go to the next phase | |
| | | |
| **DWO Distribution** | Update DWO on requests (new WP and repairs)? (10% chance) | 1x day |
| **Phase** | | |
| | ***If True***: | |
| | Send Repair and New WP lists (requests) | |
| | ***If False***: | |
| | Go to the END phase | |
| **END phase** | | |
| | | |

[131] Of the districts' WUCs

## 9.9 Model design: Objects properties and model formalization

In this appendix the properties and the concept formalization of the objects are shown. First the properties of the water point is described, followed by a description of the Database of failed water points.

### 9.9.1 Water point

The properties of the WP are described in Table 31. The block shows the network and location around the WP. The other properties are related to determining the WSL of the WP.

**Table 31 Properties of WP**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | District | Integer | >=0 |
| **2** | WPs in district | integer (ID) | >=0 |
| **3** | 'his' WUC | Integer | >=0 |
| **4** | HPM in district | List of integers (IDs) | |
| **5** | DWO ID | Integer (ID) | >=0 |
| **6** | HPMA ID | Integer (ID) | >=0 |
| **7** | Functionality | Floating point | >=0, <=1 |
| **8** | ID transferring 'noise' | Floating point | >=0, <=1 |
| **9** | Functionality increase after Normal repair | Floating point | >=0, <=1 |
| **10** | Functionality increase after Large repair | Floating point | >=0, <=1 |
| **11** | Functionality increase after Maintenance | Floating point | >=0, <=1 |
| **12** | Daily Functionality decrease | Floating point | >=-1, <=0 |
| **13** | Water User list | List of integers (IDs) | |
| **14** | Crowding at WP | Integer | >=0, <=5 |
| **15** | Reliability | Integer | >=0, <=5 |
| **16** | Mean time between failures | Integer | >= 0 |
| **17** | Dates of failures and repairs list | List of integers (data) | |
| **18** | Distance | Integer | >=0, <=5[132] |
| **19** | Quality | Integer | >=0, <=5 |
| **20** | Quantity | Integer | >=0, <=5[133] |
| **21** | WUs within 1,5 km (group 1) | List of integers (IDs) | (static) |
| **22** | WSL for group 1 | Integer | >=0, <=5 |
| **23** | WUs between 1,5 and 3 km (group 2) | List of integers (IDs) | (static) |
| **24** | WSL for group 2 | Integer | >=0, <=5 |
| **25** | WSL decrease between group 1 and 2 | Floating point | >=-1, <=0 |
| **26** | Large repair threshold | Floating point | >=0, <=1 |
| **27** | Normal repair threshold | Floating point | >=0, <=1 |
| **28** | Status Information | Boolean | |
| **29** | Dependency increase (if Status information= False) | Integer | 1 |
| **30** | Dependency decrease (if Status information= True) | Integer | 1 |

[132] Group 1 distance rate is 5, group 2 distance rate is 3 and interactors further than 3 km do not receive a WSL for the SDI distance (distance rate 0)

[133] Group 1 quantity rate is 5, group 2 quantity rate is 3 and interactors further than 3 km do not receive a WSL for the SDI quantity (quantity rate 0)

**Rules**

In Table 32 it is shown how the WP updates it's functionality and WSL. Furthermore, the WP sends Status information, if requested, during the 'Evaluation phase'. In the 'Request phase' the WP can be asked to send it's WP ID number. In the final four phases, the WP gets a higher functionality level due to a repair/or maintenance.

**Table 32 Rules of WP**

| Theme | Action/information | Timing |
|---|---|---|
| **Water service basis** | Subtract *Functionality with Daily Functionality decrease* | 1x day |
| **phase** | Update *Functionality* | |
| | Is Functionality below *(large/normal) repair threshold*? | |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Determine *Large or Normal repair* [134] | |
| | Update *Status information* | |
| | Update *WSL to 0* | |
| | | |
| | Check receive request *water flow (status information*) | |
| | Update *Water User list* | |
| | Check *Status information* | |
| | ***If False***: | |
| | Send *WSL to group 1 and 2* | |
| | Update *Dates of failures and repairs list* | |
| | Send *Status information to WUC and group 1&2 (False)* | |
| | ***If True***: | |
| | Send *Status information to WUC and group 1&2 (True)* | |
| | Send *requested water (status information) to particular WU* | |
| | | |
| **Evaluation phase** | Check request for *Status information* | 1x day |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Send *Status information* | |
| | | |
| **Request phase** | Check request for *ID information* | 3x day |
| | ***If False***: | |
| | Go to *next phase* | |
| | ***If True***: | |
| | Send *ID Information + ID transferring 'noise'* | |
| | | |
| **Assessment phase** | Check request for *Detailed Status information* | 3x day |
| | ***If False***: | |
| | Go to *next phase* | |

[134] Assumption should be made on the chance distribution of a normal or large repair.

| | | |
|---|---|---|
| | ***If True***: | |
| | Send Detailed Status information | |
| | | |
| **HPM repair phase** | Check received spare parts and repair | 3x day |
| | ***If False***: | |
| | Go to *Check received… its WUs* (1) | |
| | ***If True***: | |
| | Request *Dependency of its WUs* | |
| | | |
| | Check received *Dependency of its WUs (1)* | |
| | ***If False:*** | |
| | Go to the *next phase* | |
| | ***If True:*** | |
| | Update *Dependency group 1 and 2* | |
| | a. Calculate amount of families (group 1 & group 2) | |
| | b. Update mean dependency of group 1 and group 2 | |
| | Update *Crowding* by dividing a with b and compare to *Table A*[135] | |
| | | |
| | Update Dates *of failures and repairs list* (henceforth: *FR list*) | |
| | Update *Mean Time Between Failures (MTBF)* with *FR list* | |
| | Update Reliability with *by using MTBF in Table B* [135] | |
| | | |
| | Update *WSL* of WP for group 1 and 2 by taking lowest Service Level of the WSL indicators. | |
| | | |
| | Send *WSL to group 1 and 2* | |
| | | |
| | Update Functionality with *Func. increase after Normal repair* | |
| | Update *Status Information* to True | |
| | Send *Dependency decrease* | |
| | Send *Status Information* to WUC and group 1 and 2 | |
| | | |
| | Send *WSL update and (with delay) Satisfaction update* | |
| | | |
| **Maintenance phase** | Check receive Maintenance | 3x day |
| | ***If False***: | |
| | Go to next phase | |
| | ***If True***: | |
| | Update Functionality with *Func. increase after Maintenance* | |
| | Send *WSL update and (with delay) Satisfaction update* | |
| | | |
| **DWO New WP** | Check received *New WP and Installation new WP* | 3x day |
| **installation** | ***If False***: | |
| | Go to next phase | |

[135] See Table 14 and Table 15 at page 154.

| | | |
|---|---|---|
| | ***If True***: | |
| | Set up WP: determine group 1 and 2 + all properties (states)[136] | |
| | Update *Status Information* (True) | |
| | Send *Dependency decrease* | |
| | Send *Status Information* to WUC and group 1 and 2 | |
| | Send *Satisfaction* | |
| | | |
| **DWO repair phase** | Check received spare parts and repair | 1x day |
| | ***If False***: | |
| | Go to *Check received… its WUs* (2) | |
| | ***If True***: | |
| | Request *Dependency of its WUs* | |
| | | |
| | Check received *Dependency of its WUs* (2) | |
| | ***If False:*** | |
| | Go to the next phase | |
| | ***If True:*** | |
| | Update Dependency group 1 and 2 | |
| | a. Calculate amount of families (group 1 & group 2) | |
| | b. Update mean dependency of group 1 and group 2 | |
| | Update *Crowding* by dividing a with b and compare to *Table A* | |
| | | |
| | Update Dates *of failures and repairs list* (henceforth: *FR list*) | |
| | Update *Mean Time Between Failures (MTBF)* with *FR list* | |
| | Update Reliability with *by using MTBF in Table B* | |
| | | |
| | Update *WSL* of WP for group 1 and 2 by taking lowest Service Level of the WSL indicators. | |
| | | |
| | Send WSL to group 1 and 2 | |
| | | |
| | Update Functionality with *Func. increase after Large repair* | |
| | Update *Status Information* to True | |
| | Send *Dependency decrease* | |
| | Send *Status Information* to WUC and group 1 and 2 | |
| | | |
| | Send *WSL update and (with delay) Satisfaction update* | |
| | | |
| **END phase** | | |

In the next section the Database of failed WPs is described.

[136] Determine WSL (by calculating/determining the different WSL indicators), District (same as WUC who requested the WP or random if environment (NGO) organized it) and related IDs, Functionality is setup as 1 (100% functionality), Group 1 and 2 (dependent on District and # of WUs in the district). Status information is one, True, Mean Time Between Failures and FR list are empty. The rest of the properties which are the same for all WPs.

### 9.9.2 Database of failed WPs

The states, see Table 33, specify and describe the Database of failed WPs more precise.

**Table 33 Properties Database of failed WPs**

| | Variable | Type | Range |
|---|---|---|---|
| **1** | List of District & related HPMs, WUCs & WPs | List of integers | |
| **2** | List of WP IDs | List of integers | |
| **3** | List of Database list | List of integers | |
| **4** | ID transferring 'noise' | Floating point | >=0, <=1 |
| **5** | ID noise threshold | Floating point | >=0, <=1 |
| **6** | Error SMS | Text | |

**Rules:**

The Database of failed WPs can send an error SMS if the WP ID code is incorrect. Furthermore, it informs the necessary HPM. The database can also be entered by the DWO, to add to the Conditional Grant proposal, see Figure 34.

**Table 34 Rules of failed WPs**

| **Theme** | **Action/information** | **Timing** |
|---|---|---|
| **Request phase** | Check received *Request assessment* | 1x day |
| | ***If False***: | |
| | Go to next phase | |
| | ***If True***: | |
| | Check if ID transferring noise =/> ID noise threshold: | |
| | ***If True***: | |
| | Send *Error SMS* to sender | |
| | ***If False***: | |
| | Check *List of District & related HPMs, WUCs & WPs* | |
| | Send received *Request assessment*[137] | |
| | Update *Database list* | |
| | | |
| **DWO grant phase** | Check received *Request Database list* | 1x day |
| | ***If False***: | |
| | Go to the next phase | |
| | ***If True***: | |
| | Send *Request Database list* | |
| | | |
| **END phase** | | |

[137] To HPM who is in the same district as failed WP.

## 9.10 Validation

In this appendix the received feedback is shown. First, an overview of the feedback is given, followed with the exact received feedback.

**Validation of the case interviews**

The interviewees were asked to check the interviews summaries on content. The revised interviews[138] are included in the appendix 9.6. Together the interviews give a complete picture of the current water services delivery system. The interview itself (the questions, set up etcetera) is validated by Maartje E.D. van den Boogaard, who is a researcher at the Technical University in Delft and a teacher in interview techniques. Her recommendations are all taken into account and the adjusted version of the interview is shown in appendix *Interview setup for IRC's Water* Services Experts.

**Validation of the pattern of interactions figures**

In Appendix 9.10.1 and 9.10.2 the feedback on the pattern of interaction (Figure 25 till Figure 38) is validated by Uganda expert Valerie de Bey.

**Valerie de Bey – *16-01-2014***

A summary of Valerie de Bey's comments is given in this paragraph. First of all, the readability of the figures had to be improved, as several different colored arrows were present in the figures. This is adapted to two colors (one for information streams (fact memes) and one for actions (regulation memes)). Furthermore, she commented that the local government had to be included in the action arena, as they prepare the Conditional Grant proposal for the DWO.

In the' Basis phase' there should be some requests added:

1. The HPMA should also have a possible input of management knowledge.
2. There should be a standard (possible) stream of payment for day-to-day services, from the WU to the WUC. The WUC can also have the money, before they ask for an assessment.

An assessment request list and a repair request list can be created or the assessments should be included in the current 'Request List'. Updates of assessment requests should also be included in the current Flow diagram.

Valerie also commented that in reality the WUC can also ask for support of the local government in requesting people to pay for the repair/maintenance. This additional information is very valuable as this helps the WUC (who is motivated) out of the negative vicious cycle, because the relative budget that people are willing to pay (which can be 0%) is forced up. Now, the WUC can pay a repair and change the vicious cycle upward.

Finally, the WU's sanction (a relatively low budget) should motivate or demotivate the WUC.

[138] The interview summary of Peter Magara is not checked on its content.

These points of reflection seem to be valuable to the model design and are therefore added to the model design.

**Validation of the model conceptualization and formalization**

In appendix 9.10.2 the complete validation by Deirdre Casella and Kristof Bostoen is shown. Here the main points of validation are summarized, starting with Deirdre's comments (16-02-2014).

From Deirdre's perspective the model conceptualization and formalization is satisfactory valid enough in light of the identified problem. She suspects that only in the next step of coding and building an agent-based model flaws in the logic or assumptions will be revealed.

A broader point of reflection is that choices are made to frame the 'problem' which determined how the system is decomposed. In this model design the *community management model* of rural water services delivery is incorporated. The national policy of Uganda is however heading towards a service delivery management model based upon networked piped water schemes. This subject should be included in a following model.

**Kristof Bostoen – 20-2-2014**

In the appendix 9.10.2 it can be read that Kristof thinks that the model design is a nice piece of work, that describes a relatively complex process. He is, however, also interested in a model that is more generic and less focused on Uganda. '*However, it is impossible to make this model complete formal as it is quite complicated there are issues I would simplify, implement differently while others I would probably extend. Some differences we would not even agree amongst yourself in IRC. All this to explain reading this was tricky not to speak of a complete different language'.*

The suggestions on improvement of the model design are very useful for the Master student that will take over my 'job'. A few examples of improvements are mentioned below, the rest can be read in appendix 9.10.2.For example, Kristof states that there should be more payment modalities, at least:

- Pay as you go (price per volume)
- Fixed monthly fees as in the model

Furthermore, Kristof states that due to the fact that the WP is inert, the WP cannot communicate its functionality to the WUC. Kristof thinks that the dysfunction should be communicated by a WU that notices that the WP is broken down. The designer (S. van Tongeren) simplified this interaction by letting the object communicate with the WUC and WU directly, because it does not seem important that the WU in person tells the WUC that the water points broke down.

It also did not become clear to Kristof what the relation is between the WU and a household.

*The designer chose to model one water user as one household.*

Finally, two important comments by Kristof are:

- Changeable probability, of for example the likelihood of using SMS to report a problem, needs to be incorporated.

- More random behavior should be incorporated in the model design, to simulate that not everything is logical.

These points are valuable for the model design. Currently the model design is not adapted in line with the comments. However, for the modeler, who is continuing this project, it is valuable input.

### 9.10.1 Feedback on Flow diagrams of IRC expert

*Valerie de Bey at 16-01-2014*

The Sub-County staff should be included. The Sub-County staff prepare the Conditional Grant proposal for their Sub-county, with the information of the Parishes. So, the Local Governments (including Sub-County and Parishes) needs to be added to the flow diagrams.

Why is the Database a separate thing? Answer: The Database can either exist or not, depending on the M4W policy. In other words, the environment influences the possible existence of the Database.

There should be a difference made between actions and information streams. Now there are sort of random colored arrows, which have to change to logical colored arrows.

In the Basis phase there should be some requests added.

1. The HPMA should also have a possible input of management knowledge.
2. There should be a standard (possible) stream of payment for day-to-day services, from the WU to the WUC. The WUC can also have the money, before they ask for an assessment.
3. Around 1/3 of the WUCs are currently inactive.

It looks weird that the User List is updated by the WU himself. Why is that? Answer: It is a simplification. Normally the user information is received by the WUC and the WUC updates the User List.

An Assessment request list and a repair request list can be created or the assessments should be included in the current 'Request List'. Updates of assessment requests should also be included in the current Flow diagram.

In reality the WUC can also ask for support of the local government in requesting people to pay for the repair/maintenance. (Simone:)This helps the WUC (who is motivated) out of the negative vicious cycle, because the relative budget that people are willing to pay (which can be 0%) is forced up. Now, the WUC can pay a repair and change the vicious cycle upward.

WU sanctioning (which is a relative low budget) should be motivating for the WUC to do their job better.

### 9.10.2 Feedback on model conceptualization and formalization

In this section the validation of both Deirdre Casella (IRC employee) and Kristof Bostoen (IRC employee) are presented.

#### *Deirdre Casella at 16-02-2014*

Thanks so much for providing me the chance to validate the model you have been conceptualizing on behalf of Triple-S.

From my perspective, the patterns of interaction and the description of the interactors in the model that you have conceptualized are satisfactorily valid enough in light of the identified problem of failure of infrastructure to the deliver water service levels for which it was originally designed and also in light of the decomposition of the socio-technical system for rural water services delivery in Uganda that you have made.

In fact, I suspect that only in the next step of coding and building (a portion of) an ABM will any flaws in the logic or assumptions be revealed. But now, with what you have created, a useful model could conceivably be created.

A broader reflection I have is about the need for this following point to be as explicit as possible in the description of the scope of the thesis:
We made choices about how to frame the 'problem' which determined how the system was decomposed.

In designing this model we chose to conceptualize the *community management model* of rural water services delivery and its current state of existence as the predominant model for water services in rural Uganda.

As a result the focus is on 'water points' with a choice made for the most common type for communally managed rural water points: namely bore hole with hand pump which led logically to the fact that HPM & HPMA are included among the relevant interactors.

I can hear you thinking now: "OK, Casella, where are you going with this ☺". So here we go:

We know that Uganda national policy is heading towards a service delivery management model based upon networked piped water schemes with pipe stands, even in remote rural areas - so gone will be the days of the community managed bore hole and hand pump services systems.
That is obviously a good subject for a following model (for exploratory purposes and comparison of 'management and provision of services when the infrastructure changes to piped schemes run by private operators with stronger government regulation).

My suggestion is that somewhere in the discussion of relevance of this model to policy dialogue this foreseen transition should to be acknowledged - that the designed model is based upon the community management model of a particular type of infrastructure / technology since it is the predominant model of service delivery currently. But that we acknowledge that in the not too distant future a different management model will emerge as the sector aims to transition to another infrastructure.

## *Kristof Bostoen at 21-2-2014*

This feedback on the code from chapter 5 of the version of the thesis printed on 10/02/2014. All other comments were given orally to Simone.

Overall I found this a good attempt to describe a relatively complex process. The model is very much geared to Uganda as asked but with some more attention it could take into account more generic approaches. It caters to explaining the current issue but the pseudo code as written does not allow to look at various alternative scenarios yet. None of that was asked from Simone so this is not a criticism to what she did which as far as I can judge is an incredible good start for somebody that needs to take this up. It is clear that the code itself will allow to draft a model but it seems that even those persons will need some support to do this.

**Overall**

A nice piece of work in particular if one does not have the luck of working in the field for two decades like most of us. One of the problems in the model as it is written is that all is based on rules and logic based but in reality that is not the case. Or to put it differently, some of the issues seems not fitting our logic or a logic we can understand so they might well considered random in our eyes which is not well represented in the current model. Some suggestions are made to consider this below.

While it is impossible to make this model complete formal as it is quite complicated there are issues I would simplify, implement differently while others I would probably extend. Some differences we would not even agree amongst yourself in IRC. All this to explain reading this was tricky not to speak of a complete different language.

At a certain point I looked more to if somebody who has to make a model would be helped and could make something out of it without redoing the work Simone did. And largely I believe that would be the case.

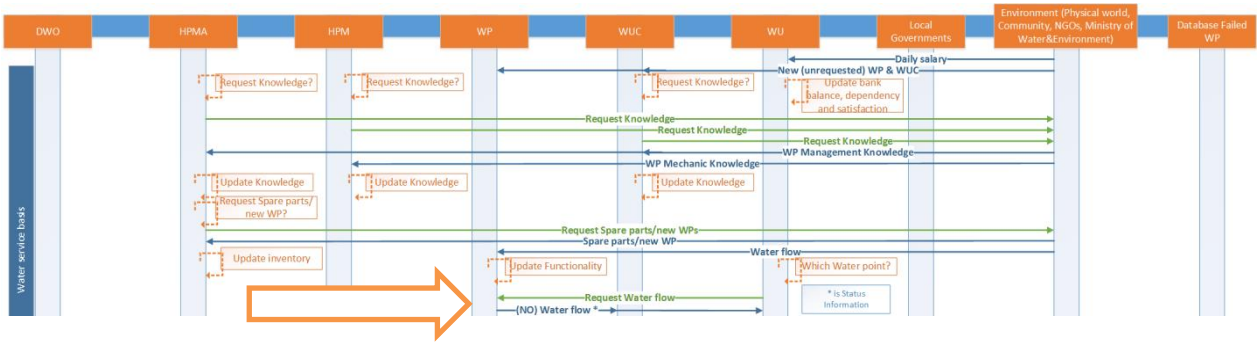
One of the problems I see with the validation of the model by sector specialist is that there is no plain text description of actions and interaction in kind of format that allows to see the structure of the model. The form of pseudo code used is already.

For all the figures discussed below the second “column” from the right covering the environment has too many different actors in it which make guessing which particular actor is mean not always easy.

Often you convert integers into categorical variable where this is not always required. Again not wrong with such approach but it seem limiting the possibilities of the model.

**Figure 21 - (NO) Water Flow**

Related “* is Status information” and the arrow from WP -> WUC




The arrow should come from the users who inform the WUC not the pump itself as in the same way the HPM could inform the WUC but the probability of a user to inform the WUC is larger as there are more users than HPM and the WU have a need and incentive to inform the WUC.

**WUC payment policy**

While understand the underlying function I do not understand the description. I do get the activation/not activation of the WUC and the request of "power" by the WUC to the local government.

**$/month**

WU -> WUC a monthly fee which is only one kind of payment modality. The reality is that there is important variations in such payments that depending on policies have different consequences might in your model be an oversimplification (or limits its use in other contexts). I think there are two modalities that I think the model should at least have:

- Pay as you go (price per volume)
- Fixed monthly fees as in the model

What is not clear to me in the model is the relation of the WU with the household, is that expressed in large water consumption of the WU for example as this could also relate to fees proportional to HH size?

**Figure 22 – WUC payment policy**

WUC do not get a salary to my knowledge (although I see the interview you had say they should :-) but get some payment in kind (chicken, a goat bag of dried corn) from the community which they serve. This is often a one-off one (not periodically like e.g. monthly) for doing the work so the only meaningful sanction is take them out but that happens mostly at the end of their term so there is some lag time between the request of the sanction and the actual sanction.

So the DWO -> WUC give fine/incentive/salary to WUC is in most cases the community of WU -> WUC or traditional leaders who most of the time do things in consultation with the same users.

In the model all is built on logic which in reality is true but not necessary your logic so you will need to a probability that the policy is not executed like you stipulated which is best done by adding a stochastic element with a low (but changeable) probability. These actions are not random but to us they seem that way as we cannot understand the complex pattern. So the simplification is adding random behavior in some of the links in your model.

**Figure 23 – increase of likelihood**

The likelihood of using SMS to report a problem will increase (apart if the cost of the SMS is absorbed by M4W) if people saw something happening the last few times they sent a message. Not having any reaction will quickly result in a reluctance to invest in reporting.

The “$ maintenance cost” van WU -> WUC are extra cost on top of monthly fees?

**Figure 24 – Inert WP**
Assuming the WP is inert, information can only come to the HPM if he visits the pump or the information is given to the HPM by M4W or another person...

**Page 55-6**
Nice description of the DWO but the capacity to do this is often lacking. I assume that level of ability is ruled by the requests for knowledge of figure 21?

**Table on page 57**
Fact memes (states). This is me being very pedantic but should your table not look like this for list?
Variable:
HPM in district
Type:
Integer (ID’s)
Range:
List of ..

From here I looked for obvious big “errors” as not all is easy to interpret and not all can be documented.

**Page 133 – Spare part 1&2**
I’m not sure such should be such discrete choices. Would this not be better served with a distribution of cost and a linked distribution of probability so changes can be easily implemented in various permutations of the model?

When I look at the code it is sometimes made too situation specific but that is logic as that is the only situation studied in this thesis.

**Page 72 – no response**
Interaction between the WU and the water authorities. While you think people would be willing to report they often do not because there has been very little happening after information is shared. The lack of capacity and the lack of reporting is in such a virtual circle that if all problems would be reported the sector has absolutely no way of reacting to them reinforcing the status quo. It would be good that the model allows to see how such circle could be breached. Not sure this way the code is written that is possible.

I think that having points around two circles at different distances might be computationally hard and in terms of modeling different situations limiting but it is a correct way of working.

**Page 77**
Again nothing wrong with the model but reduced functionality is not linear but more logarithmic with a kind of reset every time maintenance is done.

## 9.11 Assumptions of the model design overview

In this appendix the assumptions, which are made for the model design are summarized in Table 35 and Table 36.

**Table 35 Model design assumptions**

| Property | Agent-based model design assumptions overview |
|---|---|
| Conceptual framework | Here it is assumed that memes can be divided into two types: regulation memes and coding memes (henceforth fact memes), Figure 9. The way to respond to a cue (fact meme) is the way you govern certain information (regulation meme). |
| | The regulation memes are assumed to be institutions. |
| | It is assumed that the fact meme is information that triggers a certain regulatory meme and is transferred from one interactor to another with help of regulatory memes. What an interactor does when it receives a fact meme depends on its personal priority and known regulatory memes. An example of an fact meme is the number on your bank balance. |
| | A set of regulatory memes, that are triggered in sequence or parallel by the same fact meme, is seen as a routinized pattern of interaction. |
| | It is assumed that the decision to change the rules is given to the environment (the community). |
| | *It is assumed that an interaction incorporates the two types of memes.* |
| | *It is assumed that the decision to change the memes is given to the environment (the community).* |
| | In this thesis research the regulation meme can only be changed by the environment. |
| | The fact meme can be a (stimulating or repressing) selection pressure for another fact meme. |
| | The regulatory meme can be a (stimulating or repressing) selection pressure for another regulating meme. |
| | *Whether a meme is adopted in the individual memeplex depends on the controversy of the meme with respect to the current memeplex.* |
| | *The perspective of a person depends on the set of adopted memes and personal priorities of him/herself.* |
| | *Here, it is assumed that within an action arena the interactors interact with each other which helps to align the regulatory and fact meme scope.* |
| | Here it is assumed that the genotype of the routine stays the same as long as it is triggered by the same fact memes. |
| | The assumption is made that regulating and fact memes have a conditional generative mechanism and therefore can be seen as a generative replicator. |
| | The WUC payment policy can only be implemented if the Sanctioning policy is also implemented, because otherwise the WUCs can underperform without any sanction. |
| | Which WUs are assigned to a WP (close or far away) is a property of the WP. |
| | It assumed that a WU cannot be assigned to a WP that is situated further away than 3 km distance. |
| | Quantity rate is assumed to be 5 for group 1 and 3 for group 2. |
| | It is assumed that there are no abrupt breakages, so depending on the functionality distribution, which is determined during the setting up of the model and the received maintenance, the WP breaks down now or later. |
| | The Distance rate is that is received by group 1 is 5 and 3 for group 2. |

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| | The 'satisfaction with the WUC' (henceforth: satisfaction) and 'dependency on the WP' are assumed to be indirectly related to the water service level a WU receives from the WP. |
| | Motivation is assumed here to be the operationalization of 'personal priority'. |
| | Currently in the model design the speed of things is not measured, therefore, in case of the HPM, the M4W policy only causes a different route of information. |
| | An assumption of the service ladder is that the five service levels reflect the operational reality of an emerging water services delivery level. |
| | People do not receive any water service if the WP is further away than 3 km (Moriarty et al. 2011). |
| | Therefore the assumption is made that WPs can directly communicate with WUs and WUCs (which are appointed to the particular WP). |
| | It is chosen to model one water user as one household. |
| DWO | Because most DWOs are ambitious and want to have good relationships with his colleagues (Lieshout 2013), it is assumed that the percentage of DWOs who is influenced by LC5s' opinion is high. |
| | It is assumed that the salary and sanctions are all 7 USD , because that is the amount of money an average civilian in Uganda has left to spend after a month working (Smet 2013). |
| | However, the suggestion is made that the DWO has an income of 10.000 USD a year, so that the DWO can install around 4 new WPs and repair around 5 WPs (Bey 2013a; Bey 2013b). |
| HPMA | It is assumed that the HPMAs' motivation is: $\frac{\sum \text{Motivation (of HPMs of HPMAs' district)}}{\#\text{HPMs of HPMAs' district (which is 2)}}$. The reason for this average motivation is that the HPM together form the HPMA. |
| | In most districts a HPMA is present. It is assumed that the HPMA policy is always present and functions as a spare parts/new water points provider (policy level 1). If the HPMA is changed to level 2 (by the environment) the HPMA will also be able to compose a Maintenance contract. |
| | It is assumed that the environment has an inexhaustible amount of spare parts and new water points. It is chosen to bring the different types of spare parts back to two and for the water point types to one. Spare part 1 is for normal repairs (which is executed by the HPM) and spare part 2 is for a Large repair (which is executed by DWO). |
| HPM | It is assumed that motivation influences whether the HPM works or not. Due to cultural influences[139] the WUC does not request the HPM to do his job better if he is not motivated (Lieshout 2013).<br>○ The DWO can give the HPM a fine every month, if the Sanctioning policy is in place and the HPMs' motivation is below a certain threshold.<br>○ A fine/incentive will lift the HPMs' motivation with 1 point (with a range of 0 to 5). |
| | Finally, it is assumed that there is a constant amount of 2 HPMs per district (Magara 2013). |
| WUC | In the model design the WUC is not reelected because in reality. The WUC often gets reelected, for the current WUC has the most knowledge about WP management (Lieshout 2013). In the model design, the local government can, under certain conditions, assign a new WUC if inter alia the performance is too low. Zero motivation is chosen not to be possible when the WUC is just reelected. |

[139] For Ugandan people, often there is no rational explanation of why things happen. The superstition has an influence on the people ways of acting. If you sanction somebody, then you are scared that this person will send a bad spirit into your direction or that you get bewitched. *Evaluations of HPMs is for this reason not probable* (Lieshout 2013).

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| | There is a 0,01 chance that the local government replaces the current WUC. This percentage is chosen by the designer, not founded in literature, but it seems to be rare that a Local Government takes this action (Bey 2014). |
| | If the WP Management knowledge gets improved, it is assumed that the WP side gets better maintained. Therefore the Satisfaction of WUs gets updated after more knowledge is gained. |
| | The motivation of the WUC can be influenced by several factors:<br>3. 'Relative budget' WUs can demotivate the WUC. If the mean Relative budget is lower than 1/6 of the requested money, the motivation of the WUC will decrease with one point (motivation -1).<br>• If there is a negative vicious cycle, of WUs not willing to give money and low WSLs, the WUC can break this negative cycle by asking backup of the local government. They will make the WUs pay the amount of money the WUC asks them to (Bey 2014).This will give a positive boost to the WUC's motivation (motivation +1).<br>4. The motivation of the WUC can also get influenced by a sanction/salary of the DWO (motivation +1). |
| | The WUC becoming active or not depends on the WUC's Motivation, if the motivation of a WUC is 2 or lower (on a scale of 0 to 5), the WUC has a certain chance of becoming active. If the WUC has a higher motivation than 2, the WUC will always become active on that particular day. |
| | If the Motivation of the WUC is 3 or higher (on a scale of 1 to 5), the WUC will request WP Management knowledge, which will increase the ability of the WUC to manage their WP well. |
| | In the model design it is assumed that if the WUC succeeds to collect the necessary money, the WUC pays the HPM the full amount of money before the repair is executed. In reality it is paid in phases (Bey 2013b; Bey 2013a). |
| WU | 'Relative budget' of WUs is calculated as follows:<br>• Satisfaction of WU towards WUC= WSL (of x days ago).<br>○ The WSL is x days delayed before it influences the Satisfaction of WUs.<br>○ Satisfaction has a range between 0 and 5.<br>• Dependency = Amount of WPs a WU has in its reach (3 km).<br>○ 1 WP = 5, 2 WPs = 4 etc. 5 WPs = 1 and 6 WPs or more = 0<br>• Knowledge level WUC= Amount of knowledge on managing a WP.<br>○ The range in-between 0 and 2<br>• So, The relative budget is a floating point between 0 and 1.<br>• Maximum Relative budget = 12/12 = 1<br>$\text{Relative budget} = {\text{Satisfaction}}/{12} + {\text{Knowledge level WUC}}/{12} + {\text{Dependency}^{140}}/{12}$ |
| | It is assumed that if a WU becomes active and requests money for a repair to WUs from the WP users list, that all the WUs he asks it to will pay their share, as it is often the village leader who takes action (Bey 2013b). |

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| Local government | In reality the local government makes a selection of New WP requests that go to the DWO or not. This is chosen not to put that in the model design, as there are already many obstacles (Motivation rate and Knowledge level) before a WUC can request a new WP (Bey 2014). |
| | 'WUC and HPM ranking' orders the WUCs and HPMs their Motivation and Knowledge level from low to high. |
| WP | The knowledge level is assumed to go hand in hand with the level of proper care of the WP. However, it is assumed that the knowledge level of the WUC is taken into account for determining the relative budget. |
| | It is assumed that in Uganda there are just WPs with WUCs. These WUCs can be however active or inactive. |
| | Furthermore, there is no distinction made between protected and unprotected WPs, because unprotected water sources, just like protected ones, can have dirty water, can be crowded etc. So, the unprotected WPs get a Water Service Level, just like the protected WPs. |
| | Here it is assumed that it is possible to calculate the WSL of a WP (for a set group of WUs). |
| | It is assumed that people stay alive, even though the WSL is 0. In a later stage of the designing process it should be decided if it has additional value, if agents can die. |
| | Total families= WUs within 1,5 km (group 1) + WUs within 3 km (group 2)= A families<br>$\text{Dependency mean} = \frac{\sum \text{Dependency WP if WSL is} \geq 2 (\text{of A families})}{\text{A families}}$ |
| | The WSL of other WPs are taken into account while determining the WSL of a particular WP, as Crowding is related to the WSLs of WPs, which have overlapping WUs. So, determining the Dependency mean, WPs with a WSL of 2 or higher are taken into account. |
| | The Quality, Quantity and Distance are determined with the setup of the model and static afterwards, as group 1 and 2 stay the same. |
| | The Reliability Service Level is determined by calculating the Mean Time Between Failures (MTBF) with the help of the 'Dates of failures and repairs list' (henceforth: FR list). With the MTBF, the Reliability Service Level can be determined in Table B. |
| | These MTBF numbers are chosen in Table 15, because it is assumed that WPs most often break down after two years. |
| | Due to the relatively short period of ten years that the model will be running, it is assumed that WPs can be fixed. So, the new WPs are only requested if there the crowding at/dependency of the WP is too high. |
| Environment | The amount of water (flow) that is received from the environment is assumed inexhaustible at the moment, because this model doesn't describe the natural drought problem, to be but the water services delivery problem. |

[140] If a WU is dependent of 1 WP, the Dependency rate is 5. The Dependency rate has a range between 1 and 5. When a WU has 5 or more WP within 3 km distance, the rate is 1.

The information, gathered during the interviews, that is left out of the scope the model design are summarized in Table 36. In the third column the reason for not using the information is given.

**Table 36 Information that is left out of the scope of the model design.**

| ID | Piece of information | Reason for leaving out the model design |
|---|---|---|
| 1 | The DWO office is often understaffed. In an office there should be at least 5 members, however, there are often just 2 people running the office (Bey 2013b). | It seems that the amount of money the ministry gives is the main reason that causes a lack of personnel. |
| 2 | The DWO has information sharing moments with NGOs at a quarterly basis (DWSCC) (Bey 2013b). | This interaction is left out of the scope of the model design. |
| 3 | Women are often treasurers, because they see the importance of clean drinking water (Lieshout 2013) | Sexuality is left out of the scope of the model design. |
| 4 | Water collection is often done by women and children (Lieshout 2013) | Sexuality/age is left out of the scope of the model design. |
| 5 | Men often do not recognize the importance of WUCs and do not see the priority of clean drinking water (Lieshout 2013). | Gender related issues are left out of the model design. |
| 6 | The contractors always pay 10% of the value of the project to the contractor (Lieshout 2013). | Corruption is left out of the scope of the model design. |
| 7 | In the piped schemes, the Umbrella Organization (is association of Water Boards for piped schemes) staff pays a support visit every 3 month. The UO has taken away the burden for the piped schemes for the DWO (but is for 95% paid by the DPs). The DWO hopes that the HPMA is going to have a similar impact for the support to the hand pumps (Lieshout 2013). | Piped water schemes are left out of the scope as the main infrastructure in rural parts of Uganda are water points. |
| 8 | Resources are often well documented in the books, but often in reality there are a lot less resources available (Lieshout 2013). | This irregularity is left out of the scope of the model design. |
| 9 | They are proud of the way they do their work and they are not willing to change very easily or radically. They don't like experiments, you have to know what the effects are before starting the project, otherwise you are a bit stupid (Lieshout 2013). | This is left out of the scope of the model design, as the agent-based model can help to generate prove for a certain policy. |
| 10 | Distance is an important SDI, because if the distance is large it can give insecurities for women (Nabunnya 2013). | Gender related issues are left out of the model design. |
| 11 | At the village bank they can borrow a bit of money when they need to spend a bit more than they have. With some interest they will pay the lend money back (Nabunnya 2013). | This fact is left out of the model design as it seems that only a small percentage of WUCs do this. |
| 12 | Per households that pays the DWO is willing to pay 500 shilling per year (Nabunnya 2013). | This fact is left out of the decision of the DWO. |
| 13 | The Conditional Grant money that is most misused is the software money, that should organize meetings to share knowledge etcetera. These meetings are often not organized, because they don't find it important, do not have fulltime staff on the subject of water (at sub county level) (Nabunnya 2013). | Corruption (money misuse) is left out of the scope of the model design. |
| 14 | The road conditions/traffic is not very well organized, so it takes a long period to go from one place to another, especially in remote rural areas (Nabunnya 2013). | The time efficiency is not incorporated in the model design. |