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Achieving Sustainable Rural Water Services in Uganda
Collaborative Model-based Policy Analysis for Collective Reflection and Action

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Achieving Sustainable Rural Water Services in Uganda

Collaborative Model-based Policy Analysis
for Collective Reflection and Action

Achieving Sustainable Rural Water Services in Uganda

Collaborative Model-based Policy Analysis for Collective Reflection and Action

Dissertation

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chair of the Board for Doctorates
to be defended publicly on
Tuesday, June 15th, 2021 at 12.30 o'clock.

by

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An electronic version of this dissertation is available at http://repository.tudelft.nl/ and the underlying model conceptualisations may be found in 4TU.ResearchData repository.

Dedication

This work is dedicated to four people I deeply admire and who have gone before us.

- ❖ Maurice Conlin (1942-2020), much loved Uncle, *bona fide* Renaissance man.
- ❖ Ruie Arnett (1945-2013), dear family friend, Director of Management Services, University of California at Los Angeles, strong proponent of the pursuit of this PhD.
- ❖ Ton Schouten (1955-2016), dear friend and mentor, Triple-S project director from inception until 2011.
- ❖ Dr. Paul Nyeko Ogiramoi (1976-2016), respected colleague, Principal Engineer, Planning & Development, Uganda Ministry of Water and Environment, Directorate of Water Development.

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Acronyms and Abbreviations

ABM	- Agent Based Model
CAO	- Chief Administrative Officer
CapEx	- Capital Expenditure
CapManEx	- Capital Maintenance Expenditure
CAS	- Complex Adaptive System
CBO	- Community Based Organisation
CWO	- Community Water Officer
DCG	- District Conditional Grant
DLG	- District Local Government
DWO	- District Water Office
DWD	- Directorate of Water Development, Ugandan Ministry of Water & Environment
DWSSCC	- District Water Supply and Sanitation Co-ordination Council
DWSCG	- District Water and Sanitation Conditional Grant
GEMI	- UN Inter-agency Integrated SDG 6 Monitoring Initiative
GLAAS	- Global Analysis and Assessment of Sanitation and Drinking Water
GoU	- Government of Uganda
GWP	- Global Water Partnership
HPM	- Hand Pump Mechanic
HPMA	- Hand Pump Mechanic Association
IAD	- Institutional Analysis and Development framework
ICT	- Information, Communication Technology
IPCC	- Intergovernmental Panel on Climate Change
IWRM	- Integrated Water Resources Management
JMP	- Joint Monitoring Programme
LC	- Local Council
MAIA	- Modelling Agent systems based on Institutional Analysis
M4W	- Mobiles for Water
MWE	- Ministry of Water and Environment, Republic of Uganda
NGO	- Non-Governmental Organisation
RWSN	- Rural Water Supply Network

RWSS	- Rural Water Supply and Sanitation
SCWSSB	- Sub-county Water Supply and Sanitation Board
SDG(s)	- Sustainable Development Goal(s)
STS	- Socio-Technical System
TSU	- Technical Support Unit
UN	- United Nations
WASH	- Water, Sanitation and Hygiene (sector)
WHO	- World Health Organisation
WSC	- Water and Sanitation Committee
WP	- Water Point

Glossary of Terms

Term	How it is defined in this dissertation
Actor	A person, or individual, with a role to play and stake in water services.
Adaptive governance	An iterative processes of negotiated change and decision making through multi-actor processes of interaction in the context of complex and uncertain change processes.
Agent	An autonomous person or infrastructure artefact that interacts with other people or infrastructure.
Agent based model	A computer-based simulation constructed to discover possible emergent properties from a bottom-up perspective – the perspective of the agent.
Boundary object	A representational form, an artefact or a theory, shared between different communities, each of which holds a different understanding of the representation.
Decomposition	The process of identifying the system, its agents, their states, relationships, behaviours and interactions in order to be able to describe the system in more formal, specific terms that are both human- and computer-understandable.
Institution	Institutions are rules that are accepted by all those involved, are used in practice and have some sort of durability. After Ghorbani, 2013.
Meme	A unit of information.
Model narrative	The informal account of the generative theory of the system under study, leading to emergent patters of interest. After Dam et al., 2013.
Pseudo code	The description of an algorithm in human-readable form that bridges the gap between an informal model narrative and computer code. After Dam et al., 2013.
Service	The institutional, organisational and financial arrangements that collectively result in the delivery of water supply, electricity, health and other similar benefits and which require actions from multiple actors across different levels of governance.
Stagnating	The situation where a service level is demonstrably neither increasing, nor decreasing, but rather remaining at a steady performance rate despite increasing demands – such as population growth, expansion of human settlements, etc. - for an increase in the level of service.

Structure of this Dissertation

Chapter 1: Introduction

This chapter introduces the research topic and approach taken during this study of water supply in rural Uganda. The context of the research, the scope of the problem under consideration and theoretical lens of this research project are presented along with the key research questions of this research.

Chapter 2: Rural Water Services in the Republic of Uganda | A systems perspective

This chapter sets out the empirical field of this research. The prevailing policy framework and arrangements for the delivery of rural water services in the Republic of Uganda are presented and discussed from a socio-technical system perspective. The notion of adaptive governance is introduced

Chapter 3: The Research Approach, Timeline and Process

This chapter presents the approach to research taken during this research project. The 'state of the art' on useful theories of considering water services from a complexity perspective, involving multi-actor governance, learning and institutions for structuring insights into how change might arise in multi-level, multi-actor socio-technical systems. The research questions are revisited to guide the research approach, and the chapter introduces the timeline and key stakeholders of the research.

Chapter 4: Conceptualising rural water services in Uganda

This chapter details a conceptualisation of the rural water services system in Uganda. Drawing upon the Institutional Analysis and Development framework, a language to describe institutions and concepts from evolution, the work arrives at a consistent description of the system, its agents and the rules that influence agent interaction. This work presented in this chapter primarily addresses Research Questions 2 and 3.

Chapter 5: Case 1 | Water Services That Last model

This chapter describes an initial agent based model conceptualised to establish whether the chosen simulation method could serve as a useful medium for modelling the empirical problem of stagnating water points in rural Uganda along with promising interventions that could result in improved water service levels. This chapter operationalises the actor landscape presented in Chapter 3 in a dynamic model and simulates community-level rural water services to explore the scenario of water point redundancy for improved water service levels. This chapter primarily addresses Research Questions 1 and 3.

Chapter 6: Case 2 | Mobiles 4 Water (M4W) model

This chapter describes a slightly more complex agent based model: the rural water dynamics arising from the Mobiles4Water initiative. This case operationalises the actor and institutions landscape presented in Chapter 2. A greater number of agents and choices are introduced to examine the use of ICT tools for water service level monitoring involving more actors, policy choices, action choices and financial boundary conditions. This chapter primarily addresses Research Questions 1 and 3.

Chapter 7: Case 3 | Perspectives on social learning in multi-actor, multi-level systems model

This chapter presents the subsequent model conceptualisation and results from experiments in an agent based model that simulates the impact of distinctly different, archetypal forms of learning about the prevailing financial allocation policy on rural water service levels. The model conceptualisation is based upon a collaboratively constructed sector landscape model, the theoretical framework offered by the grammar of institutions and simplified evolutionary concepts applied to learning processes. This chapter primarily addresses changes in water service levels arising from varying financial policy options under different learning and adaptive management regimes. Herewith, the work presented in this chapter addresses Research Questions 1, 2 and 3.

Chapter 8: Conclusions, Discussions, Further Research Directions

This chapter revisits the research questions based upon the findings from the model conceptualisations. New insights arising from the aggregate results of Chapters 4-7 are presented and proposed adaptations to the methods, tools, model designs and collaborative modelling processes are provided.

The contributions and limitations of this work are discussed and future directions for collaborative model-based policy analysis are offered.

Chapters 2 through 6 of this dissertation are based upon research activities conducted by the researcher in Uganda and the Netherlands collaboratively with the IRC Uganda team including the national and district Learning Facilitators, project consortium partners of IRC Uganda and BSc and MSc candidates of the Faculty of Technology, Policy and Management of the Delft University of Technology. Portions of Chapter 2 and 3 were published previously as a Working Paper by IRC Wash.

Summary

In this empirically-driven, practice oriented research, the rural water sector in sub-Saharan Africa is examined from a systems perspective. In the face of rapidly changing and uncertain futures, the need for policy makers and practitioners to identify and respond to the multiple, seemingly intractable problems that give rise to stagnating water services levels despite decades of national and international efforts to achieve universal water service coverage, has never been more pressing.

The aim of the research is to establish a way to consistently conceptualise the dynamics among actors in multi-level, multi-actor socio-technical systems, involved in the implementation of national policies and strategies to deliver nationally determined water service levels.

The domain of inquiry is rural water services in the Republic of Uganda. It was conducted under the auspices of the Triple-S action research programme in which the researcher took part as a team member in the period 2008-2014.

This study seeks practical, actionable insights into the extent to which the complexity sciences, and in specific agent-based modelling, can provide a useful policy analysis and planning approach for examining promising policy, technological and learning mechanisms for achieving universal water services in a given context.

The main contribution of this research is to deliver a consistent and reproducible description of the problem arena, a language to be able to systematically describe and conceptualise agent behaviour in the system and a series of agent-based models that operationalise the system description under different policy and implementation conditions. Additionally, the suite of models, including the meta-data, underlying code and necessary datasets are made openly available for future replication, adaptation and expansion for other research and policy analysis purposes.

The questions we sought to answer were:

1. What system-level insights can be garnered through a systematic approach for the analysis of water services policy and implementation measures in the Republic of Uganda when a policy intervention is simulated in a model of the rural water sector?

2. How is it possible to conceptualise institutional interactions in the rural water services sector based upon collaborative model conceptualisation processes and rich empirical data?

3. What is the potential of computer based (in-silico) testing of policy scenarios for insights into actionable strategies for delivering systemic change?

Systems-based approaches to understanding and engaging with the water sector are increasingly recognised and applied by water sector actors though variation exists across organisations and actors. This diversity of approaches represents concerted attempts to demarcate what constitutes a 'system' in which interventions take place.

Large-scale, socio-technical systems are a type of complex adaptive system that comprise continuous action, interaction, adaptation and change between and among people, infrastructure, institutions and natural resources that give rise to a certain outcome or outcomes. The prevailing institutions (or 'rules of the game') in socio-technical systems emerge over (tens of) decades rendering real-world experimentation on the outcomes of policy instruments impractical.

The rural water sector is one such system that encompasses people, infrastructure, institutions and ecological resources that (inter-)act through multi-level processes of water governance that give rise to the delivery of sustainable water services. These emergent dynamics and their impact over time are not easily observed or experimented upon in a real world setting.

While it is common practice to conduct inception studies, ex-post evaluation and impact assessment studies to identify policy and programmatic outcomes and impacts, these valuable studies do not offer the potential to study system level dynamics arising from micro-level interactions. In contrast, computer simulations, and specifically, agent based models are boundary objects that collaborating parties may collectively use to conceptualise persistent challenges, envisaged promising solutions and desired future scenarios.

To arrive at a scientifically rigorous common language for simulating interventions, this interdisciplinary, mixed-methods research study drew from theory and methods offered by the complexity sciences, social sciences and design sciences as well as empirical evidence generated in the Triple-S action research project. This information was synthesized to formulate a robust, replicable means to simulate macro-level patterns arising from micro-level behaviours of actors in Uganda's rural water sector.

The mixed methods include collaborative actor landscaping methods, desk studies of Ugandan water sector policy frameworks and directives, Triple-S an action research initiative, theoretical perspectives as well as semi-structured interviews and expert consultations with key stakeholders, and agent based modelling. The researcher, with nearly 20 years of professional and academic experience in the international water and sanitation sector, was a member of the Triple-S team between 2008 and 2014. This experience enabled her to contribute empirical knowledge and experience in the steps and choices made during this research project. This mix of methods was selected due to their suitability for researching actors, their behaviours patterns in an ongoing action research project system for insights into system level dynamics with minimal disruption to the project and system under examination.

To provide a substantive focal point around which system actors and dynamics may be observed and experimented upon in the simulations, national policy mechanisms and action research initiatives of the Triple-S Uganda project the period of 2008-2014 were modelled. Each model conceptualised here was based upon the collaboratively generated multi-actor, multi-level sector landscape map with various policy mechanisms and action research initiatives further encoded. The language offered by Ostrom's Institutional Analysis and Development is combined with theory about how information is exchanged, learned, adapted and applied in social learning processes. By describing system agents, their behaviour and the institutions that influence their choices, in a systematic, replicable manner we have made it possible to create simulations of action research interventions implemented in the rural water services system under different conditions.

The iterative, collaborative model conceptualisation processes were followed by ***'in-silico'*** experimentations run over long time periods (20 and 50 years) to observe emergent patterns arising from the conditions set at the model-creation stage. The aim of conceptualising the dynamics arising from the implementation of these different policies was to conduct ***in silico*** experiments to test the effects of different policy and implementation interventions on water service levels in rural areas – the leading national indicator of sustainable water services set out in Uganda's policy framework.

In brief, the substantive findings of the *in silico* experiments indicate that:

- Where the Ugandan Ministry of Water and Environment's nationally determined financial ratio allocation policy was 'relaxed' so that local government could determine a locally suitable financial allocation ratio, water service levels were higher.
- Full access to information horizontally across all districts about financial allocation ratios and water service levels resulted in higher water service levels, pointing to the importance of learning platforms across the different vertical sector governance levels in fostering the flow of information.
- Where individual agents learned about water service levels, higher service levels were delivered.

Key conclusions derived from the conceptualisation and analysed model results from Chapters 5, 6 and 7 point to the importance of information flows between connected individual and groups of stakeholders located across horizontal and vertical levels of the system. Additionally, the results from both the M4W and the Perspectives on Social Learning models suggest that the Community-Based water service delivery model is not viable in the absence of adequate and reliable financial resources. These factors - information flow and accessibility along with sustainable financial resources affect rural water service delivery levels in a complex and emergent manner. These dynamics can be studied and explored in through the dynamic, institution-based models conceptualised in this study.

The development of a formalised language based upon a combination of theory on the development and evolution of institutions with empirical information and knowledge was achieved through a mixed methods research approach. The methods included collaborative analysis and mapping activities, feedback on the underlying model assumptions and validation of theoretical choices. Moreover, stakeholder feedback about this research revealed that the selected methods and tools are suitable for gathering fundamental system information such as its boundaries, agents and their (inter-)actions as well as the formal and informal institutions guiding agent behavior.

The conclusions arising from the third research question suggest that where model conceptualisation and design choices are known and understood by key stakeholders, the value of the models in explore specific problems is enhanced. Even more salient is the conclusion that high quality processes that guide stakeholders through collaborative process of model conceptualisation, including the steps of data analysis and sense making, contribute to the generation of results that not only offer a realistic simulation of real world dynamics, but which can build a broad base of support for model outputs and results from *in silico* experiments.

The research concludes with recommendations for policy, practice and future research directions.

For the **policy domain**, key conclusions include the observation decentralisation and de-concentration of responsibility to local government for delivery of water services implies that local water service authorities also lead in determining financial allocations for different, competing purposes. Policy provisions for community based management of water services require significant modifications if they are expected to contribute to achieving the Sustainable Development Goals.

For the domain of **water sector practice** the insights confirm that which Uganda already practices - formally instituted and facilitated learning platforms designed to connect actors and information across horizontal and vertical levels form a critical feature of multi-level, multi-actor governance systems involved in sustainable delivery of services. Concerted resources for facilitation of such learning structures and processes contributes to a wider information based for actors to draw upon thereby an accelerating the pace of institutional change. In a similar vein, collaborative iterations of model conceptualisation that garner information inputs from key stakeholders results in valid and useful models as they reflect a wide range of perspectives of actors involved in addressing the pressing, complex challenges.

A series of r**ecommendations for future research** are also offered to point the way to others wishing to apply this work in new, or extended, research undertakings. This suite of models may be extended to implement multiple institutions in parallel to observe emergent systems dynamics. To support this, more precise conceptualisations of the prevailing policy and social institutions in the context of study – Uganda – may be incorporated into the existing conceptualisations. Extending the iterative collaborative model conceptualisation approach to include validation with key stakeholders from more local-levels of the system (TSUs and District Water Officers) would enrich the conceptualisations with further empirical evidence and insights. The conceptualisations may be extended to include detailed descriptions of the local context in all 111 districts of Uganda which would entail encoding different and more diverse combinations of types of water supply infrastructure, service delivery models (e.g. self-service, or networked supply models) and geo-hydrological conditions in existing models. A final valuable further direction for research and practice would be to adapt the conceptualisations to system descriptions of other national contexts.

This thesis offers decision makers a means to create shared perceptions of such new arrangements and collectively assess the potential sustainability of promising solutions over the long-term. The generic modelling language and process discussed in this thesis thus contributes to the urgent international challenge to ensure sustainable water services for everyone everywhere.

Samenvatting

In dit empirisch onderbouwde, praktijkgerichte onderzoek wordt de rurale watersector in Afrika ten zuiden van de Sahara vanuit een systeemperspectief onderzocht. In het licht van een snel veranderende en onzekere toekomst, is de noodzaak voor beleidsmakers en praktijkmensen nog nooit zo dringend geweest om de meervoudige, schijnbaar hardnekkige problemen te identificeren en aan te pakken die aanleiding geven tot stagnerende watervoorzieningen, ondanks decennia van nationale en internationale inspanningen om universele watervoorziening te bereiken.

Het doel van het onderzoek is een manier te vinden om de dynamiek tussen actoren in multi-level, multi-actor socio-technische systemen, die betrokken zijn bij de implementatie van nationaal beleid en strategieën om nationaal bepaalde niveaus van watervoorziening te leveren, consequent te conceptualiseren.

Het domein van onderzoek is de watervoorziening op het platteland in de Republiek Oeganda. Het werd uitgevoerd onder auspiciën van het Triple-S actie-onderzoeksprogramma waaraan de onderzoeker deelnam als teamlid in de periode 2008-2014.

Deze studie zoekt naar praktische, bruikbare inzichten in de mate waarin de complexiteitswetenschappen, en in het bijzonder agent-gebaseerde modellering, een bruikbare beleidsanalyse en planningsbenadering kunnen bieden voor het onderzoeken van veelbelovende beleids-, technologische- en leermechanismen voor het bereiken van universele watervoorzieningen in een gegeven context.

De belangrijkste bijdrage van dit onderzoek is het leveren van een consistente en reproduceerbare beschrijving van het probleemgebied, een taal om het gedrag van agenten in het systeem systematisch te kunnen beschrijven en conceptualiseren en een reeks agent-gebaseerde modellen die de systeembeschrijving operationaliseren onder verschillende beleids- en uitvoeringscondities. Bovendien wordt de reeks modellen, met inbegrip van de meta-gegevens, de onderliggende code en de nodige datasets openlijk beschikbaar gesteld voor toekomstige replicatie, aanpassing en uitbreiding voor andere onderzoeks- en beleidsanalysedoeleinden.

De vragen die wij trachtten te beantwoorden waren:

1. Welke inzichten op systeemniveau kunnen worden verkregen via een systematische aanpak voor de analyse van het drinkwatervoorziening en de uitvoeringsinterventies in de Republiek Oeganda, wanneer een beleid wordt gesimuleerd in een model van de rurale watersector?

2. Hoe is het mogelijk om institutionele interacties in de rurale watervoorzieningen sector te conceptualiseren op basis van collaboratieve model-conceptualisatieprocessen en rijke empirische data?

3. Wat is het potentieel van computerondersteund (in-silico) testen van

beleidsscenario's voor inzichten in bruikbare strategieën voor het bewerkstelligen van systeemniveau verandering?

Een op systemen gebaseerde benadering van het begrip van en de omgang met de watersector wordt steeds meer erkend en toegepast door actoren uit de watersector, hoewel er tussen organisaties en actoren verschillen bestaan. Deze verscheidenheid aan benaderingen is het resultaat van gezamenlijke pogingen om af te bakenen wat een "systeem" is waarbinnen interventies plaatsvinden.

Grootschalige, sociaal-technische systemen zijn een soort complexe adaptieve systemen die bestaan uit voortdurende actie, interactie, aanpassing en verandering tussen en onder mensen, infrastructuur, instellingen en natuurlijke hulpbronnen die aanleiding geven tot een bepaald resultaat of bepaalde resultaten. De heersende instellingen (of "spelregels") in socio-technische systemen ontstaan in de loop van (tientallen) decennia, waardoor experimenten met de resultaten van beleidsinstrumenten in de praktijk onuitvoerbaar zijn.

De rurale watersector is zo'n systeem dat mensen, infrastructuur, instellingen en ecologische hulpbronnen omvat die (inter-)acteren via multi-level processen van waterbeheer die leiden tot de levering van duurzame watervoorzieningen. Deze opkomende dynamiek en de gevolgen ervan in de tijd zijn niet gemakkelijk waar te nemen of er valt niet mee te experimenteren in een reële wereld.

Hoewel het gebruikelijk is om aanvangsstudies, ex-postevaluaties en impact assessment studies uit te voeren om de resultaten en effecten van beleid en programma's te bepalen, bieden deze waardevolle studies niet de mogelijkheid om de dynamiek op systeemniveau te bestuderen die voortvloeit uit interacties op microniveau. Computersimulaties, en met name agent-gebaseerde modellen, zijn daarentegen boundary objecten die de samenwerkende partijen collectief kunnen gebruiken om een concept te ontwikkelen van de aanhoudende uitdagingen, de beoogde veelbelovende oplossingen en de gewenste toekomstscenario's.

Om te komen tot een wetenschappelijk rigoureuze gemeenschappelijke taal voor het simuleren van interventies, werd in dit interdisciplinair, mixed-methods onderzoek geput uit theorie en methoden uit de complexiteitswetenschappen, sociale wetenschappen en design wetenschappen en uit empirisch bewijs gegenereerd in het Triple-S actie-onderzoeksprogramma. Deze informatie werd samengevoegd om een robuuste, herhaalbare manier te formuleren om patronen op macroniveau te simuleren die voortkomen uit gedragingen op microniveau van actoren in de drinkwatervoorziening op het platteland van Oeganda.

De gemengde methodes omvatten collaboratieve actor landscaping methodes, desk studies van Oegandese beleidskaders en richtlijnen voor de watersector, Triple-S een actie-onderzoeksinitiatief, theoretische perspectieven alsook semi-gestructureerde interviews en expert consultaties met de belangrijkste stakeholders, en agent based modelling. De onderzoeker, met bijna 20 jaar professionele en academische ervaring in de internationale water- en sanitatiesector, was tussen 2008 en 2014 lid van het Triple-S team. Deze ervaring stelde haar in staat empirische kennis en ervaring in te brengen in de stappen en keuzes die tijdens dit onderzoeksproject werden gemaakt. Deze mix van methoden werd gekozen vanwege hun geschiktheid voor het onderzoeken van actoren, hun gedragspatronen in een lopend actie-onderzoeksproject systeem voor inzichten in de dynamiek op systeemniveau met minimale verstoring van het onderzochte project en systeem.

Om een inhoudelijk referentiepunt te bieden waarrond actoren en -dynamieken in de simulaties kunnen worden geobserveerd en geëxperimenteerd, werden nationale beleidsmechanismen en actieonderzoeksinitiatieven van het Triple-S Uganda project voor de periode 2008-2014 gemodelleerd. Elk hier geconceptualiseerd model was gebaseerd op de gezamenlijk gegenereerde sector landscape kaart met meerdere actoren en niveaus, waarin verschillende beleidsmechanismen en actie-onderzoeksinitiatieven verder waren gecodeerd. De taal van Ostroms Institutionele Analyse en Ontwikkeling wordt gecombineerd met theorie over hoe informatie wordt uitgewisseld, geleerd, aangepast en toegepast in sociale leerprocessen. Door de systeemactoren, hun gedrag en de instellingen die hun keuzes beïnvloeden op een systematische, reproduceerbare manier te beschrijven, hebben we het mogelijk gemaakt simulaties te maken van actie-onderzoeksinterventies die onder verschillende omstandigheden in het rurale drinkwatervoorziening systeem zijn geïmplementeerd.

De iteratieve, collaboratieve model conceptualiseringsprocessen werden gevolgd door "in-silico"-experimenten over lange perioden (20 en 50 jaar) om opkomende patronen te observeren die voortkwamen uit de voorwaarden die in de fase van de model creatie waren gesteld. Het doel van het conceptualiseren van de dynamiek die voortkomt uit de implementatie van deze verschillende beleidsmaatregelen was het uitvoeren van in-silico experimenten om de effecten te testen van verschillende beleids- en implementatie-interventies op het niveau van de watervoorziening in plattelandsgebieden - de belangrijkste nationale indicator van duurzame watervoorziening zoals vastgelegd in het beleidskader van Oeganda.

Kort samengevat blijkt uit de inhoudelijke bevindingen van de in silico-experimenten dat:

- Waar het nationaal bepaalde toewijzingsbeleid van het Oegandese Ministerie van Water en Milieu werd 'versoepeld', zodat de lokale overheid een lokaal geschikte financiële toewijzingsratio kon bepalen, waren de watervoorziening niveaus hoger.
- Volledige horizontale toegang tot informatie in alle districten over de financiële toewijzingsratio's en de niveaus van waterservice leidde tot hogere niveaus van waterservice, wat wijst op het belang van leerplatforms tussen de verschillende verticale bestuursniveaus in de sector voor het bevorderen van de informatiestroom.
- Waar individuele agenten informatie kregen over de waterdienstniveaus, werden hogere dienstverleningsniveaus geleverd.

De belangrijkste conclusies uit de conceptualisatie en de geanalyseerde model resultaten van de hoofdstukken 5, 6 en 7 wijzen op het belang van informatiestromen tussen verbonden individuen en groepen van belanghebbenden die zich op horizontale en verticale niveaus van het systeem bevinden. Bovendien wijzen de resultaten van zowel het M4W-model als het Perspectives on Social Learning-model erop dat het model voor Community Based Water Services niet levensvatbaar is bij gebrek aan voldoende en betrouwbare financiële middelen. Deze factoren - informatiestroom en toegankelijkheid samen met duurzame financiële middelen beïnvloeden het niveau van watervoorziening op het platteland op een complexe en opkomende manier. Deze dynamiek kan worden bestudeerd en onderzocht met behulp van de dynamische, op instellingen gebaseerde modellen die in deze studie worden geconceptualiseerd.

De ontwikkeling van een geformaliseerde taal gebaseerd op een combinatie van theorie over de ontwikkeling en evolutie van instellingen met empirische informatie en kennis werd bereikt door een gemengde methode van onderzoek. De methoden omvatten gezamenlijke analyse- en mapping activiteiten, feedback over de onderliggende modelaannames en validatie van theoretische keuzes. Bovendien bleek uit de feedback van belanghebbenden over dit onderzoek dat de geselecteerde methoden en instrumenten geschikt zijn voor het verzamelen van fundamentele systeeminformatie, zoals de grenzen van het systeem, de agenten en hun (inter-)acties, alsmede de formele en informele instellingen die het gedrag van agenten sturen.

De conclusies die voortvloeien uit de derde onderzoeksvraag suggereren dat wanneer de voornaamste belanghebbenden de keuzes inzake modelconceptualisering en -ontwerp kennen en begrijpen, de waarde van de modellen bij het verkennen van specifieke problemen wordt vergroot. Nog opmerkelijker is de conclusie dat hoogwaardige processen die de belanghebbenden begeleiden bij het proces van modelconceptualisering in samenwerkingsverband, met inbegrip van de stappen van data-analyse en het maken van keuzes, bijdragen tot de totstandkoming van resultaten die niet alleen een realistische simulatie van de dynamiek van de echte wereld bieden, maar ook een breed draagvlak kunnen creëren voor model outputs en resultaten van in silico-experimenten.

Het onderzoek wordt afgesloten met aanbevelingen voor beleid, praktijk en toekomstige onderzoeksrichtingen.

Voor het beleidsdomein zijn de belangrijkste conclusies de constatering dat decentralisatie en deconcentratie van de verantwoordelijkheid voor de levering van watervoorzieningen naar de plaatselijke overheid impliceert dat de plaatselijke watervoorzieningen autoriteiten ook de leiding hebben bij het bepalen van de financiële toewijzingen voor verschillende, met elkaar concurrerende doeleinden. Beleidsbepalingen voor een op de gemeenschap gebaseerd beheer van watervoorzieningen moeten ingrijpend worden gewijzigd als men wil dat zij bijdragen tot de verwezenlijking van de duurzame-ontwikkelingsdoelstellingen.

Voor het domein van de watersector bevestigen de inzichten dat wat Oeganda reeds praktiseert - formeel ingestelde en gefaciliteerde leerplatforms, ontworpen om actoren en informatie over horizontale en verticale niveaus met elkaar te verbinden, vormen een kritisch kenmerk van multi-level, multi-actor bestuurssystemen die betrokken zijn bij duurzame levering van diensten. Gecoördineerde middelen voor het faciliteren van dergelijke leerstructuren en -processen dragen bij tot een bredere informatie basis waaruit actoren kunnen putten en versnellen zo het tempo van institutionele verandering. In dezelfde geest leiden gezamenlijke iteraties van modelconceptualisering waarbij informatie-input van de voornaamste belanghebbenden wordt verzameld, tot geldige en bruikbare modellen, aangezien zij een breed scala van perspectieven weerspiegelen van actoren die betrokken zijn bij de aanpak van de urgente, complexe uitdagingen.

Er wordt ook een reeks aanbevelingen voor toekomstig onderzoek gedaan om anderen de weg te wijzen die dit werk willen toepassen in nieuwe, of uitgebreide, onderzoeksprojecten. Deze reeks modellen kan worden uitgebreid om meerdere instellingen tegelijk te implementeren en zo de dynamiek van opkomende systemen te observeren. Om dit te ondersteunen, kunnen meer precieze conceptualiseringen van de heersende beleids- en sociale instellingen in de bestudeerde context - Oeganda - worden opgenomen in de bestaande conceptualiseringen. Uitbreiding van de iteratieve aanpak van gezamenlijke modelconceptualisering tot validatie met de belangrijkste belanghebbenden op meer lokale niveaus van het systeem (TSU's en de ambtenaren van het water district) zou de conceptualiseringen verrijken met meer empirisch bewijs en inzichten. De conceptualiseringen kunnen worden uitgebreid met gedetailleerde beschrijvingen van de lokale context in alle 111 districten van Oeganda, waardoor verschillende en meer diverse combinaties van soorten watervoorzieningsinfrastructuren, dienstverleningsmodellen (bv. self service - of netwerk watervoorzieningen modellen) en geohydrologische omstandigheden in de bestaande modellen zouden worden opgenomen. Een laatste waardevolle verdere richting voor onderzoek en praktijk zou zijn de conceptualiseringen aan te passen aan systeembeschrijvingen van andere nationale contexten.

Deze dissertatie biedt besluitvormers een middel om een gedeelde perceptie van dergelijke nieuwe regelingen te creëren en collectief de potentiële duurzaamheid van veelbelovende oplossingen op de lange termijn te beoordelen. De generieke modelleertaal en het modelleerproces die in deze dissertatie worden besproken, dragen zo bij aan de urgente internationale uitdaging om duurzame watervoorzieningen voor iedereen overal te garanderen.

1

Introduction

Research is formalized curiosity. It is poking and prying with a purpose.

— Zora Neale Hurston (1891-1960)
Author, anthropologist, filmmaker and civil-rights activist

Somewhere, something incredible is waiting to be known.

— Carl Sagan (1934-1996)
Astronomer, cosmologist, astrophysicist, author, science communicator

In this chapter...

....the central topic of this dissertation - rural water service delivery in the Republic of Uganda - is introduced.

The global goal of providing sustainable universal access to water services is discussed from the global and national perspectives. Several multiple and intractable challenges society faces in achieving this goal along with a reflection on the role of the international development cooperation sector are reviewed.

Governance arrangements for delivery of rural water services commonly found in Sub-Saharan African countries are presented. Given Uganda's well-established institutional and organisational framework for water governance, discussed in Chapter 2, the Ugandan sector offered a suitable context for this research which drew upon the Triple-S action research initiatives as case examples. Empirical information from this multi-actor action research intervention, in which the researcher was involved in the role of 'Learning Working Group' lead, informed the approach, method and modelling choices of this research.

The concepts of complexity, institutions, adaptive management and learning are introduced as potentially useful concepts for addressing the initial research questions presented in this Chapter's final section.

Water is essential to human existence and well-being. Access to and control over water contributes directly to people's ability to exercise what Sen has referred to as the ***five freedoms*** which form the primary end and principle means of development, namely political freedoms, economic facilities, social opportunities, transparency guarantees and protective security (Sen, 2000). Social inclusion and the ability to claim one's human rights are also dependent on access to safe and sufficient water (UNICEF and WHO, 2019). Water is a fundamental resource that features in discourses around national security, environmental sustainability, efficient use and protection of the ecological resource and socio-economic prosperity and development.

However, access to, and control over, water resources and services are not a realisable right or reality for large portions of the world's population, particularly in sub-Saharan Africa, Asia and Latin, Central and South America (UNICEF and WHO, 2019; UN-Water, 2019).

Unequal access to safely managed water services for personal, domestic and productive uses, combined with increasing uncertainty around determinants of water quality and quantity connected with changes in climatic and hydrological conditions, amplifies the need for adaptive approaches to the inclusive management of water resources and services to balance competing demands and requirements (Huitema et al., 2009; McEvoy, 2019; Onencan, 2019; Pigmans et al., 2019; Pahl-Wostl et al., 2008; Pahl-Wostl et al., 2011;). This research project explores the potential of collaborative model conceptualisation and design processes to support policy analysis, and it explores the potential of concerted learning strategies in achieving nationally determined water service levels.

This chapter describes rural water services, the context of this research, and presents perspectives on seemingly intractable causes of low-level water services. It describes a turn by the WASH sector towards systems-based approaches to developing policies and practices that fill gaps in the sector's collective knowledge and practice and make it more likely that we 'leave no one behind' as pledged to by the UN General Assembly in Resolution 70/1 of 2015.

Section 1.1 shows how the United Nations targets to ensure availability and sustainable management of water and sanitation for all is being only party realised and that sub-Saharan Africa, including Uganda which is the focus of this thesis, is facing some of the most intractable problems. Section 1.2 reflects on why water services are important to the collective wellbeing of society and describes the recognised "roles and functions" of key actors and institutions involved in their delivery. Section 1.3 provides an overview of the multiple, interlinked and intractable challenges to delivering services, reflecting on the fact that the solutions are not hardware based. Section 1.4 discusses the role of international development cooperation *vis a vis* domestic policy in the financial and technical aspects of rural water services in low- and middle-income countries. Section 1.5 discusses the notion of institutional change and the role of social learning in interventions aimed at contributing to institutional change. The research questions are detailed in section 1.6 and a reader guide is provided in section 1.7.

1.1 Targeting universal access

In adopting *Transforming our world: the 2030 Agenda for Sustainable Development,* Resolution 70/1, the United Nations pledged to leave no one behind in its commitment to a set of goals to achieve sustainable and resilient economic, social and environmental development (UN, 2015). Among the 17 Sustainable Development Goals, number 6 highlights the need to "ensure availability and sustainable management of water and sanitation for all" as a key requirement for achieving sustainable development and human wellbeing (UN, 2015).

In 2018, three years after the UN Resolution adopting the SDGs, UN-Water published the *Sustainable Development Goal 6 2018 Synthesis Report on Water and Sanitation*. This report on national level progress towards SDG6 noted that while significant progress had been achieved, regional variations persist and insufficient progress was being made towards the goal of *available and sustainably managed water services for all* (UN, 2018, p. 12). The World Health Organisation (WHO) and United Nations International Children's Fund (UNICEF) Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP) found in the period 2000-2017 that the global population using safely managed drinking water services increased from 61% to 71% (UNICEF and WHO, 2019. P. 26). Nevertheless, an estimated 785 million people globally 'still used limited services [and/or] unimproved sources of surface water' (UNICEF and WHO, 2019. P. 26). Figure 1 sets out the applicable definitions revised in 2017 by WHO for levels of water services.

Service level	Definition
Safely managed	Drinking water from an improved water source which is located on premises, available when needed and free of faecal and priority contamination
Basic	Drinking water from an improved source provided collection time is not more than 30 minutes for a roundtrip including queuing
Limited	Drinking water from an improved source where collection time exceeds over 30 minutes for a roundtrip to collect water, including queuing
Unimproved	Drinking water from an unprotected dug well or unprotected spring
No service	Drinking water collected directly from a river, dam, lake, pond, stream, canal or irrigation channel

Figure 1. The new JMP ladder for household drinking water services

Source: Safely managed drinking water - thematic report on drinking water 2017. Geneva, Switzerland: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO. P.12. https://data.unicef.org/resources/safely-managed-drinking-water/. Accessed 15/02/2020.

The UN-Water 2018 Synthesis Report specifically on SDG 6 places the number lacking basic water services even higher at 844 million people. It estimates that 2.1 billion people lack safely managed water defined as 'water accessible on premises, available when needed and free from contamination' (UN-Water, 2018. P.13).

Despite significant improvements in recent decades, an estimated 400 million people in sub-Saharan Africa – 39% of the region's population – rely upon limited services, unimproved sources and/or surface water (UNICEF and WHO, 2019. P.24) to meet their daily water needs. Figure 2 shows this is a higher percentage than in any other region of the world. In sub-Saharan Africa, only 27% of the population uses safely managed water.

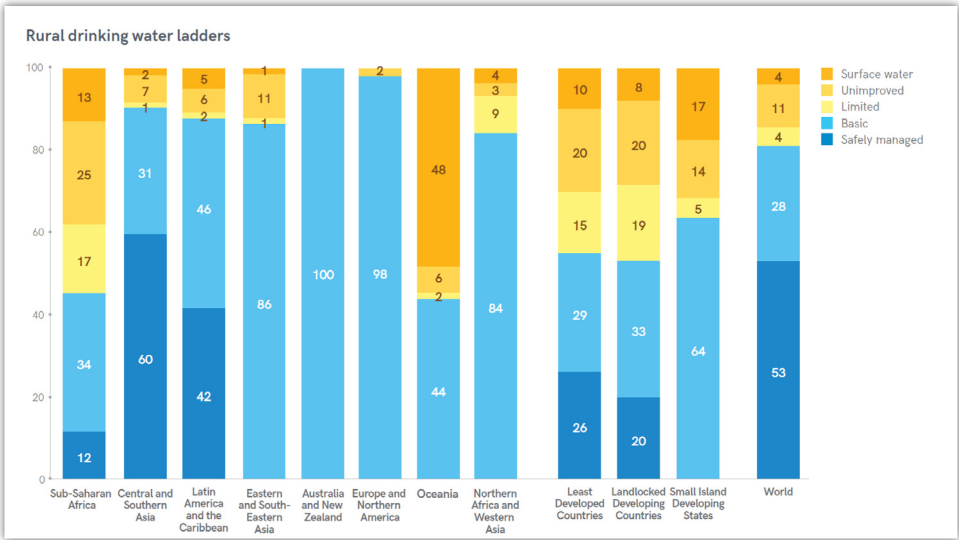


Figure 2. **Rural Drinking Water Coverage (in %) by SDG region in 2017.F**

Source: UNICEF and WHO, 2019, p. 47.

Figure 3 provides a clear picture of the differences in water service levels between rural and (peri-) urban areas in sub-Saharan Africa.

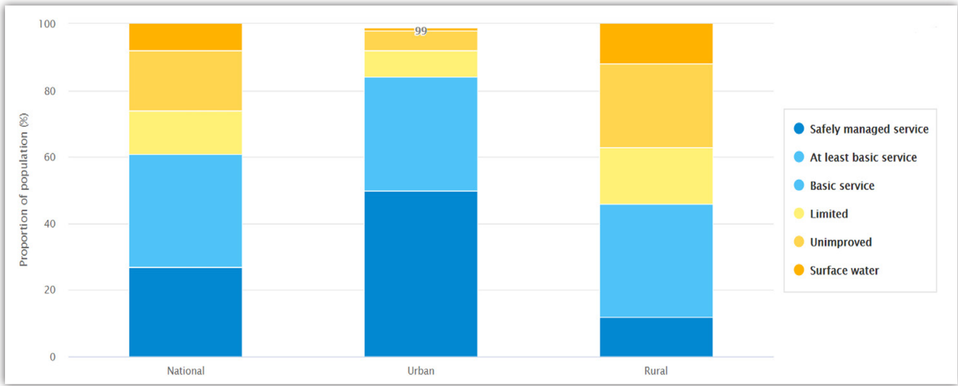


Figure 3. Proportion of population using drinking water services in sub-Saharan Africa, by service level and by location (2017)

Source: WHO/UNICEF, 2019, exported from UN-Water http://sdg6data.org, 27 October 2019

Comparative data across the region by location of residence provide further insights into the scope of the challenge to achieve universal access to sustainable services. Peri-urban areas, including informal settlements and other forms of socially excluded or disenfranchised urban settlements experience significant difficulties related to sustainable water services arising from context-specific political, technical and administrative challenges and tensions. Still, as Figure 3 underscores, the data consistently shows that the situation in rural areas is worse, with eight out of ten people lacking even basic services (UNICEF and WHO, 2019. P.7).

In the Republic of Uganda, the country of focus in this study, Figure 4 shows that the proportion of population using improved drinking-water sources increased from 60% in 2000 to over 80% in 2017. The most recent approximation is that only 7% of the population – both rural and urban - uses safely managed water services (WHO/UNICEF, 2019).

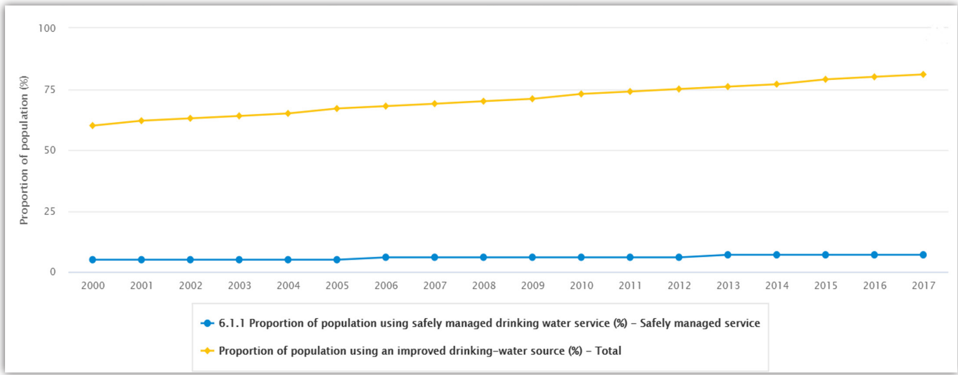


Figure 4. Proportion of population using drinking water services in Uganda, progress over time

Source: WHO/UNICEF, 2019, exported from UN-Water http://sdg6data.org, 27 October 2019

As evident in Figure 5, in Uganda's rural areas, access to safely managed services is around 4% and access to basic services is approximately 37%. With a national population of 43 million people, these figures translate into roughly 1.72 million people using safely managed water services and 15.91 million with basic services.

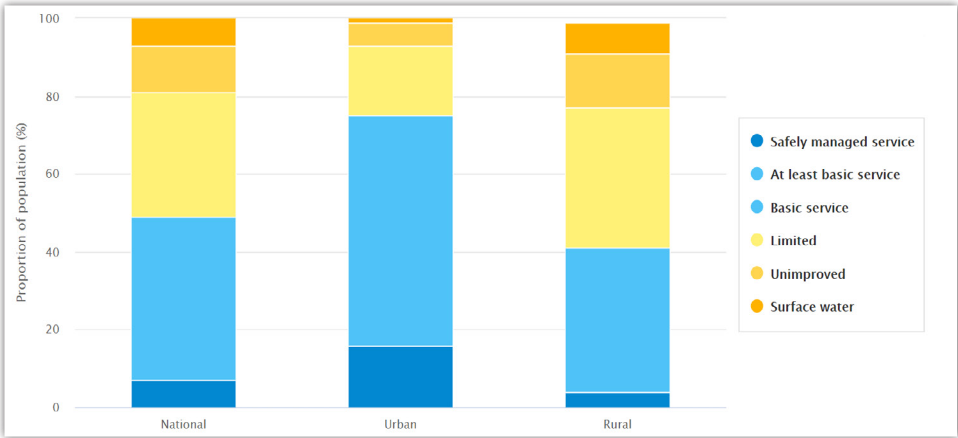


Figure 5. Proportion of population using drinking water services in Uganda, by service level and by location (2017)

Source: WHO/UNICEF, 2017, exported from UN-Water http://sdg6data.org, 27 October 2019

In other words, approximately 55% - or 23.65 million people - in rural Uganda use limited, unimproved or surface water sources to meet their daily needs.

The gravity of this situation and its broader implications with regards to human and societal well-being, ecological sustainability and socio-economic development form the leading motivation for this research. Technological innovations for the delivery of water supply and point-of-use treatments certainly have a role to play in achieving improved water availability and safety. However, changes in the 'enabling environment' including WASH sector policy, finance and practice are needed to extend sustainable safely managed water services to the most marginalised and disadvantaged populations. While there is great consensus in the WASH sector that these 'software' aspects are critical to achieving universal access to water services, there are divergent views about the route to achieving this goal. The reality of large scale institutional change is that approaches and mechanisms are virtually impossible to test for their effectiveness, at scale, in real world settings. Yet the urgency to act and deliver change is real if universal coverage is to be realised by 2030.

The following section describes the commonly found roles and functions – in terms of policy making, technical and operational arrangements – for water services delivery. This serves as the underlying narrative for the system analysis elaborated in later Chapters.

1.2 Water services: essential basic services

Despite its central role in our survival, the human right to water was only recognised by the United Nations General Assembly in 2010. UN Resolution 64/292 "[r]ecognizes the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights" and calls upon "…States and international organizations to provide financial resources, help capacity-building and technology transfer to help countries, in particular developing countries, to provide safe, clean, accessible and affordable drinking water and sanitation for all" (UN, 2010.)

Concerted efforts to ensure regular and safe water supply are key in international, regional, national and local social and economic development processes. Human populations in urban, semi-urban, semi-rural and rural settings require reliable, safe water supply and have developed a myriad of arrangements to deliver water supplies over the course of history.

The delivery of water services involves technologies, policies, governance processes and resources that are interlinked in order to result in the delivery of reliable, safe, sufficient and accessible water supply for users (De la Harpe, 2007; Moriarty et al., 2014; Rogers and Hall, 2003). This range of actions and interactions among people, infrastructure, institutions and natural resources gives rise to a discernible pattern of *water service delivery* (Moriarty et al. 2014; Naiga et al., 2015; Plummer and Slaymaker, 2007).

De la Harpe (2007) described six essential functions of WASH services governance: infrastructure, institutional arrangements, regulation, policies and bylaws, planning, and finance.

These essential functions, depicted in Figure 6, are required for service delivery to be achieved. In turn, they are supported by ten elements of good governance depicted the outer circle.

Figure 6. **Essential functions and elements of WASH Governance**

Source: De la Harpe (2007). Strengthening local governance for improved water and sanitation services 2007, p.1.

This conceptualisation of functions and elements of water services governance is insightful, but stops short of addressing the question of who is involved.

With water supply, sanitation and hygiene services as central focal point, in Figure 6 concentric circles with ever-lighter shades denote administrative levels from international to national to sub-national and community level actors involved in delivery of different facets of WASH services and their associated roles. Featured here are government actors, community organisations, private sector actors, researchers, service users and financiers including philanthropic agencies, development banks and non-governmental organisations. The functions these actors fulfill include policy making, water infrastructure construction and maintenance, service use, advocacy and social protection, regulatory and governance functions as well as financial support from different sources for the water supply sector.

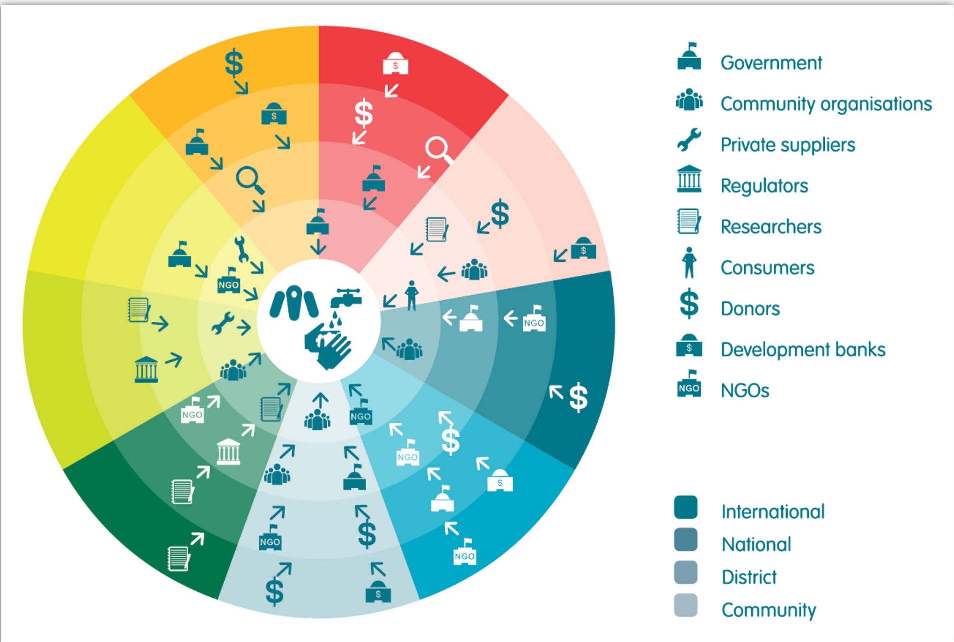


Figure 7. Actors and functions across administrative levels for WASH services delivery

Source: Huston and Moriarty, 2018, p. 9.

While Figure 6 offers an initial framework of functions involved in 'good enough governance' in non-conflict contexts (De la Harpe, 2007), Figure 7 goes further to depict how actors involved in the essential functions are dispersed across administrative levels and hold different mandates in a deconcentrated, decentralised system for delivering services to end users in communities (Huston and Moriarty, 2018).

Global variation on the precise arrangements among these roles and functions exist across countries and regions. Nonetheless, there is wide recognition of the existence of fundamental roles and functions of actors required for the delivery of sustainable water services (De la Harpe, 2007; Hutchings et al., 2015; Lockwood and Smits, 2011; Huston and Moriarty, 2018; Valcourt et al. 2019). This study focuses on the arrangements and dynamics between these actors involved in the delivery of water services to rural households and communities in the Republic of Uganda.

1.3 Rural water: the challenge of stagnating service levels

Failing rural water services arise from multiple, interconnected and intractable factors and business as usual does not deliver lasting change (Hulland et al., 2015; Hutchings et al., 2015; Lockwood and Smits, 2011; Mwangangi and Wanyoike, 2016; Olela and Wanyonyi, 2018; Schouten and Moriarty, 2003; Taylor, 2009; WaterAid, 2019). Yet, if water is so important to human survival and wellbeing, why do so many people still lack safely managed water and what is the source of this failure:

where are things going off track (WHO/UNICEF, 2019; UN-Water 2019)?

There is no single, or simple, solution that will achieve sustainable services and enable citizens to exercise their human right to water. The WASH sector has made tremendous advances in appreciating that infrastructure-based, technocratic approaches alone will not resolve the problem of underserved populations. It is increasingly recognised that the traditional approach of focusing on water infrastructure construction or innovations in water supply technologies, combined with community-based models of water delivery which expect users and communities to finance, build, operate and maintain water supply systems, do not result in sustainable services that stand the test of time (Hutchings et al, 2015; Lockwood and Smits, 2011; Neely, 2019; Schouten and Moriarty, 2003).

In terms of infrastructure, common sources of water point failure noted by the Government of Uganda in the 2013 Water Supply Design Manual include:

1. *Failure of the water treatment system to provide water of acceptable quality.*
2. *Failure of the pumping, storage and distribution system to supply adequate water supply to the consumers.*
3. *Failure of boreholes to provide adequate quantity and/or quality of water.*
4. *Design failures where the new systems have failed to perform due to poor system design.*
5. *Destruction of water supplies by storm water, earth movements, lightning strikes or other natural catastrophes.*
6. *Drying up of the main source of raw water.*
7. *Abandonment of water sources due to pollution.*
8. *Abandonment of sources due to environmental considerations such as gazetting of the source area as a protected zone.*

Source: Water Supply Design Manual, 2013, Government of Uganda. P. 31.

Research from other countries echoes this list but also recognises that system[1]-level issues related to prevailing models of rural water service delivery contribute to failing water services (Mutono et al., 2015; Mwangangi and Wanyoike, 2016; Neely, 2019; Nimanya et al. 2011). Contributing factors to rural water service delivery failure globally include:

1 A system is defined by Ryan (2008) as 'a representation of an entity as a complex whole open to feedback from its environment'. Ryan (2008) and others on systems and complexity sciences make the important observation that such representations are idealisations based on simplified assumptions. Thus, although they offer a valid means for identifying and analysing an entity and its dynamics, 'there are limits to their application' (Mowles et al., 2008; Ryan, 2008).

1 *Neglect of the rural water supply sector at national/central level of government.*

2 *Capital investment provided largely from development partners.*

3 *Uncoordinated interventions by development partners resulting in stand-alone projects, each with a different design, hardware type and financing, make it more complex to render efficiencies and coordination of rural water services across a district or other administrative unit.*

4 *The predominant model for rural water supply services—community based management with village-level operations and maintenance—which assumes users have the skills and motivation to sustain service delivery without support from government or other actors.*

5 *National water sectors struggle to articulate a leading vision, strategy and capacity for sustaining water services, to which development partners must adhere.*

6 *Lack of long-term planning, including for regular maintenance, results in irregular, unreliable supply.*

7 *Financial models for sustainable service delivery and eventual replacement of infrastructure are not in place; provision of services remains ad hoc.*

8 *Systems fail before their design lifetime wasting capital investment while multiple reinvestments are sometimes made in the same communities.*

Adapted from: Lockwood and Smits, 2011

There are multiple pathways to water service failure either in the physical domain arising from hardware breakdown, changes in environmental / hydro-geological conditions and poor hardware maintenance practices, or in the enabling environment which includes policy mechanisms, strategic operations and maintenance planning, financial arrangements and the division of roles and responsibilities (Mutono et al. 2015; Naiga et al., 2015; Nimanya et al., 2011). Sometimes failure is attributable to a shortcoming in one domain. More often failure is due to an intractable set of factors that result in people and communities being unable to receive an agreed level of service so that they are unable to exercise their human right of sustainable access to safe water.

1.4 The role of the development cooperation sector

The international development aid sector plays a significant role in shaping national development agendas of low- and middle-income countries.

Realising resilient national systems with the capability to develop and deliver sustainable and equitable public services is an important national imperative as well as a key goal of development aid and cooperation (Mowles et al., 2008). The international development aid sector provides policy, financial and technical support to low- and middle-income nations for use in education, health, transportation, energy, local and regional economic development and trade as well as in the WASH sector. Understanding the dynamic created by the involvement of influential external support agencies is critical to understanding the current challenges to achieving sustainable water services. The current architecture of international development sector has the potential to boost or to hinder countries in their efforts to determine and pursue social, environmental and economic development goals.

Low- and middle-income countries commonly seek capital investment for infrastructure development for public services from external support agencies (ESAs). These include an array of international and regional development banks, funders and bi-lateral government agencies as well as non-governmental organisations and philanthropic organisations. ESAs have come to be viewed as key partners of country development strategies and generally cooperate through nationally led strategies, policies, budgets and/or technical support platforms (UN-Water and WHO, 2019; Mowles et al., 2008; Ramalingam, 2013).

It is not uncommon for development partners to bypass nationally-led processes to directly implement their own programmes and priorities at the levels of user and community (Matyama, 2015; Naiga et al., 2015; Nimanya et al., 2011; Schouten and Moriarty, 2003). The visions, missions and mandates of ESAs vary and determine the nature of their interactions with domestic partners, including financial investment decisions. In addition to investing in infrastructure, ESAs may support organisational, policy and capacity development related to the sustainable delivery of a service, including direct support (monitoring, maintenance, repairs, replacements, training of staff) and indirect support (macro-level planning and policy making). These essential components of sustainable water services, known as post-construction support or 'software', and more recently as 'systems strengthening', are as important as the infrastructure, or 'hardware', yet are often neglected, resulting in actual levels of financial support being considered insufficient (Darteh et al., 2018; De la Harpe, 2007; Lockwood and Smits, 2011; Rogers and Hall, 2003).

Contributing factors for this neglect include a desire to focus resources on increasing coverage rates for unserved populations (WHO, 2012), perceptions about the risk of corruption, assumptions about the 'best' governance arrangements for post-construction activities (Schouten and Moriarty, 2003), and a desire to see tangible, easily measurable results from an investment (Garandeau et al., 2009).

Understanding the sources of financing provides insight into how WASH sector policy priorities are determined. The Organisation for Economic Co-operation and Development (OECD, 2009) distinguishes the sources of financing for WASH services as the three Ts: tariffs paid by service users; transfers from development partners; and taxes levied by national or regional governments. In some countries, funding from international aid (transfers, to use the OECD nomenclature) is at least as much as, if not exceeding, funding from the two domestic sources, tariffs and taxes combined (Figure 8).

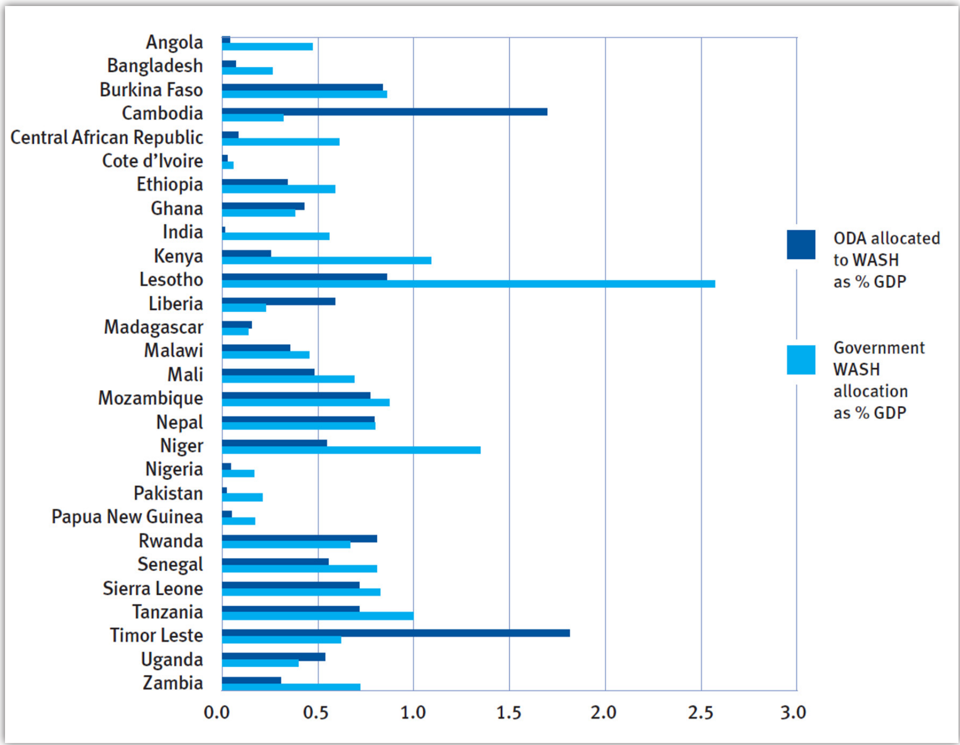


Figure 8. Development partner funding and national allocations to WASH, as percentage of GDP

Source: Water Aid, 2011. (Note: ODA = overseas development aid).

Financing from transfers is not problematic on its own and in fact does tremendous good in many countries. However, in line with the maxim that 'he who pays the piper calls the tune', national policy, strategy and governance reform interventions are influenced by development partners' priorities (UN-Water and WHO, 2019; Winpenny et al., 2016; Water Aid, 2011), especially where transfers are collectively greater than domestic sources of financing generated through taxes and tariffs and where transfers are made outside the national policy agenda.

As Figure 8 shows, ESA support 'to the WASH sector as a percentage of GDP is higher than government budget allocations for WASH in Cambodia, Ghana, Liberia, Madagascar, Rwanda, Timor-Leste and Uganda, indicating both a donor-dominated sector and also that significant amounts of aid to the WASH sector in these countries is not recorded in central government budgets and accounts, or is 'off-budget' (WaterAid, 2011, p.35). This imbalance between external and domestic funding potentially translates into disproportionate levels of influence by ESAs in shaping national and sub-national development agenda priorities (GLAAS, 2019; WaterAid, 2011). In Uganda, the focus country for this research, one estimate puts the ESA proportion of investment in the WASH sector at 30% (Nimanya et al., 2011). More recently, in a 2019 evaluation of their sector support programme, Danish international development cooperation agency Danida noted the outsized role of international aid in the Ugandan WASH sector, estimating support they provided at 15-20% of the total budget for water and environmental sectors in Uganda over the past decade (Danida, 2019).

Development partners are a heterogeneous group in terms of organisational visions, missions and approaches to providing aid. Some operate with and through national policy, budget and coordination processes; others work 'off-budget' and may provide a significant proportion of investment in the rural sub-sector. Development partners are not democratically elected entities, yet as indicated in Figure 8, in some cases aid to national WASH sectors may exceed domestic sources of financing from mandated public authorities (WaterAid, 2011). This influence must be accounted for when seeking to understand how systemic change can occur.

ESAs make well-intended interventions to strengthen governance, foster resilient national systems and build sector capacity, often by introducing governance structures based on examples of more or less effective national systems in high-income countries. The concept of 'systemic isomorphic mimicry,' borrowed from the natural sciences, denotes the evolution of a species to resemble the form of another species without its functions, e.g., a fly that evolves to look like a bee to avoid predation but lacks the bee's toxic sting (Andrews et al., 2013). In governance and policy reform initiatives, this form of imitation to address 'capability traps' can prove problematic (Pritchett et al., 2010). A copy-and-paste approach to implementing large-scale policy and organisational reform in one system based on best practices from another setting is unlikely to produce the desired results. The differences between the policy and organisational environments that have evolved from distinct social, political, economic and technical selection pressures lead to different trajectories in terms of roll out and implementation (Andrews et al., 2013).

A further observation is that external support – both technical and financial – is delivered through three- to five-year programme cycles. In contrast, Williamson (2000) posits that institutional change interventions such as those focusing on the developing the strong and resilient institutions capable of delivering sustainable WASH services, require longer time frames in contrast to short, project-driven, cycles. As depicted in Figure 9, 'getting the institution right', including the 'rules of the game' such as policies, legal frameworks and bureaucratic procedures is an institutional change process requiring a time duration of between 10 and 100 years (Williamson, 2000).

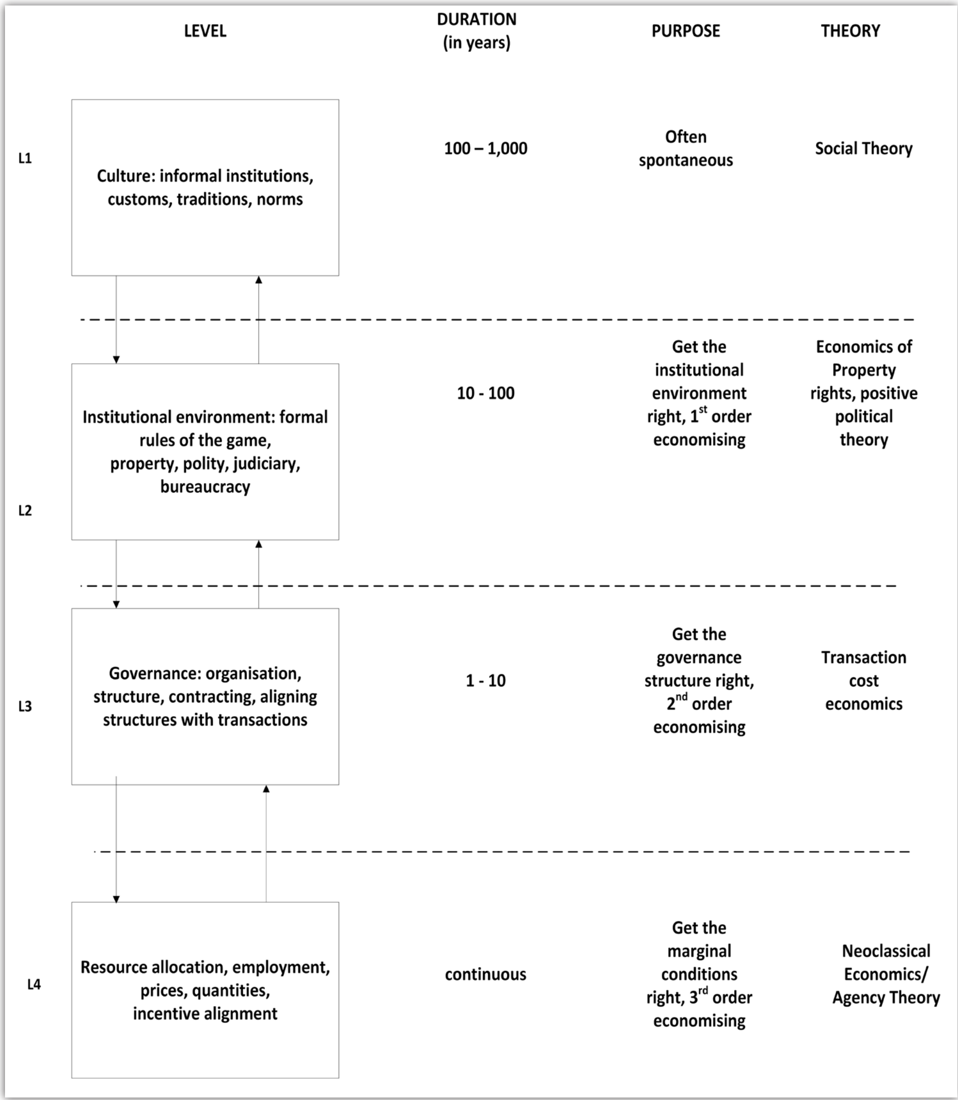


Figure 9. Institutional Economy, Four Levels of Social Analysis

Source: Williamson, 2000. The New Institutional Economics: Taking Stock, Looking Ahead.

Williamson's work is revisited in Chapter 3 where the analytical lens it offers for identifying the *rules of the game* and *play of the game* in effect in a given context is further explored. Here, however, the perspective about the time duration required to achieve changes in prevailing institutional and governance regimes provides an important take on the relative influence and time scale of external support programmes. This perspective suggests that in the context of development programmes, large-scale interventions designed to address backlog in delivery of public services may be overambitious in their project trajectory for delivering the envisaged change.

1.5 Institutional change and the role of learning

Adaptive governance is a concept discussed in relation to socio-technical systems and to institutional change in complex settings.

Wenger (2000) discussed the notion of 'negotiated meaning' and 'participation' as required dynamics to arrive at collective agreement on social development aims through Communities of Practice. De Bruijn et al. (2010) discuss 'negotiated change' and the characteristics of the multi-actor processes of interaction that may take place over long periods of time in the context of complex change processes. Merry et al (2012) relate the notion of an inclusive 'organic creative approach' to strengthening river basin and other water management institutions. Pahl-Wostl et al (2007) discuss 'collaborative governance' and 'adaptive management' (Pahl-Wostl 2007) in relation to natural resources management and water resources in specific given the inherent socio-technical complexity of multi-actor landscape involved in these endeavours (multiple, autonomous, interacting agents with individual and shared priorities) and the seeming intractable challenges to attaining the shared goals for sustainable management of natural resources such as water.

Huitema et al. (2009) propose a combination of the concepts of adaptive management and co-management. This composite concept of adaptive co-management combines learning and structured experimentation of adaptive management with co-management's emphasis on shared rights, responsibilities and powers 'between different levels and sectors of government and civil society' (Huitema et al, 2009. P.1). The authors further incorporate governance following Peters and Pierre (2000) as meaning 'the whole range of institutions and relationships involved in the process of governing', including formal and informal institutions. These perspectives underscore to the centrality of learning in governance and in change in complex adaptive systems.

The topics of adaptive governance and learning return in Chapters 2 and 3 where the case is made to consider rural water services in Uganda from a complex systems perspective. A complexity perspective offers a valuable lens to considering the water services sector in that the arising pattern of water service levels is an emergent phenomenon arising from the actions of multiple interacting autonomous agents. If considered individually, the actions of these agents do not seem to directly give rise to sustainable water service levels. When the patterns of action and interaction is considered from a dynamic and system level perspective, however, the complexity of the relationships and dependencies that give rise to the service levels becomes apparent.

In Chapter 3 the literature review explores the current knowledge base of learning processes in sustainable water services delivery. Learning platforms are key elements of the WASH sector in many countries and encompass critical processes that connect sector actors across water service governance levels. These actors may coalesce spontaneously, or are brought together by organisations/individuals mandated to lead multi-actor platforms. The behaviour of this 'constellation' of actors whose actions and interactions give rise to water sector outcomes are of interest in simulations of policy and problem scenarios for insights into which courses of action may deliver which outcomes.

Given Uganda's well-established institutional and organisational framework for water governance, including a significant role for a nationally-led multi-actor, multi-level sector learning mechanism, presented in Chapter 2, the Ugandan rural water sector offered a highly suitable context for this research. Case examples from the action research initiatives of the Triple-S Uganda programme - which engaged representatives from each level of the sector governance landscape - were selected for model conceptualisations given their prominence in Triple-S as focal points around which concerted sector learning and adaptive management processes were organised. Empirical information from these action research initiatives informed the research approach, method and modelling choices made in this study and are detailed at the outset of Chapters 4 - 7.

Before the theoretical lenses and the empirical case material are explored further and in-depth in the next chapters, initial research questions are introduced here in order to set the stage for this exploration. The questions will be revisited and detailed at the end of Chapter 3.

1.6 Initial Research Questions

Following from the overview of the problem set out in this chapter, the literature study and the study of the empirical case material are guided by the following three initial questions:

RQ1: What system-level insights can be garnered through a systematic approach for the analysis of water services policy and implementation measures in the Republic of Uganda when a policy intervention is simulated in a model of the rural water sector?

RQ2: How is it possible to conceptualise institutional interactions in the rural water services sector based upon collaborative model conceptualisation processes and rich empirical data?

RQ3: What is the potential of computer based (in-silico) testing of policy scenarios for insights into actionable strategies for delivering systemic change?

In the next chapter the technical and institutional arrangements for water service delivery arrangements for rural communities in the Republic of Uganda are described. Thereafter, they are reframed from a systems perspective through which rural water services are located in the discourse of socio-technical systems.

2

Water Services in the Republic of Uganda

A system description

Anyone who has ever struggled with poverty knows how extremely expensive it is to be poor.

— James Baldwin (1924-1987)
American novelist, playwright and activist

'When you get these jobs that you have been so brilliantly trained for,
just remember that your real job is that if you are free,
you need to free somebody else.
If you have some power, then your job is to empower somebody else.'

— Toni Morrison (1931 – 2019)
Nobel laureate, American novelist, essayist, college professor

In this chapter…

…rural water services as presented in Chapter 1, are further described from a systems perspective.

Specific attention is given the Republic of Uganda and the arrangements for rural water services in that context.

This initial description of the rural water sector from a systems perspective informs subsequent choices made in Chapter 3 in the development of the theoretical framework for conceptualising institutions.

2.1 Introduction

This chapter sets out the domain, or setting, of the research inquiry. The arrangements for water services governance and delivery are detailed from a global perspective. The arrangements for rural water services in Uganda is presented as the basis for agent based models presented in Chapter 4, 5 and 6. Section 2.2 describes the prevailing arrangements, including agreements, roles and responsibilities, as they commonly feature in multi-level sector governance systems involved in rural water services delivery in low- and middle-income countries. In Section 2.3 the rural service delivery model in the Republic of Uganda - Community Based Management - is described, based on literature from the academic and practitioner domains. Section 2.4 explains why it is useful to understand rural water services as a socio-technical complex adaptive system with multiple actors and external forces. Section 2.5 notes the most salient elements that form the basis for the system which in later chapters are used to conceptualise the rural water system and build a dynamic model of interaction.

2.2 Water Services: an initial system description

The overarching purpose of a national water, sanitation and hygiene (WASH) sector is to develop and deliver sustainable water, sanitation and hygiene services to users for domestic and productive purposes (Plummer and Slaymaker, 2007). Although the WASH sector is not clearly demarcated as an entity with precisely identifiable boundaries, a number of attributes, activities and interactions identifiable across various national and regional contexts make it possible to define the WASH sector a 'system'.

In addition to the technical system of hardware and infrastructure, a range of actions and interactions among people, infrastructure, institutions and ecological resources is required to deliver a discernible pattern of what can be considered water services.

Within nation states legal and organisational arrangements – in other words, institutional arrangements –guide the delivery of these water services (Rogers and Hall, 2003).

A central line-ministry or department is the most common highest-mandated authority responsible for ensuring protection and management of the water resource and is tasked with developing and delivering water services to the population for domestic and productive purposes. In many countries this same national authority may also hold the remit for development and delivery of sanitation and hygiene services.

In decentralised water service delivery models, a wide range of other organisations and actors are also involved in policy making, financial planning and management, regulation and service provision activities across multiple administrative levels (Rogers and Hall, 2003). Depending upon the national context, these actors include sub-national government entities (e.g. provinces, regions, districts, communes, zones, municipalities, *woredas, panchayats*), water utilities, non-governmental organisations (NGOs), users, community representatives, private operators and capacity-building and financing bodies (De la Harpe, 2007).

These legal, administrative, organisational and operational attributes and (inter-)actions—can be said to make up the 'social' components of a water service. Among this host of actors, roles and responsibilities may be differentiated. As Smits et al. (2011) highlighted, a key distinction is the role of the service authority versus that of the service provider.

The **service authority**, generally a government body, holds the legal mandate and responsibility for planning, coordination, regulation and oversight activities required for service delivery. The service authority may also be required to provide technical assistance to water service providers (Smits et al., 2011; Lockwood and Smits, 2011).

The **service provider** is the organisation, or individual, responsible for day-to-day water service delivery including the operation and maintenance of the water system and administration of the water services.

How the water service provision role is fulfilled varies widely across countries and regions. In practice, most low and middle income countries have a range of service provision options, or service delivery models, whereby ***'the service authority can opt to provide services itself (through a municipal department or municipal company) or … delegate this responsibility by contracting an outside agency such as a community-based organisation (CBO), private operator, public sector utility or company, or non-governmental organisation (NGO), who in turn may hire a private person (plumber or mechanic) to carry out parts of the work' (Smits et al., 2011, p.5).***

The physical infrastructure involved in domestic water supply varies greatly among and even within service areas[2] depending upon factors such as geographical and hydrological conditions, preferences for certain technologies, available financial resources, and population size and density.

Whether the infrastructure is a stand-alone hand pump or a networked, gravity-fed piped scheme, formal and informal arrangements among the authority, provider, users, civil society and international development organisations are required to ensure sustainable water services (Keohane and Ostrom, 1995; Rogers and Hall, 2003; Plummer and Slaymaker, 2007). These arrangements entail policy- and decision-making processes about responsibilities and actor relationships

2 A service area is the area of jurisdiction and population covered by a service authority. Service areas are typically linked to the boundaries of human settlement (towns, villages, hamlets and scattered rural settlements) but may not correspond precisely with administrative boundaries (**IRC Glossary**, accessed 16 October 2014).

through which the power, responsibilities, norms, values and formal agreements embedded in laws and policies are negotiated among and implemented by the array of stakeholders, whose roles and responsibilities may overlap (De La Harpe, 2007; Ostrom and Janssen, 2004).

2.3 Rural water services in Uganda

An initial description of the rural water services in Uganda is presented to locate subsequent choices with regards to the theoretical and analytical framing of the problem scenario and research approach that are addressed in greater detail in subsequent sections.

From a conceptual perspective, Uganda enjoys what may be considered a well-established institutional and organisational establishment in its WASH sector (Naiga, 2015; Nimanya et al., 2011; Oriono, 2019). The national water sector, which has undergone a shift from supply-driven to demand-driven rural water supply since 1990, has clearly articulated and accessible policy and implementation frameworks (GoU, MoH, 2009; Naiga, 2015; Nimanya, 2011). The Ministry of Water and Environment coordinates an extensive network of governmental, non-governmental, academic and civil society actors which interact through a dynamic array of national, regional and local platforms that serve as strategic review, planning and learning bodies for the management and delivery of water services (Oriono, 2019).

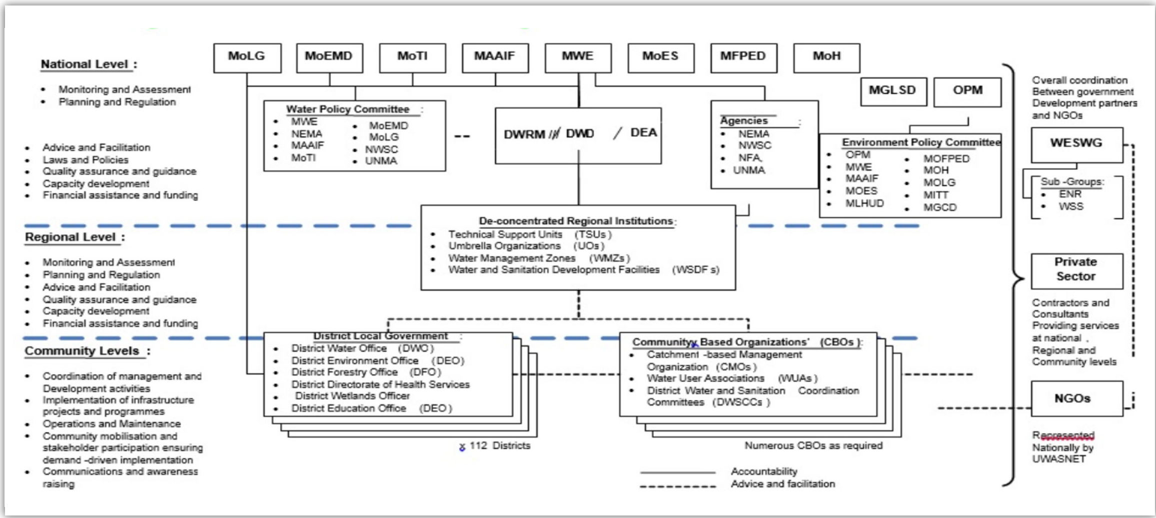


Figure 10. Uganda Water and Environment Sector Institutional Framework

Source: MWE, 2019. URL: https://www.mwe.go.ug/mwe/institutional-framework-water-and-environment. Accessed 30/10/2019.

In this multi-actor system, a wide range of interests and priorities are distributed across multiple levels of the WASH sector provides a rich context for the study of macro level dynamics arising from the actions and interactions.

These actors operate within clearly set out articulated roles and functions as set out in Figure 9 (GoU, 2013; Nimanya et al., 2011).

The MWE publishes an extensive, publically available and regularly updated body of policies and technical guidance documents that govern roles and responsibilities of different sector actors in the rural water and sanitation service sector (GoU, 2019; Nimanya et al., 2011). The provision for these services "…covers communities or villages (at the level of Local Council 1 (LC1) with scattered population in settlements up to 1,500 people, and Rural Growth Centres (RGCs) with populations between 1,500 and 5,000" (GoU, 2019). The leading directives for rural water and sanitation, openly accessible via MWE's website are set out in the following documents:

1. The Constitution of Uganda (1995)
2. The Uganda Water Action Plan (1995)
3. The National Water Policy (1999)

These policy frameworks are complemented by a large number of other policies, including from other sectors such as Health, Environmental Management and Local Government. Leading technical guidelines and directives for rural water services that articulate the 'rules of the game' regarding the nature of actions, and interactions, of sector actors include:

1. Community Management Handbook for Extension Workers, 2016
2. Technology Handbook for Extension Workers, 2016
3. District Implementation Manual, revised 2013
4. Design Guidelines for Water Supply Infrastructure in Uganda, 2013
5. Water Supply Design Manual, 2013
6. Framework and Guidelines for Water Source Protection, vol. 1-5, 2013
7. Uganda Local Government function profiles, 2011

Source: MWE, 2019. URL: https://www.mwe.go.ug/library. Accessed 27/10/2019.

Sector Joint Review reports are freely available and the Water Atlas, launched by MWE in 2004, is an openly available source of information about the state of water supply in the country. These resources about the institutional arrangements and progress towards nationally determined water service goals provide essential information and data from monitoring and reporting processes. The information is used to inform the national platform for sector learning and strategic planning – the Joint Sector Review and its associated task teams. A set of indicators is used by the Ugandan WASH sector to track and monitor water service levels. In this study indicators for *quality, quantity, accessibility and reliability* applicable in the period of 2013-2016, set out in table 1, are used as these featured in the system descriptions and narratives that are developed in subsequent Chapters.

Indicator	**Metric – National Standard**
Accessibility	
Number of Users	Borehole: 300 persons, 60 household
Distance to Facility	% of people within 1 km of water point
Walking Time	No national standard specified (2013).
Water Quantity	
Quantity Delivered	>=20 litres per person/day
Quantity Accessed	No national standard specified (2013).
Water Quality	
E. Coli	Not detected in min. 95% of samples. Not detected in max. 4% of samples. Count 1 in max. 1% of samples of 100 mL.
Total Dissolved Solids	500 mg/L
Turbidity	5 Nephelometric Turbidity Units
Reliability	
Uptime of Source	No national standards specified (2013).

Table 1. Ugandan water service level indicators, 2013

Source: Adapted from Knipschild, 2016. Based upon Biteete et al, 2013.

At the time of the research, the sub-indicators of ***quantity accessed, walking time, and, uptime of source*** had unspecified national standards. An updated list of indicators and standards was published in the 2017 Uganda Water and Environment Sector Performance Report (GoU, 2017). They have not been used in this research but should be used in future simulations.

From the perspective of scientific research, access to well-articulated 'rules of the game', insights into the shared understanding of sector actors about the boundaries of their 'system' (as evidenced by the wealth of policy directives and frameworks that delineate actors' roles and responsibilities), is tremendously valuable. With this information, a process of structured examination and analysis of the problem scenario – failing water services levels – arising from the patterns of action and interaction among system actors, is made possible.

From the pragmatic perspective, the choice to focus on the context and dynamics of rural water services in Uganda was two-fold. Firstly, there is a good deal of available data about Uganda's rural water service levels, financial policies, technical/infrastructure policies and patterns of interaction between and among key sector actors upon which to base simulated scenarios (IRC Uganda, 2015; Katuramu, 2014). The researcher also had access to key sector actors prior to and during the period of study between the years 2008 - 2015. This contact was essential to developing a coherent narrative upon which to develop the model narrative as well as for purposes of model validation at later stages.

The ability to work with 'story holders' and discuss their experience of driving change in the Uganda water sector provided rich insights to a complex and not always evident on the surface narrative. These insights feed what we know and have set out as the system description in later sections.

2.4 A systems perspective

The description above of Uganda rural water services informed the first research step of mapping key sector actors and strategic learning platforms for policy- and decision-making in the country. This step was necessary to understand that system structure, its boundaries and how interventions designed to promote systemic change 'move through the system' as actors make decisions and interact. The previous section showed how the rural water sector in Uganda is a system comprised of boundaries, rules and agents, or actors. The case is made in this section for taking a systems-perspective to the study of complex and intractable challenges in socio-technical systems.

The notions of a systems perspective and systems strengthening are increasingly common in the language and practice of international and national level WASH sector actors (UN-Water and WHO, 2019; Huston and Moriarty, 2018; Neely, 2016; Valcourt et al., 2019). The sustainable delivery of water services to a population requires ongoing interactions between people, the natural environment, institutions and infrastructure. This understanding of the key actors involved in the delivery of water services allows us to frame the water services sector as a socio-technical system, a particular type of complex adaptive system (Mowles et al., 2008; Neely, 2019; Ramalingam, 2013; Trist, 1981; Valcourt et al., 2019). This research focuses on the water services 'system' in which people, infrastructure, policy and environment interact in a manner that gives rise to the delivery of water services to end users.

The urgency of expanding the capacity of actors to perceive the water service delivery system in which they operate so as to respond adaptively to external events and stimuli is increased by uncertainties created by changing climate and weather patterns, water-related and other sources of human conflict, changes in regional and national socio-economic development levels and unforeseeable natural or man-made crises (Grant and Willetts, 2019; Huitema et al, 2009; Onencan, 2019; Pahl-Wostl, 2002). Shared perception among key stakeholders about the actors, interactions and interdependencies supports dialogue about what change could look like and what is required to achieve the desired change.

Concepts and tools offered by a systems perspective, and in particular socio-technical systems, are appealing (Barder, 2012; Burns, 2007; Geels, 2002; Meadows, 2009; Mowles, 2008; Neely, 2015). Systems-informed approaches support collective analysis and sensemaking about the landscape of actors, functions and boundaries of a 'system' involved in services delivery. This process of social learning, through which policy makers and practitioners can develop a shared description of the system to support stakeholders to collectively address intractable, 'wicked', challenges is discussed in Chapter 3.

2.5 Salient system elements

The system elements that can be distilled from the previous sections as significant include:

- The key actors involved at different governance levels in the delivery of water services, including end users
- The water service infrastructure
- The prevailing policies (institutions)
- The sector processes and platforms for policy- and decision-making through which key sector actors are connected
- Information and information systems that allow key actors to form choices and decisions about the functioning of the infrastructure, financial options, water collection options, policy options, etc.

These system elements are distributed across multi-stakeholder platforms. Upward and downward flows of information and authority feature in this system and play a key role in shaping Uganda's WASH sector priorities. In all, this is considered to depict a self-organising system. Lastly, the system receives and provides flows of information, financial and other resources—international development aid, water from the ecosystem, macro-level economic systems, etc.—ensuring that the system is open and may be shaped or affected by the 'environment outside the system'.

These elements form the basis of the socio-technical system and in later chapters are detailed in the conceptualisation of the rural water system which subsequently is used to build a dynamic model of interaction.

In chapter 3 the research approach is described. The theory and methods selected to address the research questions are presented along with gaps in the existing knowledge base to which this research seeks to contribute.

3

Theory and Approach

It's been a long time coming
But I know a change is gonna come.

— Sam Cooke (1932 – 1964)
Singer, songwriter, civil-rights activist

It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.

— Richard P. Feynman (1918-1988)
Theoretical physicist

In this chapter…

…a review of literature on multi-level, multi-actor governance, socio-technical systems and the role of social learning in adaptive governance form a basis for further elaboration of the systems perspective set out in Chapter 2. The concept of boundary objects is introduced in the context of learning processes and agent based modelling is introduced as a tool for supporting the research approach taken to address the research questions.

These concepts underpin the collaborative model-based policy analysis approach taken in this project. The steps entailed in the research approach are decribed in the final section of this Chapter.

This chapter draws from research steps conducted in 2013 – 2015:

a) Work conducted with S.A.E. Van Tongeren, MSc candidate (2014) supervised by the author.

b) Casella, D. van Tongeren, S. and Nikolic, I. (2015). Change in complex adaptive systems: A review of concepts, theory and approaches for tackling 'wicked' problems in achieving sustainable rural water services. IRC Working Paper. The Hague, The Netherlands.

3.1 Introduction

This chapter describes and formalises options for understanding the rural water sector from a systems perspective. Specifically, the language and grammar for describing real world scenarios from a complex adaptive systems perspective are detailed. The research process, timeline and approach are detailed here to provide guidance on how activities and outputs of a country-led action research project provided foundational inputs to this research study.

3.2 State of the Art

This section reviews and discusses the theory and methods that substantiate the choice to research institutional change questions in the rural water sector from a socio-technical systems and learning perspective. Current knowledge gaps are addressed.

3.2.1 Linking multi-level governance and complexity sciences

The Global Water Partnership (GWP) defined water governance in 2003 as 'the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society' (Rogers and Hall, 2003).

Tracking independent networks of multiple actors or agents across multiple administrative levels means understanding it from a governance perspective (Kooiman, 1993; Stoker, 1998; DFID, 2007). In reflecting on how to provide for a collective interest, such as the provision of public services, the governance perspective offers a 'framework for understanding changing processes of governing, characterised by processes of adaptation, learning and experiment' (Stoker, 1998, p.18). Taking a governance perspective is a step towards introducing a systems perspective to understanding the rural water sector.

A governance perspective recognises that functions related to service delivery are dispersed over a wide array of actors, organisations and coordination platforms spanning different national development sectors and administrative levels. While national governments continue to play a role in how public services are provided, their role is increasingly one of coordination and steering, concomitant with an increase in the involvement of non-government actors in policy-making and service delivery. The literature on governance also highlights the importance of public participation in governance processes for the potential to improve the quality of decision making by 'opening up the decision-making process and making better use of the information and creativity that is available in society, improve public understanding of the management issues at stake, make decision making more transparent, and …stimulate the different government bodies involved to coordinate their actions more in order to provide serious follow-up to the inputs received' (Huitema et al., 2009, p.5). This has the potential to strengthen democratic processes where government does not have all the resources required to 'manage an issue effectively' (Huitema et al., 2009, p.5). By framing water services as a system that is open to feedback from its environment, it is possible to factor in the role of external support agencies (as discussed in Chapter 1), for their effect on national development agendas, including how water service delivery priorities and arrangements are formed and implemented.

Prevailing governance approaches in low- and middle-income countries are context specific and have evolved over long periods of time in response to specific political, social and economic processes (Plummer and Slaymaker, 2007).

3.2.2 A socio-technical systems perspective

Complexity sciences offer a useful set of theories, terminology and tools to examine the water services sector as a complex adaptive system (Holland, 1992; Ison et al., 2007; Knipschild, 2016; Ramalingam, 2013; Senge et al, 2007; Van der Lei et al., 2010; Waddel, 2016).

Drawing on Dijkema et al. (2013; see Section 3.1), Dam et al. (2013) characterise complex adaptive systems as follows:

- Multi-actor: many different (heterogeneous) actors or agents act and interact with intention through social networks.
- Multi-objective: different actors within the system hold different priorities.
- Feedback loops: connections (e.g., information or financial flows) run across the hierarchical levels, time scales, individuals and social networks (Dijkema et al., in Dam et al., 2013, p.2).
- Self-organising, hierarchical and open (SOHO):
    a. Self-organising: 'the process by which a system develops a structure or pattern without the imposition of structure from a central or outside authority or when a system displays a different output as a result of internal processes' (Prigogine and Stengers, 1984; Kay, 2002, cited in Nikolic and Kasmire, in Dam et al., 2013, p.50);
    b. Hierarchical: multiple hierarchical levels; and

c. Open: 'where matter and energy [and information] flow in and out, and where things inside the system are affected by the environment outside the system…' (Nikolic and Kasmire, in Dam et al., 2013, P.15)

Socio-technical systems are a specific type of complex adaptive system in which social (people and social institutions) and technical (infrastructure) artefacts are interconnected and interact on a continuous basis (Geels, 2004; Knipschild, 2016; Dam et al, 2012).

As elaborated upon in chapters 1 and 2, a system of interconnected social actors, institutions (policies, norms and beliefs) and ecological features is required to ensure that water services are delivered as intended over the lifetime of the technical system.

In the discussion on water services governance in section 1.2, the WASH sector was depicted as a multi-level system comprised of multiple different actors carrying out various functions under varying mandates. While a clear national hierarchy of interconnected actors and organisations is observable, behaviours of individual and groups of actors is not rigidly prescribed.

Multi-actor platforms and collaborations for learning and exchange arising on a needs basis in parallel to formally established national, regional and local fora. Alliances are regularly formed or disbanded around thematic campaigns and large infrastructure initiatives. The openness of the system is evident in the fact that phenomena of a national water sector can impact phenomena outside the sector and vice versa given the intersectionality of water with other key development sectors such as health, education, energy, transport and current events in the realms of international diplomacy and climate change.

For these reasons, the concept of a socio-technical system is applied in this research as a means to conceptualise rural water services from a systems perspective.

3.2.3 Adaptive governance: the role of learning

Chapter 1 identified that progress towards achieving the SDG for water has been patchy and insufficient. It explained how the vast majority of people living in rural areas of Uganda do not have access even to a basic level of water services, using limited, unimproved or surface water sources to meet their daily needs. Traditional approaches do not result in sustainable services that stand the test of time.

There are no panaceas or silver bullets to address the interconnected failings across a socio-technical system whose problems have evolved over time and largely become intractable. Literature on governance and on complexity addresses the need for identifying the context-specific nature of challenges along with locally relevant solutions that receive popular understanding and support (Huitema et al., 2009; Mowles et al. 2008; Burns, 2007; Bramson and Buss, 2002).

Literature from the domains of scientific research as well as water sector practice increasingly promotes adaptive governance and adaptive management informed by a systems perspective as essential to addressing the multiple, inter-connected challenges and failures of socio-technical systems (De Bruijn and Ten Heuvelhof, 2010; Geels, 2004 and 2005) and specifically water governance systems (Huitema et al, 2009; Ison et al., 2007; Merrey and Cook, 2012; Mostert et al. 2008; Pahl-Wostl, 2007; Rogers and Hall, 2003; Romina, 2014; UN-Water, 2019).

Adaptive governance is discussed variously by researchers in relation to a number of different socio-technical systems and change in complex settings. Wenger (2000) discussed the notion of 'negotiated meaning' and 'participation' the dynamics inherent in arriving at negotiated meaning about social development through Communities of Practice. De Bruijn et al. (2010) discuss 'negotiated change' and the characteristics of the multi-actor processes of interaction that may take place over long periods of time in the context of complex change processes. Merry et al (2012) relate the notion of an inclusive 'organic creative approach' to strengthening river basin and other water management institutions. Pahl-Wostl et al (2007) discuss the notion of 'collaborative governance' and 'adaptive management' (Pahl-Wostl 2007) in relation to natural resources management and water resources.

A critical element across this literature on adaptive governance identified, is the role of learning processes in the governance of multi-actor, multi-scale (or level) water service delivery systems. The literature about social learning encompasses various definitions offered by scholars and examples of practice from various international development cooperation actors (Beers et al, 2014; Bousquet et al., 2002; van Bruggen et al., 2019; Geels, 2005; Kania and Kramer, 2013; Onencan, 2019; Pretty, 1995; Senge et al, 2007; Pahl-Wostl et al., 2007; Voinov et al., 2016; Waddel, 2005 and 2016; Waddock et al, 2015).

The body of literature on the role of adaptive governance and social learning processes in water governance and natural resource management regimes is extensive. In the context of integrated water resources management, Pahl-Wostl et al. (2007) focus on 'transformative change' arising from multi-level social, or 'societal', learning and adaptive management approaches for achieving paradigm changes where system elements, such as actors, organisations, infrastructure, knowledge and power relations, are highly interdependent. Pahl-Wostl (2009, p.354) developed a conceptual framework for use in analysing adaptive capacity and multi-level learning processes to enable deeper insights into 'complex and diverse resource governance regimes'.

Huitema et al. (2009) summarise approaches to effecting change that recognise the polycentric nature of public services, involve public participation, employ experimentation and are bioregional in nature. In this context, 'bioregional' refers to river basins as the relevant scale at which to conceptualise the system (Huitema et al., 2009, p.9).

In defining social learning, Pahl-Wostl emphasises the need to embrace "… those components that are crucial for decision making" in a resource governance regime she identifies as a socio-technical-ecological system (2002, p. 400). Pahl-Wostl further identifies those components as the "…understanding of the dynamics of the system to be managed and the relationships within the social network" (2002, p. 400).

Pahl-Wostl defines social learning along the following processes:

1. *"Build up a shared problem perception in a group of actors, in particular when the problem is largely ill-defined (this does not imply consensus building).*
2. *Build trust as base for a critical self-reflection, which implied recognition of individual mental frames and images and how they pertain to decision making.*
3. *Recognize mutual dependencies and interactions in the actor network.*
4. *Reflect on assumptions about the dynamics and cause-effect relationships in the system to be managed.*
5. *Reflect on subjective valuation schemes.*
6. *Engage in collective decision- and learning processes (this may include the development of new management strategies, and the introduction of new formal and informal rules)."*

Source: Pahl-Wostl, 2002, p. 400.

Pahl-Wostl proposes these steps as a "…base for a methodological approach on how these processes [social learning] may be explored and managed" (2002, p.400). Bousquet et al. (2002) connect the knowledge arising from inclusive, participatory modelling for resource management with model design resulting in the 'companion modelling' approach. Bousquet et al. (2002) make a further connection between the participatory model conceptualisation, design and use phases with empirical, field-based, data collection (Pahl-Wostl and Hare, 2004).

Bos et al. (2013) develop an analytical "…framework that outlines enabling starting conditions and features for designing and organising learning. The framework comprises focus projects, multi-organisational peer groups, distributed facilitation, adaptability and flexibility, time and science/research." (Bos et al., 2013). This work specifically relates to socio-technical systems and interventions for systemic change in the context of the Australian urban water sector.

From these efforts to delineate the essence of a social learning approach as a concerted process, the following elements are distilled for this work:

1. *convening key stakeholders with an interest in addressing a pressing problem*

2. *collaborative processes to align common goal(s) and problem identification*
3. *concerted facilitation of the learning process*
4. *gathering information about the problem*
5. *identifying and testing potential solutions in local contexts*
6. *inquiring whether solution is delivering desired result*
7. *where appropriate taking solutions to scale*

Several steps described here were implemented as a fundamental action research elements of the Triple-S project which explicitly set out "learning about sector learning" as one research objective with the broader aim of contributing to strong nationally-led processes for water service delivery.

Outputs of those steps are documented in the published practice literature still available in IRC's digital archives. Moreover, these process steps contributed to this research through the empirical information they generated that was used to inform design choices for conceptualisation and modelling real-world policy and practice challenges in increasingly complex simulations of the prevailing institutions. These inputs varied per model conceptualisation. How they feature in each model is detailed in section 3.4 Research Approach and at the outset of Chapters 4 through 7. In the next section, a review of the literature that informs those conceptualisations is presented.

3.2.4 Information exchange and change processes in socio-technical systems

The fields of behaviourism, cognitive perspective and social learning (as a combination of the former two within a given social context) offer varying perspectives on how actors in socio-technical systems learn and adapt. These perspectives place the person in the central, active role in the processes of learning and change.

Another theory, known as of *memetics*, describes learning processes from the starting point of the unit of information (Dawkins, 2006). In memetics, people are the means, or vehicle, for units of (cultural) information exchange in (social) learning processes. Memetics postulates that the units of information people receive or exchange change as a result of the process of exchange as people may add new information or may modify a unit of information based on personal perceptions or priorities. In this manner, the principles of evolution, that is selection, replication and variation, can serve as the means by which information is transferred and evolves through interaction between and among people and groups of people.

While other theories also offer valid descriptions for how learning occurs and how information is transferred between and among agents, the choice is made here to apply the theory of memetics. When institutions (understood as laws, norms and shared strategies after Crawford and Ostrom, 1995) are implemented as the content of the memes, the connection between how institutions evolve and adapt with the manner in which social agents transfer institutions can be encoded. In other words, the processes of replication, variation and selection can be applied as a means to rather simply delineate and categorise types of information transfer and adaptation among social agents. This choice is in keeping with the principle of parsimony which, in the context of modelling, prioritises modelling choices resulting in as few parameters as possible over a more complex model (Marsh and Hau, 1996 as cited in Ghorbani, 2013).

For this reason, memetics is selected to describe the processes of replication, transfer and evolution of information in the form of institutions among agents in the conceptualisation presented in Chapter 4 where it serves as the mode of exchange of units of information in the simulated social learning processes. In Chapter 7 a further simplified version of the processes of replication, variation and selection of the financial allocation institution are implemented as distinctly different archetypal learning styles in order to explore how such different styles give rise to sustainable water service levels.

3.2.5 Policy analysis: visualising and conceptualising institutional change

In *Generative Social Science* (2006), Epstein asks how could "…the decentralized local interactions of heterogeneous autonomous agents generate the given regularity [of the system]?' (2006, p.5). Here, 'given regularity' refers to macro level patterns arising from micro-level patterns of agent behaviour and interaction.

A consistent means to identify and represent these patterns in a simulation of the multi-level, multi-actor rural water system would provide decision makers with a common, shared artefact, or object, around which to focus policy analysis processes (van Bruggen, 2017; van Bruggen et al., 2019). This requires both a collectively shared means of representation as well as a common language for speaking about the problem and system in which it occurs.

Real-world institutions and policies identified in various Uganda water sector scoping studies (Nimanya et al., 2011; Bey and Abisa, 2014; Bitetee, 2013; Kahangire, 2012) and further examined during the course of selection of the action research initiatives, were incorporated into iterations of increasingly complex model conceptualisations in this research study. These include the organisational structure of the Ugandan water sector - incuding multi-actor, multi-level learning platforms, flows of information between actors across verticle and horizontal governance levels, roles and responsibilities of key actors, nationally determined water service levels set out in the Government of Uganda's national policy framework and the financial allocation policy for disbursement of funds from national to local government for water supply management.

3.2.6 Boundary objects in learning processes

Ongoing, collaborative, efforts to learn about what is working, and what is not, as well as about potentially promising alternatives requires collaboration and the ability to learn and adapt one's strategies and course of action. Both individuals as well as groups, in coalitions, networks, communities of practice and alliances commonly found in WASH governance systems, hold the ability to learn and adapt. Formalised social learning approaches in national governance regimes are found in many national contexts. Among many other countries, WASH sector coordination platforms with an explicit learning mandate in sub-Saharan Africa are established in Ethiopia, Burkina Faso, Ghana and Uganda. Moreover, in many instances, dedicated resources and facilitators to lead such social learning processes are in place in recognition of the importance of multi-actor coordination efforts to delivery of national development agendas.

Boundary objects, following the definition set out by Star and Griesemer (1989), are 'objects inhabiting multiple contexts at the same time whilst having both local and shared meaning' (Light and Anderson, 2009). Bowker and Star propose that boundary objects are '…objects that…inhabit several communities of practice and satisfy the informational requirements of each of them' (Bowker & Star, 1999, p.297). Boundary objects may therefore take the form of visual attributes such as maps, landscapes, problem trees, logical framework analyses and theories of change that represent information gathered by and from a range of stakeholders. The objects offer familiar and useful means for establishing a collective, as well as domain-specific, understanding about system boundaries, rules and patterns of interaction as well as arising dynamics (Barreteau et al., 2012; 2006; Star and Griesemer, 1989; Light and Anderson, 2009; Walker et al., 2008).

Boundary objects may take the form of any artefact that stakeholders in a process recognise as having a given meaning, albeit from the different perspectives of the multiple stakeholders. A familiar set of boundary objects from the domain of community development are the collaboratively developed maps, rankings, stories and visual artefacts developed through the steps of Participatory Rural / Rapid Appraisal approaches. Any manner of boundary object developed in social learning processes may be used to foster reflection, discussion and identification of possible courses of action. These may take the form of financial spreadsheets, (social) network or resources maps, images, power and influence maps, dashboards that depict the status of commonly agreed set of indicators, etc.

Agent based models are another such object. Such models can serve to enable stakeholders / actors to collectively experiment with and observe the potential implications of various policy choices across time, location and context. This model-based policy analysis offers stakeholders a means to collectively define and consider the impact of their choices about potential solutions under different policy and implementation scenarios. Such a boundary object can serve to help multi-stakeholder deliberative platforms such as collaborative councils, learning alliances, etc to consider different policy and strategy approaches.

The actor landscape in Figure 11 depicts the complexity of the sector governance arrangements. The image depicts salient water sector actors and platforms, and offered an opportunity for rich discussions about connecting elements between sector actors and stakeholder platforms such as information, financial resources, policies and formal authority. In this figure, features of a complex adaptive system are observable. The water services sector comprises multiple, polycentric, autonomous actors who act and interact according to various formal and informal rules in the context of dedicated learning and coordination platforms.

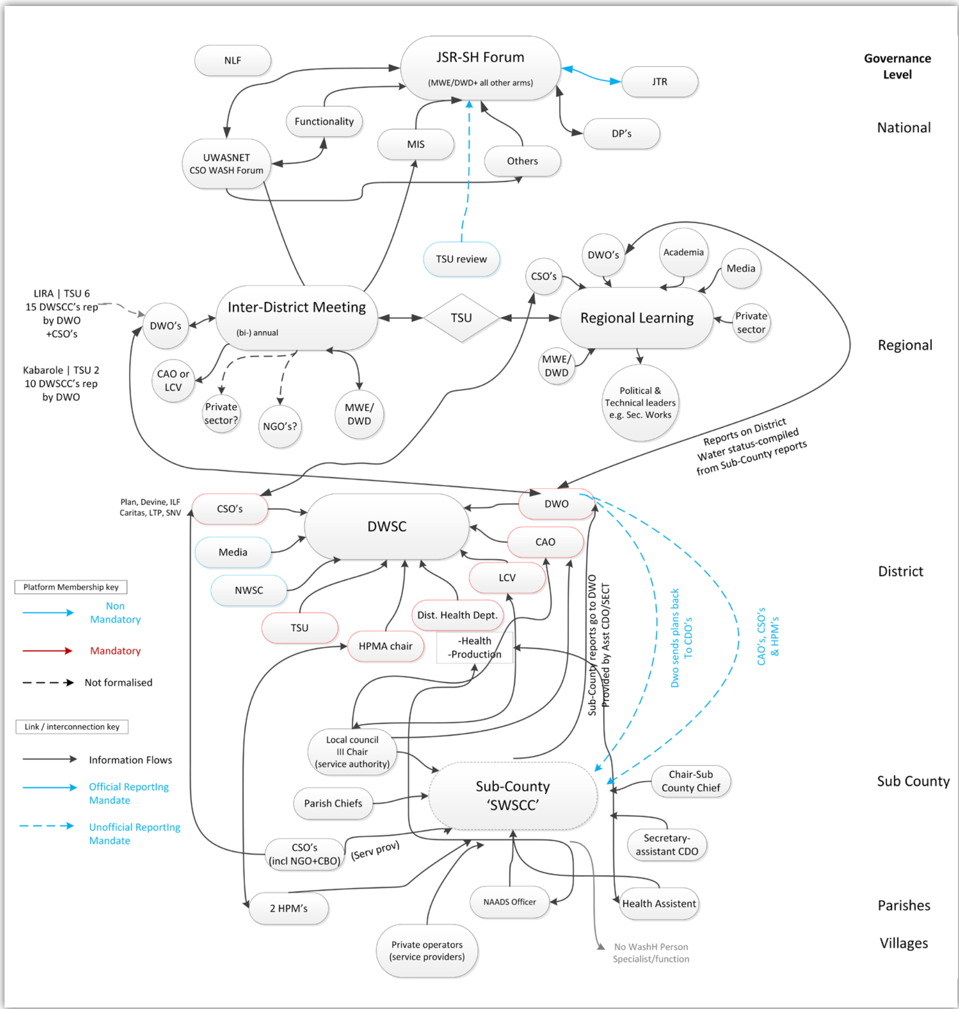


Figure 11. Rural water sector actor landscape, Republic of Uganda

Source: Casella et al. (2013)

The actors depicted hold different but often overlapping priorities. Each actor —individual, organisation or network—has capabilities, beliefs, values, skills and resources that evolve over time and guide how the actor acts, and interacts, with others. This high degree of interconnectedness creates multiple feedback and feed-forward loops: actions, interactions, dependencies and networks are interconnected through information, financial and human resources, trust, directives, etc. that span hierarchical levels and time scales (Dijkema et al., in Dam et al., 2013, p. 2). To help interpret the actor landscape, a key is provided in table 2.

Acronym	Full Title
CAO	Chief Administrative Officer
CBO	Community Based Organisation
CDO	Community Development Officer
CSO	Civil Society Organisations
DHD	Distric Health Department
DP's	Development Partners
DWD	Directorate of Water Development
DWO	District Water Officers
DWSCC	District Water and Sanitation Coordination Committee
GoU	Government of Uganda
HPMA	Handpump Mechanic Association
IDM	Inter-District Meetings
JSR-SH	Joint Sector Review Stakeholder Forum
JTR	Joint Technical Review
LC 3 / LCIII	Local Council level 3
LC5 / LCV	Local Council level 5 / District Chairperson
MIS	Management Information System
MWE	Ministry of Water and Environment
NAADS	National Agricultural Advisory Services
NGO	Non-Governmental Organisation
NLF	National Learning Forum
NWSC	National Water and Sewerage Corporation
SWSCC	Sub-County Water and Sanitation Coordination Committee
TSU	Technical Support Units
UWASNET	Uganda Water and Sanitation Network

Table 2. **Key for rural water sector actor landscape, Republic of Uganda**

Even this visual representation does not fully represent the full complexity of the Ugandan rural water sector. For instance financial flows and exchanges between levels are not well depicted, neither are power and interest relations that inform how actors interact.

Following the development of this understanding of the rural water sector as a complex, adaptive, socio-technical system, it was evident that the one-dimensional boundary object – the actor landscape – could usefully depict key actors and (inter-)connections within the water sector. The dynamics arising from the interactions of agents following set institutions are however, not depicted. Nonetheless, if we understand institutions as a set of rules to organise repetitive activities and shape human interaction (Gardner and Ostrom, 1991, Ostrom, 2011) it becomes possible to 'conceptualise the dynamic interplay between actors and structures' (Geels, 2004, p.897) – a fundamental step in creating a model that could offer more meaningful representation of a real-world scenario and thereby become more useful to policy makers and practitioners.

3.2.7 Agent Based Modelling

As a computational model that simulates actions and interactions between autonomous agents, the main elements modelled in an agent based model include the agents, the environment and time. The agent is the smallest element of an ABM (Dam et al., 2013). Agents are autonomous and act based upon states and rules. Agents interact within an environment which is everything that the ABM encompasses, but which is not an agent (Dam et al., 2013).

The environment is used to structure the (inter-)actions of agents. In this work the environment contains rules, or institutions, set out by national government which in turn determine behaviour of agents at district government level. Time is an important element. A time step in an ABM, called a tick, represents a discrete measure of time during which agents (inter-)act according to specified sets of rules. A guiding principle for determining tick duration is that it should represent the smallest time step of interest in the system under examination. Furthermore, the parallelism of time is assumed in an agent based model (Dam et al., 2013) meaning it is assumed that all actions within a tick are performed in parallel. In the model these are actually implemented one by one in sequential order.

In the simulated system, if multiple agents perform an action, the order is randomly chosen by the software (Wilensky, 2016). This is important as interdependent actions can result in different outcomes depending upon the order in which they are implemented. A final consideration is the total simulation time which reflects the greatest time scale of interest in the real-world setting.

Given these salient features of agent based modelling, the choice was made to select this experimental tool to examine arising systemic level changes over longer periods of time than are reasonable to research in real world settings. Agent based models (ABMs) examining challenges in water resource conflict management at watershed level (Akhbari and Grigg, 2013), water resources planning and management (Berglund, 2015; Hyun et al., 2019; Valkering et al., 2009) and domestic water management in an urban setting (Galán et al., 2009) indicate the potential of ABM as a suitable tool for exploring problem scenarios in the water supply sector. ABMs may be extended to include more, and different, combinations of prevailing institutions, agents, or inputs from the environment, offering policy and decision makers a useful decision support tool. A common means for conceptualising the water service sector is not however, found in the literature.

3.2.8 A common language to learn about institutions and change

Two approaches to analysing relationships and interactions in a real-world setting involve institutional analysis and development (IAD) (Polski and Ostrom, 1999) and the 'grammar' of institutions (Crawford and Ostrom, 1995).

The grammar of institutions, known by its acronym ADICO, and the IAD framework together make explicit the regularities, or patterns, of human behaviour, thereby providing a consistent foundation for a computational model to simulate patterns of interactions among agents in a given system following a set of rules.

In the grammar of institutions provided by ADICO, the patterns of interaction of agents are delineated into the **A**ttributes (participants), **D**eontic (obligated, permitted, forbidden, etc.), a**I**m (action or outcome), **C**ondition (parameters when an ADICO statement applies), **O**r else (sanction) (Crawford and Ostrom, 1995).

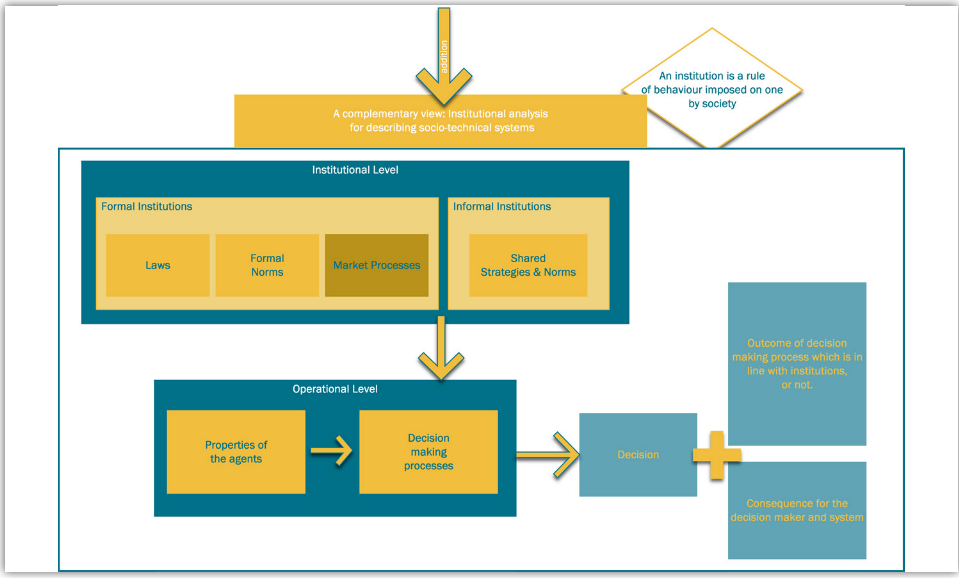


Figure 12. Institutional Analysis and Development Framework

Source: Adapted from van Tongeren, 2016. (adapted from Polski and Ostrom, 1999)

This 'grammar' is selected as a means to rigorously describe the prevailing institutions in a given action arena. When applied consistently, the grammar can be used to articulate and observe the rules of the game – both formal and informal – as they evolve following from interactions and choices of individual agents under certain conditions and parameters.

Crawford and Ostrom establish the grounds for considering institutions as norms and regulations whereby *institutions as norms* assumes that many patterns of interaction are based on a group of individuals' shared perceptions about proper and improper behaviour in particular situations (Crawford and Ostrom, 1995), and *institutions as regulations* assumes that many patterns of interaction are based on a common understanding among actors. An institutional grammar makes it possible to examine different institutions such as norms (both formal and informal in nature), laws and shared strategies (Crawford and Ostrom, 1995). ADICO includes sanctions ('or else') and amounts to laws, ADIC (without sanctions) are 'norms' and AIC (without the duties and obligations) are shared strategies. Unlike shared strategies and norms, laws alone have sanctions (the o from 'or else').

Figure 12 separates the operational from the institutional level. On the institutional level, formal institutions and informal institutions are apparent. Market processes are recognised as an institution, but, given the indirect relation of market processes on rural water service levels and tariffs, they are excluded in the conceptualisations. Here, institutional levels operate through laws, norms and shared strategies and operational level actors focus on priorities and decision making.

Priorities of the agents are taken into account in decision making (Polski and Ostrom, 1999) and may be rational or irrational; in other words, agents are conscious and capable of self-reflection. The decision may or may not be in line with the institution, and if not, consequences may ensue. For example, a water user who draws water without paying for the service places a higher priority on obtaining water than on obeying the law on water tariffs but risks receiving a fine or losing access to the safely managed service.

The grammar of institutions and IAD offer a means to structure the description and analysis of socio-technical systems systematically by recognising that while individual behaviour is not easily extractable, formal social rules and institutions are fairly well extractable and therefore measurable (Crawford and Ostrom, 1995; Ghorbani, 2013). To further decompose and formalise the problem arena related to water service failure from a systems perspective, an analytical framework based upon IAD was developed.

3.2.9 Modelling Institutions | the MAIA framework

The IAD framework was formalised and extended in the *Modelling agents based on Institutional Analysis* (MAIA) framework, which integrates social structures such as policies, legal frameworks and shared strategies (institutions) into agent based models of socio-technical systems (Ghorbani, 2013). Following the IAD framework, the creators of MAIA organised the meta-model into five structures that '*…serve as place holders (i.e. categories) for related concepts:*

1. *Collective structure: agents and their attributes*
2. *Constitutional structure: the social context*
3. *Physical structure: the physical aspects of the system*
4. *Operational structure: the dynamics of the system*
5. *Evaluative structure: the concepts used to validate and measure the outcomes of the system'*

Source: Ghorbani (2013), p. 31.

The MAIA framework is suited to the approach in this study as the researcher gradually completes the description of these structure categories during the iterative modelling process. In the case of collaborative modelling, the iterative approach to developing the system description and model narrative means that the resulting simulation represents a collaboratively developed system depiction shared by stakeholders, incorporating the richness of their different views, mandates and interests. IAD was selected as the theoretical framework and MAIA for its application in operationalising the system conceptualisation and modelling activities described in Chapters 4 and 7.

3.3 Insights from theory

From the literature review, two key knowledge gaps were identified, namely domain-specific gaps and methodological gaps.

3.3.1 Domain-specific gaps

The role of learning has been located as a feature of sector policy processes. However, specific mechanisms for, and different types of, learning approaches, and their impact on the sustainability of rural water service levels - are not specified in the existing literature.

Additionally, while 'systems-informed' approaches are increasingly adopted, this mind-set and way of working is open to multiple interpretations. How can such an approach be operationalised by practitioners and policy makers alike? Here too there exist gaps in the literature and knowledge base.

3.3.2 Methodological & theoretical gaps

There exists a gap in the language and theoretical framework needed to conceptualise and model policy interventions in a multi-level multi-actor water service delivery system from a systems perspective, and specifically a socio-technical perspective. There is an incomplete understanding about how Ostrom's IAD concepts could be applied to governance of water services delivery as well as incomplete insight into key institutional processes such as concerted learning processes and mechanisms of vertical and horizontal information exchange. Lastly, the literature about agent-based models built based upon collaborative (action) research methods such as group problem analysis, actor landscape mapping, institutional analysis and stakeholder interviews to study water services delivery challenges in Sub-Saharan is sparse.

3.3.3 Research Questions Revisited

Now that the main theoretical lenses and gaps are identified, the research questions have been further refined into:

RQ1: What system-level insights do complexity sciences offer for the analysis of water services policy and implementation measures in the Republic of Uganda when a policy intervention, selected through a collaborative action research approach, is simulated in an agent-based model of the rural water sector?

RQ2: How is it possible to conceptualise institutional interactions in the rural water services sector from a complexity sciences perspective in an agent-based model based upon collaborative model conceptualisation processes?

RQ3: What is the potential of computer based (*in-silico*) testing of policy scenarios in an agent based model for insights into actionable strategies for delivering systemic change based upon social learning?

3.4 Research approach

This section sets out the research approach taken in this study which entails collaborative iterations of theoretical studies, empirical studies, model conceptualisation and experimentation. An interdisciplinary, mixed methods approach incorporated theories, methods and tools from the systems sciences, design sciences and social sciences for their relevance in addressing the research questions. An important part of the research comprised the cases upon which the collaborative modelling exercises were conducted. It was therefore key to select those cases for which rich empirical data would be available, and in which the researcher would be able to set up a collaborative and iterative modelling approach. In keeping with studying and modelling complex evolving systems, the research approach was iterative and comprised in-between learning. Hence, with each subsequent iteration a conscious choice was made to study and model a more complex case study.

3.4.1 Empirical data processing

The Triple-S Uganda action research initiative features as the central case study in this research. This work draws upon empirical information from the rural water sector in Uganda, information from sector scoping studies (Nimanya et al., 2011;

Kahangire, 2013 and Bitetee, 2013), analysis of national policy and action research initiatives and knowledge products developed by Triple-S consortium partners.

The mapping and analysis activities entailed compiling empirical and policy sources of information, desk research to elaborate a conceptual framework on mechanisms for change in multi-actor, multi-level complex systems. Methods from design research, collaborative analysis and mapping techniques were used to gather information about actor behaviour in a synchronous manner with Triple-S Uganda action research activities. The intention was to obtain the necessary theory and practice insights for this study in a minimally disruptive manner for Triple-S Uganda's programme activities.

The action research initiatives implemented by the Triple-S Uganda consortium provided a rich source of suitable cases. Following the literature review on systems thinking and modelling, characteristics of Uganda's water sector that lend themselves to being formalised in system descriptions and model formalisations include:

- a well-structured WASH sector, depicted in Fig. 10 and 11, buttressed by a robust policy framework;
- a deliberate multi-actor stakeholder engagement approach spanning all sector levels to address pressing challenges;
- stagnation of a key desired system output (rural water service levels); and,
- multiple promising policy solutions with interdependencies.

A final selection of cases, of increasing complexity, was made based upon the match with the initial research questions and the readily available empirical evidence from the field work happening in parallel as well as the proximity and access to empirical evidence from domain experts and key stakeholders during this study. The methods used to conduct collaborative model conceptualisation are detailed in the next section. Salient synchronous and asynchronous activities and outputs of this research and of Triple-S, including milestones in the professional and academic experience of the researcher, served as baseline knowledge and informed choices in this research.

3.4.2 Approach to collaborative model conceptualisation

In *Dissecting the Social: The analytical tradition in sociology*, Peter Hedström, states is not sufficient to understand why actors 'act as they do' (2005, p.9), but researchers must seek to explain 'why, acting as they do, they bring about the social outcomes they do.'

Neely (2019) reflects that systems thinking is embodied in "…*group model building as a transdisciplinary method for research and development. Group model building is a highly participatory method and its use with mixed groups has been effective in many areas. The application of transdisciplinary methods within development practice is …a means of increasing the diversity of voices in WASH and ensuring that we hear from the residents of development focused communities.*" (Neely et al, 2019).

In this study an interdisciplinary, mixed methods approach was employed to harness theory and methods from different disciplines: complexity sciences, social sciences and policy analysis. This approach to *collaborative model conceptualisation* to arrive at a useful understanding of the system and agent behaviour is depicted in Figure 13. This approach made it possible to operationalise the system description generated through collaborative problem analysis and actor landscaping sessions. This approach allows for description and analysis of formal and informal rules and shared strategies that guide micro-level agent interactions that give rise to observed system-level patterns. The literature review, sector landscape mapping and policy analysis were the basis for the formulation of algorithms required to build computational models. The transdisciplinary nature of this approach ensured perspectives and knowledge from different experts and stakeholders informed this work.

The research approach was deliberatively collaborative and iterative. Real-world water service delivery challenges were selected by the Triple-S Uganda team, led by Ministry of Water and Environment of Uganda, as action research 'experiments'. These experiments engaged representatives of the national, regional and local government and civil society organisations in the Ugandan water sector and included Mobiles 4 Water (M4W), the Hand Pump Mechanic Association and the Sub-county Water Supply and Sanitation Boards experiments. These were analysed in the sector landscape mapping workshops in 2013 and 2014. Given their real-world relevance to key sector stakeholders, the experiments were formalised as institutions (after Crawford and Ostrom, 1995) in model conceptualisations in Chapters 4 - 7 to explore their effects on agent behaviour and arising system level dynamics in the simulated system. The choice to conceptualise problems commonly faced by sector policy makers and practitioners ensured salient stakeholder perspectives grounded the research with empirical evidence from their daily experience.

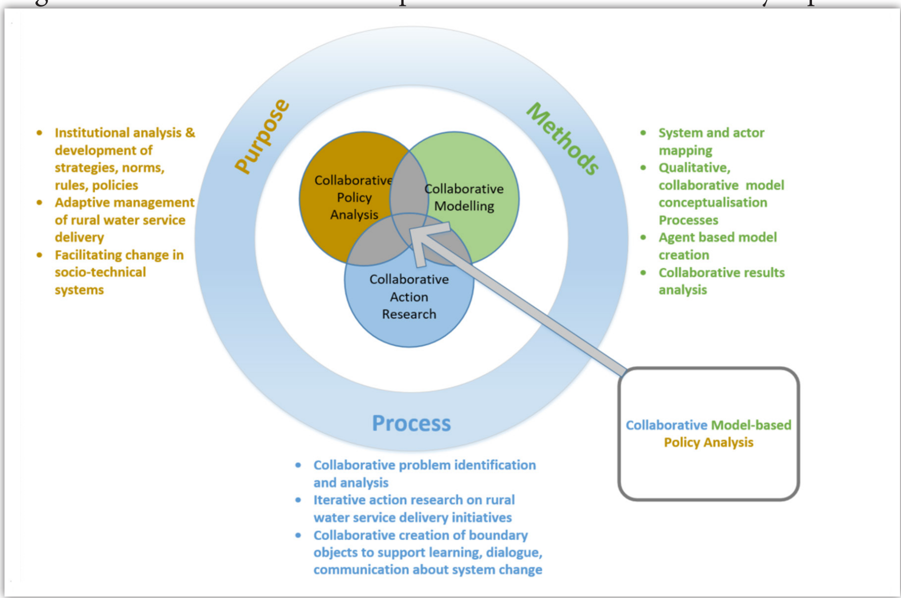


Figure 13. Theory, methods and approach

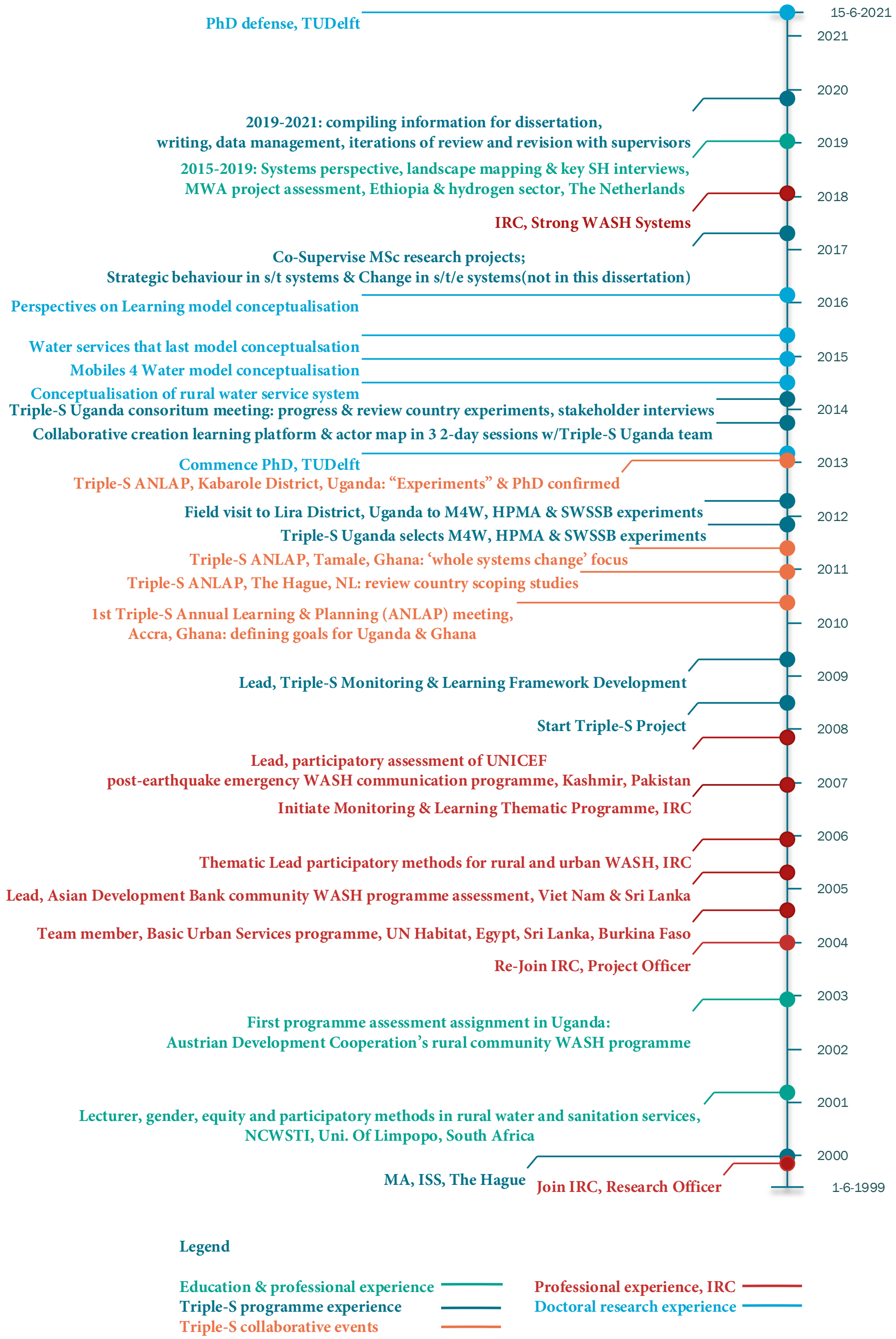


Figure 14. Research Timeline

Appropriate research methods were employed to gather insights and information from key stakeholders and direct colleagues known to the researcher. Semi-structured interviews were conducted to gather and triangulate information about the structure and dynamics of the rural water sector and agent behaviour. A semi-structured method was employed to elicit open-ended responses by interviewees about their empirical experience beyond the insights deliberately sought on agent roles, behaviour choices and emergent system dynamics. This information informed initial model conceptualisations and later refinements. Detailed information about these interviews in provided in Chapters 4 - 7.

The collaborative aspect of this research included problem identification and analysis conducted in Uganda with key stakeholders involved in the Triple-S Uganda consortium who identified and analysed pressing sector challenges and promising action research experiments, the sector landscape mapping sessions led by the researcher with the Triple-S Uganda team and expert consultations on the veracity of the conceptualisation in feedback sessions. These iterations of project and research activities moved between the distinctions of participatory modelling and collaborative modelling as delineated by Basco-Carrera et al. (2017, p104). In some research steps, committed groups with an interest and role in addressing the identified problem were directly and intensively involved in key steps of Triple-S Uganda and this research following the 'representative' modelling discussed by Voinov and Bousquet (2010) and Voinov et al. (2016). In other steps, stakeholder involvement was limited to discussion and feedback on steps and outputs generated by the researcher in a more instrumental manner (van Bruggen et al., 2019). The timing, process and role of key stakeholders are described in sections 3.4.3 and 3.4.4.

3.4.3 Research timeline and process

Since the context and the role of the researcher in this empirically-driven, practice-oriented research are important in this research, the timeline of the research steps and the role of the researcher in the decade preceding the modelling efforts are clarified in Figure 14 and in this section. Supplemental details about this timeline and sequence of activities - of the Triple-S project groundwork and the analytical and modelling work - are provided hereafter to further illuminate the research logic.

1. **Pre-2008**

The researcher gained academic and professional experience as a researcher, educator and practitioner in rural and urban water service delivery in different contexts across Sub-Saharan Africa, the MENA region, South and South East Asia, Latin America and Eastern Europe.

2. **2008-2014: The Triple-S project**

Empirical information gathered and documented between 2008 and 2014 by a range of colleagues and experts involved in the Triple-S project, including the researcher, cited throughout this work informed choices related to the system description, the landscape map and model conceptualisations.

3. **2013-2014: Commence doctoral research project, ongoing Triple-S project activities**

The start of the doctoral research process signaled a period of desk research that occurred simultaneously with collaborative sector landscape mapping led by the researcher and model conceptualisation activities. Project and sector-led timings determined these parallel tracks of empirical and theoretical research steps. The results of this phase were a literature review, information gained through iterations of collaborative model conceptualisation, stakeholder consultation & validation.

Perhaps most significantly, in a series of workshops held in 2013 and 2014, the Triple-S Uganda learning facilitators, facilitated by the researcher, created the landscape map of actors and institutions depicted in Figure 11. This boundary object depicts the rural water service sector in the Republic of Uganda as a constellation of interconnected agents, located across multiple governance levels (community, district, municipal, regional, national), with the shared aim of ensuring access to water services by rural populations. This landscape map is the basis for all of the conceptualisations in this study. Desk studies of relevant literature and policy documents were conducted as well as key stakeholder interviews to triangulate and substantiate existing sources of information gathered from the empirical work conducted during the course of the Triple-S project.

4. **2015-2018: Model creation, consultation, modification, analysis & sense making of results**

Iterative rounds of model conceptualisation resulted in the models presented in Chapters 4 - 7. The model conceptualisations, the resulting agent-based models and their results were shared and discussed with colleagues in both The Netherlands and Uganda for the purpose of verifying the veracity of these research outputs. At each stage, modifications were made to the conceptualisations to ensure stakeholders' perspectives were incorporated in the designs. A detailed description of the stakeholders involved in the iterations of action research and model conceptualisation activities is presented in Table 3.

5. **2019-2021: Compiling research outputs, reflection, writing**

Phases 1 - 3 involving iterations of research agenda setting, action research, collaborative model conceptualisation and analysis were followed by a period of reflection on research data, inputs and outputs from the first three research phases and eventually dissertation shaping and writing.

The individual steps involved in the development of the conceptualisations and designs presented in Chapters 4 - 7 are visually depicted at the outset of those chapters. The graphics indicate which inputs from theory and empirical work informed the work presented in that chapter along with the outputs as a guide to readers. This visual aid is supported by more a detailed explanation of the steps, the questions each model set out to address, key choices made in the conceptualisation and modelling process and who was involved in the collaborative processes.

The legend for the individual model graphics is provided in Figure 15.

Further details about the steps are provided at the outset of Chapters 4 - 7 on the theories, empirical evidence and collaborative iterations that informed choices made in the model design and conceptualisations presented in those chapters.

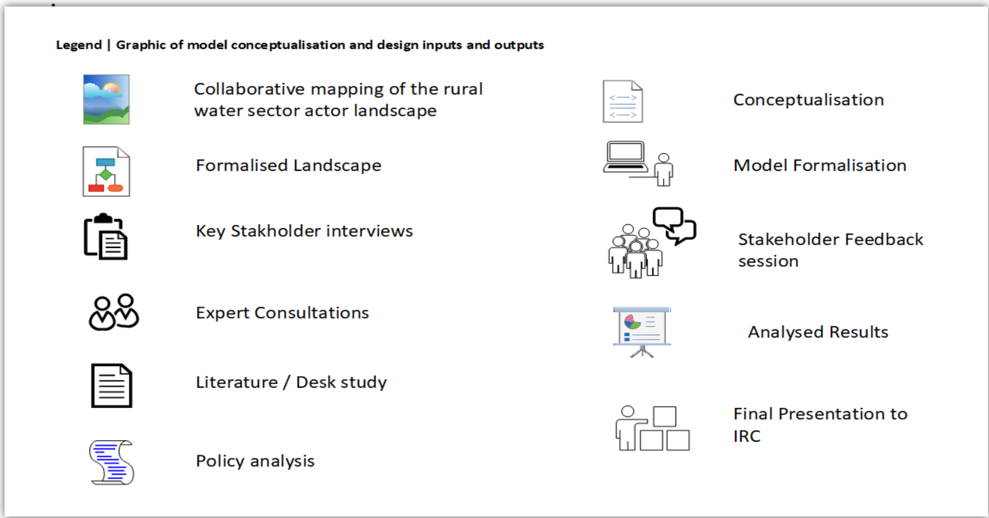


Figure 15. Legend of inputs and outputs of model conceptualisations

3.4.4 Key stakeholder involvement in this research

Key stakeholders, many familiar with Triple-S and a few with sector knowledge but no in-depth knowledge about Triple-S, were engaged at various stages in the research process. An anonymized overview of these stakeholders, their relation to Triple-S and their role in this research is provided in Table 3.

Organisation	Role	Contribution
Uganda Ministry of Water & Environment	Principle Engineer, Directorate of Water Development, Triple-S Liaison Officer	Collaborative selection, planning Triple-S action research. Semi-structured interviewee on Triple-S approach to sector change.
IRC Uganda	Country Director IRC Uganda / Triple-S Project Lead	Collaborative selection, planning Triple-S action research. Semi-structured interviewee.
IRC Uganda	National Learning Facilitator	Collaborative selection, planning Triple-S action research. Co-creation sector landscape. Expert testimonial.

Organisation	Role	Contribution
IRC Uganda	Learning Facilitator Lira District	Co-creation sector landscape, planning Triple-S action research, expert consultation on conceptualisations. Expert testimonial.
IRC Uganda	Learning Facilitator Kabarole District / Regional WASH Advisor IRC Uganda	Collaborative selection, planning Triple-S action research. Co-creation sector landscape. Expert testimonial. Semi-structured interviewee conceptualisation and Perspectives on Social Learning model. Stakeholder feedback on conceptualisation, M4W and Perspectives models.
IRC Uganda	Triple-S Research Coordinator	Co-creation sector landscape. Expert testimonial.
IRC Uganda	Triple-S Communication and Advocacy Officer	Collaborative selection, planning Triple-S action research. Co-creation sector landscape. Expert testimonial.
IRC Uganda	Researcher Officer	Collaborative selection, planning Triple-S action research. Semi-structured interview on conceptualization and Perspective model. Main author report on *Performance of Service Delivery Models in Uganda* report.
IRC Wash	CEO	Expert advisor on model conceptualisations, feedback M4W, Perspectives on Social learning models.
IRC Wash	Monitoring & Learning Officer	Expert advisor Water Services that Last model
IRC Wash	Former Director IRC Uganda	Semi-structured interviewee conceptualization.
IRC Wash	Former Director IRC Uganda	Semi-structured interviewee conceptualization.
IRC Wash	IRC Africa Regional Manager	Semi-structured interviewee conceptualization.
SNV Uganda	WASH Advisor	Semi-structured interviewee Triple-S approach to sector change. Expert advisor Triple-S action research.
Water Aid Uganda	Knowledge Management Coordinator	Semi-structured interviewee Triple-S approach to sector change. Expert advisor Triple-S action research.
UWASNET	Executive Director	Expert advisor, Triple-S action research.
Water for People	Country Director	Expert advisor, Triple-S action research initiatives. Main author *Triple-S sector scoping study*, 2011.
Independent Consultant	WASH advisor, East Africa Region	Expert advisor, Water Services that Last model.
IHE Water Institute Delft	Researcher, urban water systems, modelling expert	Semi-structured interviewee on model conceptualization and observed dynamics in model.
TU Delft, Faculty of TPM	Researcher, water governance policy, Nile River Basin	Semi-structured interviewee on conceptualization of multi-level governance system.

Table 3. Anonymized Overview of Key Stakeholder roles and contributions

For the purposes of this dissertation, the overview of collaborating stakeholders has been anonymized. The semi-structured interview formats and transcripts (Knipschild, 2016, Mirembe et al., 2014, van Tongeren, 2014), testimonials (Mirembe et al., 2014), the sector scoping studies (Nimanya et al., 2011 and Kahangire et al., 2013) and the performance of service delivery models assessment report (Bey, Abisa and Magara, 2014) are openly available in the public domain and cited in the references of this dissertation and referenced again in the appropriate case study chapters.

3.5 FAIR Research Principles and Practices

In keeping with the FAIR Data Principles (that research data, meta-data and code are findable, accessible, interoperable and reproducible), a central aim of this research is to go beyond reporting on the research results arising from analysis of the models developed in this research. The methods, procedures, underlying pseudocode and code are openly available with Ugandan national policies and country data available via the MWE website; project information available on IRC's website; underlying studies and (pseudo)code available in 4TU.ResearchData repository. These sources of information are openly available in the public domain and are cited here to enhance the potential of this work being found and reused by other researchers to conduct further analysis or create new extensions of the models.

3.6 Outlook

The theories, methods and tools from this chapter set the scene for choices made in subsequent research steps. In Chapter 4, the water service system in Uganda is re-conceptualised from a systems perspective. In Chapters 5 and 6, two different policy problems are analysed by modelling simplified versions of the conceptualisation of the rural water service system, along with implementation of selected institutions to observe potential system-level effects. Following these examinations of the feasibility of the modelling method, in Chapter 7, a more complex policy problem is modelled and analysed, in which the modelling effort builds and expands upon these earlier research steps and choices is presented.

4

Conceptualising the System | Rural Water Services in Uganda

A system is like in dance class where one girl is at the head of the line with other girls in line behind her. When the music starts, they all dance together. That is a kind of system.

— Nieve Emily Casella, 8 years, March 16, 2019, Delft

My interest in creating anything is that it be useful.

— Alice Walker (1944 -)
Novelist, short story writer, poet and social activist

In this chapter…

… a coherent and consistent conceptualisation of the rural water sector in Uganda is set out. The conceptualisation describes the system to specifications set out in the actor and issue mapping, now through the lens of Ostrom's Institutional Analysis and Development framework. The articulation of consistent behavioural rules and choices for technical and social agents makes it possible to simulate a 'base case' that represents the constellation of interacting agents across the Ugandan water sector within the bounds of the rules of the game set out in previous research steps.

This conceptualisation offers a rich, highly detailed description of actors found in the rural water sector in Uganda along with the patterns of behaviour and interaction that may be expected arising from the application of the IAD framework. The conceptualisation and pseudocode can be used to build a model for policy analysis purposes as the narrative of agent choices and behaviours can enable policy- and decision-makers to explore potential outcomes of varying policy choices and desired end results in terms of sustainable water service levels. The model is adaptable and can be expanded, or modified to reflect another national context or policy scenario.

This chapter incorporates information about the model narrative developed as part of the Master's Thesis of S.A.E. van Tongeren, 2014: *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. S. Van Tongeren's thesis is openly accessible here via the TU Delft education repository.*

4.1 Introduction

This chapter details the design process, choices, methods and outcomes for arriving at an operable, consistent formalised description of the rural water services sector in Uganda.

The collaborative work conducted to arrive at a description of the system of agents, institutions and action patterns that also include a means by which agents can learn and adapt their behaviour represents a first critical step in the creation of an agent-based model used in policy- and decision making processes.

Following insights obtained through the collaborative action research approach and processes of the Triple-S project detailed in Chapter 3, attention shifts here to identifying a theoretically coherent and consistent approach to conceptualising the rural water sector. A consistent means to describe and model a given scenario space, complete with agent behaviour and rules of the game would establish a set of consistent 'ingredients' for building extended or modified replications of the same scenario space. This would enable rigorous, comparable *in silico* experimentation with different combinations of agents, governance levels and policy mechanisms, applying the same underlying conceptualisation and design specifications.

The chapter provides information relevant to formalising a more complex, consistent conceptualisation of the rural water service system in Uganda. Details of the model conceptualisation and formalisation, informed by Ostrom's Institutional Analysis and Development (IAD), are provided. The choices made to arrive at this conceptualisation – model parameters and assumptions – are presented. Domain expert validation of the formalised description and conceptualisation is documented. The chapter concludes with a discussion of both the process and outcomes generated.

4.2 Collaborative Model Design Approach

The collaborative model design steps that inform the conceptualisation presented in this chapter are described in this section. The aim in this research step was to arrive at a comprehensive conceptualisation of rural water services for use in creating consistent, replicable and comparable agent based models (ABM) of multi-level, multi-actor systems.

Following the overall mixed method approach, an initial desk study was conducted to ground information and choices arising from empirical experience in relevant theory about socio-technical systems, institutions and their evolution over time, including potential mechanisms for change. Policy documents included the National Water Policy (GoU, 1999), the National Framework for Operation and Maintenance of Rural Water Supplies in Uganda (GoU, 2020), the revised District Implementation Manual (GoU, 2013).

Expert consultations were conducted with Triple-S and IRC staff to elicit feedback on the landscape map, the proposed initial selection of agents and their interactions as well as the theoretical framework choices. This feedback was incorporated into the initial model conceptualisation.

Thereafter a series of six semi-structured interviews were conducted with stakeholders closely involved in the Triple-S Uganda initiative from the outset. The interviewees included the IRC Uganda country director, IRC Uganda research officer, IRC Uganda Triple-S national learning facilitator, two former directors of IRC Uganda, IRC Wash monitoring and learning officer. These model design inputs and outputs are summarised in Figure 16.

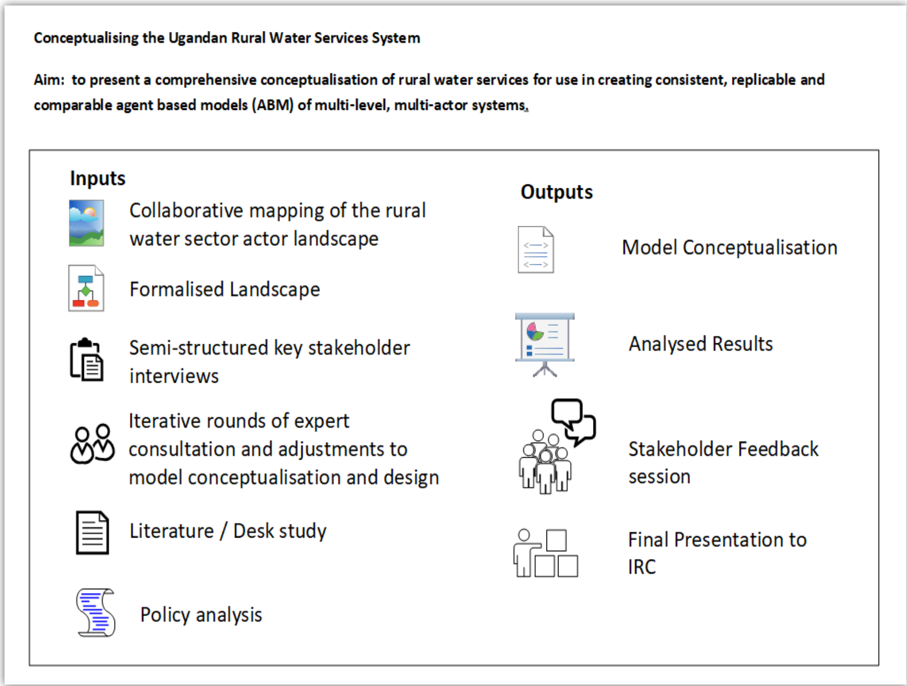


Figure 16. Uganda rural water system model conceptualisation inputs & outputs

Recordings of the interviews were transcribed for analysis purposes. An initial review by the interviewer was conducted to filter and cluster responses along thematic lines and for further validation. Given the role of the researcher as an embedded actor in the Triple-S project, the interviews were conducted, transcribed and initially processed by S. van Tongeren, MSc candidate and student researcher who provided the transcriptions and pre-processed results to the researcher. In consultation with one another and modelling expert advisors, the qualitative interview data was used to develop formalised patterns of interaction described in the model narrative in section 4.6.

In parallel, in early 2014, semi-structured interviews with four Triple-S consortium partners from the Government and civil society sectors were conducted by the researcher in Uganda. These key sector actors reflected on their experience of the learning approach being pursued by the Government of Uganda and supported by Triple-S (Mirembe et al., 2014). These interviews were recorded and transcribed and are available in the public domain (Mirembe et al., 2014). The qualitative information from the semi-structured interviews and expert consultations was used to reflect upon and modify the system description and to bolster choices made in the sector landscape mapping exercise and eventual model narrative detailed in section 4.6.

This mixed methods approach to information gathering resulted in several key design choices. Given the focus in policy and in practice on strengthening water services at the most local level, the conceptualisation focuses on the agents and interactions from the District level government to the level of village water users and water points as the agents bearing the most influence on the local water service levels. Agents from MWE, development partners, the regional-level Technical Support Unit (TSU), the physical world and the community are embedded in the environment of the conceptualisation, but they are not formalised as interacting agents in the model. Lastly, to the conceptual framework created by combining IAD and institutional evolution determines that agent interaction arises from the exchange and evolution of information between and among social and technical agents about the state or value of certain properties in the system (e.g. water availability or service level) or in the form of requests. The formalised system, agent description and model narrative articulated based upon these choices are presented in sections 4.5.

A final presentation was held to staff of IRC in the Hague and Kampala in 2014 to present and discuss the outcomes of the model conceptualisation design project as well as their significance.

4.3 An expanded understanding of Uganda's rural water sector

Uganda is generally regarded as having a well-structured water sector with coherent policies and strong coordination mechanisms (Nimanya et al., 2011). As detailed in Chapter 2, the legal framework of formal laws, norms and standards for water services in Uganda is set out in a series of national policy directives. The organisational structure it comprises, along with the distribution of roles and responsibilities across administrative levels, is depicted in Figure 17.

The Ministry of Water and Environment (MWE) is the national authority bearing the mandate to protect and manage Uganda's water resources. Within MWE, the Directorate of Water Development is responsible for "providing overall technical oversight for the planning, implementation and supervision of the delivery of urban, rural water and sanitation services, and water for production across the country".

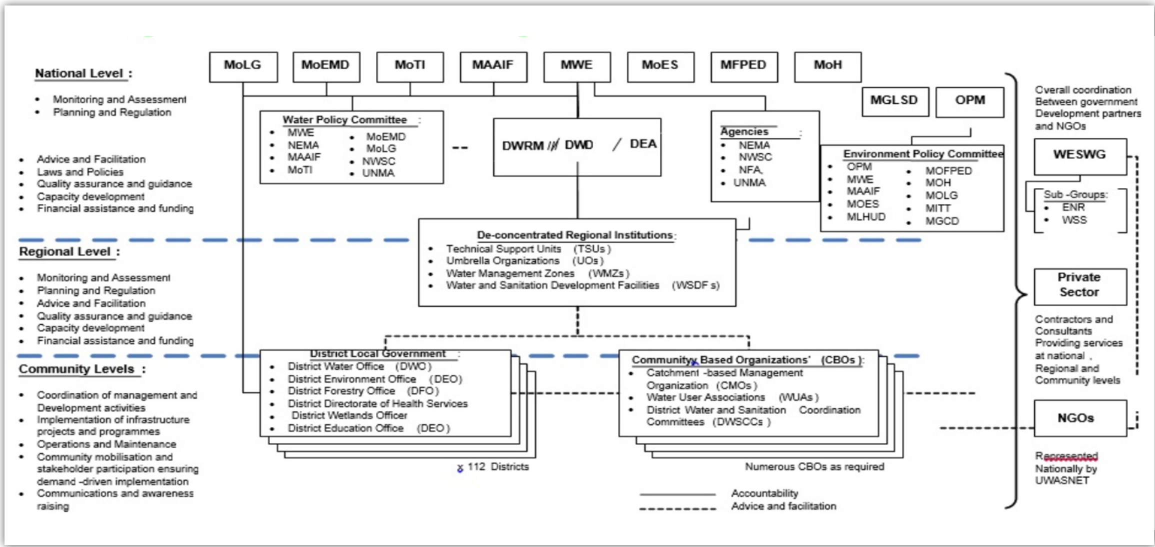


Figure 17. Republic of Uganda: Water and Environment Sector Organisational Structure

Source: MWE, 2018, http://www.mwe.go.ug/mwe/institutional-framework-water-and-environment

MWE is also responsible for "regulation of provision of water supply and sanitation and the provision of capacity development and other support services to Local Governments, Private Operators and other service providers." (MWE website https://www.mwe.go.ug/directorates/directorate-water-development, 2020).

At national level other government agencies such as the Ministry of Finance, Planning and Economic Development, Ministry of Local Government, and Ministry of Health are directly involved in WASH sector activities and decisions. Other government bodies have an interest in water services, but less direct influence over policy.

Actors from across the institutional levels meet regularly in technical and programme coordination committees, including the annual cycle of Joint Sector Performance Review and Planning.

4.4 Expanding the system decomposition

A simple system decomposition was set out in Chapter 3 in describing the proof-of-concept models. To arrive at a more comprehensive and detailed system decomposition, additional information was added through desk research and stakeholder consultations.

The prevailing model for the delivery of water services in Uganda is community based management (CBM). In the CBM approach, WUCs are established at the village level are designated as the water provider responsible for the day to day operations and (minor) maintenance of water services, including administration of water services – mainly collection of water user fees, bookkeeping and inputs to annual water development plans. The WUC is run by a volunteer committee that includes chairperson, secretary, treasurer, caretaker and other ad hoc positions.

The technical infrastructure for rural water services are points sources, piped network with household connections or a mixture of the two.

Recall Figure 11 in Chapter 3 depicting the actor landscape. Developed during a series of collaborative sessions with Triple-S Uganda team, the figure depicts the distribution of key actors across levels of the sector governance system and their interconnectedness through loops of information flows, resources and reporting mandates and authority.

Based upon the initial mapping of key sector actors in Figure 11, the key agents influencing rural water services levels in Uganda are: district water offices (DWOs), handpump mechanics (HPMs), water user committees (WUCs), water users (WUs), local government (LG), Ministry of Water and Environment (MWE), development partners and Technical Support Unit (TSU). The physical world and the community are embedded in the environment. Important technical artefacts are water points (WPs) and the database of failed water points. The basic pattern of interaction in the simulation, entails flows of information. This is the basis of the interactions between interactors, objects and the environment depicted in the model conceptualisation.

Establishing this shared understanding about the actors and their interconnecting factors informed subsequent choices about the formalisation of an agent based model described in the following section.

4.5 Formalising the system description

The pattern observed prior to and during the research is that rural water points in Uganda are neither adequately, nor regularly, maintained and repaired by the responsible party: the water service providers, in this context the water user committees. This pattern contributes to a low rate of functioning water points whereby water users do not receive nationally determined basic water service levels (Schouten & Moriarty 2013). Water service authorities and water users do not put pressure upon, nor incentivise, water service providers to do their job effectively and sustainably (Smet 2013). Additional observable patterns include:

- Sub-standard WSLs are a frequent reality for rural water users.

- Too little/no maintenance of the WP is conducted by the HPM.
- Money to meet the costs of water supply and water point maintenance and repair is not regularly collected by WUCs, or is collected late.
- WUs are not inclined to pay WUCs for the repair of a WP, especially when dependency on the WP is low because alternative, albeit unprotected, water sources are available, or when trust in and satisfaction with the WUC is low.
- Fines as a means to motivate the desired behaviour are not employed to incentivise WUCs or HPMs to act as more effective functioning entities.
- (Nabunnya 2013; Schouten & Moriarty 2013; Smet 2013; Lieshout 2013; Magara 2013)

It is important to understand some of the roots of failures in the rural water system and in particular to understand why changing motivations of relevant actors can result in different outcomes. As Peter Hedström says in *Dissecting the Social: The analytical tradition in sociology*, it is not sufficient to understand why actors 'act as they do' (2005, p.9), but researchers must further seek to explain 'why, acting as they do, they bring about the social outcomes they do.'

The following sections describe the fundamental components of the system under study in this research, namely the physical system, the actor network, properties of the actors and the prevailing institutions comprised in this understanding of the problem space. This understanding was developed based upon the literature review, a series of participatory sessions held with Ugandan learning facilitators, key sector stakeholder interviews conducted by the researcher with sector stakeholders in Uganda in 2014 and domain expert consultations conducted by S. van Tongeren at IRC Wash in 2013-2014. Further desk research was conducted to apply Ostrom's IAD framework and operationalise the concepts related to information transfer and evolution using memetics.

4.5.1 The physical system

While a range of physical infrastructure types are found in rural areas, the most commonly available infrastructure accessible to water users are water points (WPs) (GoU, 2013) shared and used by members of the community. As noted by Magara (2018), in Uganda, " [a] water point is a point source from which water is abstracted, such as a borehole, well or spring, and water supply/distribution points, such as a hand pump installed on a borehole or a standpipe in a small piped network".

Components of the physical system included in the model conceptualisation are the water points (WPs) and Database of Failed Water Points (Database of Failed WPs) developed for tracking purposes in this conceptualisation. The Database of Failed WPs is included as a means to gather information about how the status of WPs is ascertained, shared and acted upon by actors in the given scenario. It is a feature of this simulation and not based upon national water point records possibly curated by the Ministry of Water and Environment or more local level water service authorities.

4.5.2 Social actor network

The pattern of action and interaction that give rise to water services delivery comprises a network of social actors, hereafter agents, who have formal and informal roles and responsibilities in relation to the delivery of rural water services. A structured description of agents is necessary to move from static representations of roles and responsibilities towards dynamic models that can be used to explore how individual level decisions and actions give rise to system-level changes.

The social agents included in the model are described in relation to their key roles and functions in the delivery of water services. Accordingly, these agents include:

- district water offices (DWOs) fulfill the role of water service authority
- handpump mechanics (HPMs) fulfill the role of water service provider
- water user committees (WUCs) – fulfill the role of water service provider
- water users (WUs) – fulfill the role of consumer
- local government (LG) – fulfills multiple roles including service authority, provider and user
- the environment – comprising all agents found at administrative levels above District level such as MWE, development partners, TSUs, the physical environment embedded in the environment.

4.5.3 Agent properties

Agents in a given scenario space hold multiple roles, different and differing priorities, values, and norms. Agents involved in water services delivery and consumption do not always act consistently in line with processes intended to deliver nationally set WSLs. In Uganda, 'all the institutions (laws, directives) are in place to make the water services delivery system work…the difficult thing is to let people live by the rules' (Nabunnya, in Mirembe et al., 2014).

The desired emergent pattern for addressing the need for sustainable water services is that at least a basic level of service is delivered to all water users (WUs). As explained in Chapter 2, service levels are derived from nationally determined indicators: water quantity, crowding at WP, reliability, distance and water quality.

Important desired patterns in the water services delivery system are:

- Water points that function at an acceptable level of performance, in line with nationally determined standards and norms
- Basic, or higher, WSLs for all WUs

- Suitable responses to water point failures by WUC, HPM and DWO
- Realistic balance of financial resources of the WUC, HPM and DWO
- Regular maintenance that is facilitated by the WUC, executed by HPM
- Adequate supply of resources (knowledge, spare parts, new WPs and money)

A number of factors that directly or indirectly influence service levels, are described in next paragraphs. These were derived from semi-structured interviews with key informants in Kampala and The Hague over the period 2013-2014. As previously mentioned, the participatory sessions with Ugandan learning facilitators from the Triple-S project, key stakeholder interviews with sector actors conducted in 2014 and domain expert consultations held in 2013-2014.

4.5.4 Dependency and satisfaction among water users

A water user has greater motivation levels to maintain a WP in the event that the user is dependent on a particular water point and/or is satisfied with their particular WUC. Levels of water user dependency and satisfaction have a direct influence on the amount of money (henceforth: budget) that a WU is prepared to pay to a WUC for maintaining and repairing a WP.

'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.

4.5.5 Motivation of water service providers

During the interviews it became clear that the motivation of WUC and HPM can influence the WSL. The motivation of the HPM and WUC is an indication of the extent to which these actors are dedicated to doing their job towards achieving sustainable and reliable water service levels. If the motivation of these actors is low, keeping a WP working is difficult as this type of infrastructure requires a considerable amount of care. A great deal of time is required to visit all water users in their homes or place of work to collect money for the WUC funds required to pay for works related to repairs, maintenance, day-to-day management of a single water point.

In this conceptualisation, motivation is assumed to be a 'personal priority' rather than an obligation or externally coerced preference. The motivations of other actors are not taken under consideration in this aspect of the model design, because:

- The motivation of WUs is represented by a user's dependency upon and satisfaction with a particular WP/WUC, as these indicators influence the WUs' behaviour.
- The DWOs are well educated and genuinely motivated people. 'They are gen-

uinely interested in improving the water services delivery system/technique'.

- The motivation levels of the local government are assumed to be in line with the motivation of the DWO.
- The HPMA's motivation is included in the model conceptualisation.

The motivation of the WUC and/or HPM may further be influenced by various additional factors such as:

- WUCs and HPMs may be sanctioned if they do not demonstrate motivation.
- Willingness to pay: WUs pay when the WUC requests money to cover operations and maintenance and repair costs. If WUs are unwilling to pay and water service levels are low, this creates a negative cycle. The WUC can break this cycle by calling for backup from the local government. In this event, local government forces WUs to pay amount of money requested by the WUC. This series of events provides a positive boost to WUCs' motivation levels.

4.5.6 Functionality of Water Points

The functionality of the WP is an indicator that directly influences the water service levels and in return is influenced by the amount of maintenance and repair delivered by the water service provider.

When a WP is repaired, installed or maintained, the water service level, the functionality of the WP, the dependency and satisfaction of the WUs are adapted accordingly.

4.5.7 Institutions

Agents follow informal rules as well as official policies or directives. Prevailing formal and informal rules and policies with the potential to influence the scenario space during the research period include the following:

Water Point Maintenance

The 1997 Local Government Act states that maintenance is a responsibility of the District Local Councils (LC 5) in liaison with the Ministry as the ultimate body responsible for national resources such as water (GoU, 1997). The Act empowers local government to follow its own priorities, including operations and maintenance support, and to make by-laws so that village councils can control the management and maintenance of their communal water facility.

The conceptualisation allows the HPMA to contract out maintenance of a water point to the water user committee. Maintenance contracts increase revenue earning work for a handpump mechanic and contribute to the sustainability of water points. A policy to contract maintenance to the HPMA with a quarterly payment from the WUC may also be implemented. In this case, the HPMA contacts a HPM to perform maintenance four times a year.

WUC payment policy

As part of the community-based management approach the National Water Policy of the Government of Uganda (GoU), the community bears responsibilities for water service provision (GoU, 1999). The WUC payment policy includes the possibility for WUCs to receive a small salary from the DWO for their work. This modest salary is paid provided WUC performance is assessed as reasonable. The WUC payment policy is implemented if the sanctioning policy is also implemented, otherwise the WUCs could underperform without sanction.

Policy on new water points

The MWE, through its Directorate of Water Development (DWD) is the lead agency responsible for the construction of new water points (GoU 2013). New water points can be requested through various routes. At the time of the system conceptualisation (2013-2014), most WPs were being constructed by development partners without specific requests from communities (Schouten & Moriarty 2013). This situation contributes to a higher prevalence of water points in more easily accessible areas (Nabunnya 2013).

In this conceptualisation it is assumed that more equitable distribution of water points can be brought about if the WUC knows when and how to request a new WP through the government channels. In the model design, the policy on new water points can be implemented so that WUCs, under certain conditions, can request a new WP.

HPMA policy

HPMAs are generally established by groups of hand pump mechanics with encouragement by the government. The national HPMA policy (GoU, 2013) provides HPMs with an opportunity to organise collaborative associations and the supply of spare parts in a more effective manner. The policy is that the HPMA provides spare parts and new water points if requested by the handpump mechanic. Depending on its knowledge level, the HPMA has a smaller or larger stock of products. Furthermore, when a WP is repaired, installed or maintained, the WSL, functionality of the WP, the dependency and satisfaction of the WU adapt accordingly.

M4W policy

The Mobiles for Water (M4W) policy was included in the conceptualisation. Adapted from the M4W pilot initiative led by the Ugandan MWE, IRC WASH and SNV Netherlands Development Organization between 2012 and 2014, this initiative explored whether and how mobile telephone technology could contribute to improved water service delivery levels.

Discussions with Triple-S project learning facilitators and key stakeholders revealed that it was difficult to arrange in person contact with HPMs to speak with them about broken water points due to their frequent travel over great distances.

Mobile telephone use to communicate water point failure in a timely manner was expected to speed up the communication process thereby decreasing the 'down time' of failed water points. M4W was also conceived with the aim of supporting the DWO to maintain an overview of failed water points and the status of repair assignments. This information needs to be communicated with MWE in order for Districts to receive national funding resources in the form of the District Water and Sanitation Conditional Grant (DWSCG) hence forth the Conditional Grant

Including this policy in the conceptualisation provides an example of how *in silico* experimentation with different policy instruments and scenarios could offer possible levers for change envisaged through interventions. In the conceptualisation, when options for implementing the M4W policy and database of failed WPs are activated, water service providers can send a message to the database of failed WPs. The database is accessible to the DWO and sends a text message to report the failed water point to the relevant HPM. This flow of information provides the DWO with timely information to prepare the Conditional Grant proposal while also helping the handpump mechanic respond to waterpoint failures in a timely manner. The ability to experiment with the underlying assumptions of a new intervention can, in this manner, support policy dialogue about the pros and cons of an intervention and the necessary enabling factors for it to succeed.

Formal sanctioning policy

Sanctioning, a common method to ensure that individuals adhere to shared societal rules and standards, such as fines, is practiced, or is not practiced, as the case may be, in a contextually specific manner.

The system conceptualisation includes the option for the DWO to assess and give positive and/or negative sanctions to WUCs and HPMs. This means that a consequence may arise from failure to perform according to the agreed rules and standards. Assessments are conducted by the local government.

The initial premise is that when these policy options are activated, the modelled water service levels will be relatively higher than prior to activation given their influence on factors that affect water services: WUC and HPM motivation, WU satisfaction, WP functionality and WU dependency.

In the next section, the system conceptualisation is used to describe the water services delivery system in a model narrative.

4.6 Model narrative

The previous section described the system's agents including the states and properties of the system's technical artefacts, agents and policies. This section details recognisable patterns of action and interaction in the real world identified through observation, stakeholder consultations and desk research. The scenario of rural water services is further decomposed using IAD as a theoretical framework to develop a model narrative suitable for translation into code and to build an agent based model.

Information is exchanged and modified by agents within the action arena. The model user can decide on the environmental decisions, such as policy activation, knowledge input or absence.

The institutional grammar 'ADICO' offered by IAD describes institutions' as those elements that remain constant or adapt during the process of variation arising from agent interactions. These institutions are operationalised as rules in the system narrative. Information may be inherited. In this narrative, heredity pertains to the transmission of information from agent to agent in the water services delivery system and thereby helps to helps to understand how memes may spread in a socio-technical system and, if information is not passed on through heredity, to understand where and when a pattern of interaction and information transfer stagnates. In the model design the collection of information which can be transferred from agent to agent may be enlarged in the event that new knowledge is acquired, or a policy is adopted.

In the real world, information about a broken water point is communicated via water users. In the model design, the water point can directly communicate with the water user committee. Key informant interviews revealed that the information flow between WPs, WUs and WUCs is not stalled in some fashion.

A final principle which helps to understand how, and under what conditions, information is transmitted between and among agents, is the principle of selection – why a certain piece of information is, or is not, chosen by an agent for replication. The choice to select one information piece, or not, is related, among other things, to an agent's motivation. A particular piece of information may be more or less in line with the personal priority of an agent. In the model design, the WUC, for example, can select information about its regulatory powers giving it the duty to '*collect money on a regular basis*'. But the WUC will only select the specific regulatory information item if:

- The WUC is very motivated to maintain a WP.
- The particular piece of information is known to the agent.
- The information is fits within conditions imposed by other memes or institutions.
- The WP is fit (able and capable) to accomplish the goal of maintaining the WP.

In the conceptualisation, as in the real world, some WUCs may know a particular piece of information, while others may not. For example, a WUC can only request a maintenance contract from the HPMA if the WUC is informed about this strategy, as the *level of information* is fundamental to an agent's ability to operationalise or make use of the information available in the scenario.

Pattern of interaction in the model design

In the pattern of interaction, as described in Figure 18, information/resources streams (blue arrows) represent pieces of information (memes), actions (green arrows) represent regulatory memes and personal decisions/updates (red square arrows). This system conceptualisation is divided into several phases in which the main interactions between agents are shown. In the model, updates of agents and some interactions are more extensive. Here, the bank balance, for example, is not updated. Each actor in Figure 18, also available in Annex A in an enlarged format for ease of reference, is represented by a light blue column. The interactions which affect certain agents are visualized by an arrow touching the agent's column with the point or tail of the arrow. The interaction is initiated by the agent that is touched by the arrow tail. The square arrows represent a turning point arising from a decision, or update to the agent's properties.

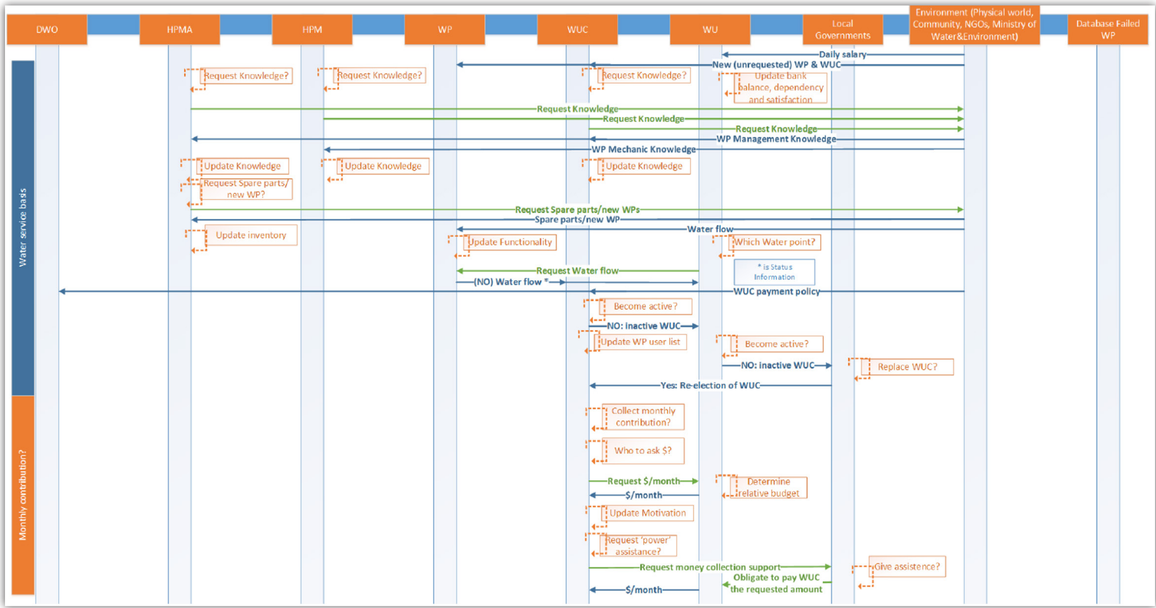


Figure 18. Pattern of interaction

Source: S. van Tongeren, 2014.

The first phase in Figure 18 is the Water Service Basis. In this phase the state of repair of a water point becomes apparent. The WUC decides whether or not to activate. A strong relationship exists between the activation of the WUC and the level of motivation to sustain the water point. If the WUC decides not to activate, the WU must decide whether or not to become active and the local government must decide whether or not to appoint a different WUC. Finally, in this phase the handpump mechanic, WUC and HPMA may request more managerial or mechanical knowledge, depending on their motivation and the environment's willingness to supply knowledge.

The Water Service Basis Phase is followed by the Monthly Contribution phase. In this phase, the WUC is active, has a certain motivation and a certain amount of financial and management knowledge to be able to conduct the monthly money collection.

In this manner, each interaction is initiated by a particular piece of information 'steered' by a rule, or institution, derived from the grammar of institutions framework.

4.7 Discussion and conclusion

Here a conceptualisation of the rural water sector of Uganda based upon the actor landscape mapped in the initial research phase and validated by key sector stakeholders is set out. The conceptualisation applies the lens provided by the IAD framework which offers a set of rules, or institutions, to describe agent behaviour in the model narrative.

This theory-based conceptualisation provides a consistent and coherent approach to describing and encoding agent behaviour and institutional rules.

Having a consistent language to decompose and describe agents, their behaviour and interactions in the complex space of the rural water sector makes it possible to develop a suite of models to examine various policy or implementation scenarios. These may include variations in policy mechanisms, programmatic strategies or water service level monitoring interventions such as the Mobiles 4 Water pilot project. Should the real-world actor landscape or national water service level norms change, this conceptualisation could be modified accordingly. The underlying theoretical framework of IAD and ADICO remain unchanged providing future researchers with guidance from the grammar of institutions on how to introduce necessary changes in the model narrative and coding texts.

The conceptualisation and narrative developed in this research were subsequently applied in a more complex model in which agents learn and adapt as described in Chapter 7 In the next chapter, a model is described in which a simplified conceptualisation is used to design and build an initial model. This step was to examine whether the basic conceptualisation of the rural water service delivery system could be implemented in a model and what results such a model could deliver.

5

Case 1 | The Water Services that Last model

How could the decentralized local interactions of heterogeneous autonomous agents generate the given regularity?

— Joshua M. Epstien, (1951 -)
Professor of Epidemiology, computational and mathematical modeller

Not everything that is faced can be changed,
but nothing can be changed until it is faced.

— James Baldwin (1924-1987)
Novelist, playwright and activist

In this chapter…

…the initial conceptualisation and design of a model built to specification based upon the actor landscape set out in an earlier research phase, is described.

The first model Water Services that Last simulates scenarios with varying conductions of water point availability and time required to collect sufficient water to examine their impacts on water service levels. This exercise served to establish the feasibility of simulating rural water services using an agent-based modelling approach in a simple fashion resulting in recognisable dynamics.

The model contributed to the research by providing a testing ground for the selected research method. Discernible system-level patterns of dynamics arising from agent action and interaction were observed.

The model detailed in this section was implemented by Sophie Tielens based upon the specifications set out by the researcher and members of the Uganda Triple-S Learning Facilitator team in a series of co-creation workshops in Uganda in 2013 and 2014 and in collaboration with associates of IRCWash.

5.1 Introduction

This chapter describes the Water Services that Last model, created through iterative collaborative modelling processes conducted in Uganda and in The Netherlands. The model narrative is described in the body of this chapter. The model conceptualisation (DOI: 10.4121/14713977) and test results (DOI: 10.4121/14713854) are available in 4TU.ResearchData's repository and the unpublished report is downloadable via Zenodo (10.5281/zenodo.4763552).

The primary aim of the Water Services that Last (WSL) models was to obtain insight into whether, and to what extent, the dynamic, real-world micro-level patterns of agent interaction involved in the delivery of water services in rural Uganda could be meaningfully simulated. The models were built based upon the system analysis and decomposition activities including stakeholder mapping and problem analysis conducted during previous stages of the research.

As key tenets of the scientific method, replicability and reproducibility are important in the context of building agent-based models for scientific research purposes.

Dam et al (2013) propose a series of ten steps for creating rigorous, well-argued, well-documented agent based models. This approach has been used in the construction of each of the models presented in this research project. The ten steps are:

1. *Problem formulation and actor identification*
2. *System identification and decomposition*
3. *Concept formalisation – including software data structures / ontology*
4. *Model formalisation – including model narrative / pseudo-code*
5. *Software implementation including modelling environment / programming practices*
6. *Model verification – recording, tracking agent behaviours / testing patterns of agent interaction*
7. *Experimentation – where scenarios are devised and experiments are designed and executed in the model*
8. *Data analysis – where exploration of the data resulting from the experiments is conducted including data exploration, pattern visualisation, identification, interpretation and explanation followed by experiment iteration to redesign experiments and/or re-run the model taking insights from prior*

iterations into account.

9 *Model validation – entails historic replay, expert validation, validation through literature comparison and model replication*

10 *Model use – outcome presentation, identifying new questions, long-term stakeholder engagement and helping stakeholders to understand model results, and comparing and contrasting of computer models with stakeholder's mental models for policy and implementation insights.*

Source: Adapted from Dam, et al. (2013).

The context of the ***Water Services that Last*** (WSL) model presented in this chapter is rural Uganda, anno 2013 -2014, during which time access to safe water service levels remained stagnant at around 64% of the population (GoU, 2013).

The aim of this step in the research was to develop a simple model that could offer insight into the behaviour of social actors involved in household water collection activities and their interactions with the technical system of the water supply infrastructure.

For the purposes of observing the whether useful simulations could be built, as opposed to models for predictive purposes, the focus here is given to describing the model narrative and design choices as well as some relevant results from the data analysis as these play a role in addressing the overall research questions of this dissertation and in shaping subsequent research activities described in Chapter 6 and 7.

5.2 Collaborative Model Design Approach

The collaborative model conceptualisation and design process for the Water Services That Last model entailed iterative steps for which the rural water sector landscape map served as an initial input to the system description.

Expert consultations with three representatives from Triple-S, IRC and an associate with field experience in the region of East Africa and one programming / modelling expert contributed to the choice to limit the problem definition and model conceptualisation to a cluster of houses that approximates a hamlet or similar sized rural community in that region. The model conceptualises the most local level of rural water service delivery to explore the affects of time, availability of water and water infrastructure functionality rates on a simplified conceptualisation of water service levels.

Literature from theory and policy were reviewed to buttress the empirical information gathered in the expert consultation rounds. The Ugandan Sectoral Specific Schedules / Guidelines 2009/10 provided information about water service level indicators and metrics for sustainable services through expansion of existing systems of construction of new infrastructure. The Uganda Population and Housing

Census 2002 (GoU, 2002) informed modelling choices related to rural settlement density and water point crowding. The Uganda Water Supply Atlas (GoU, 2010) was used for information about infrastructure types available in rural districts and water service levels accessed by rural populations. Theoretical and empirical literature informed choices about enabling environment conditions under which rural water services are sustainable and the impacts of time and distance on rural water service levels. These inputs were used to inform choices related to the model boundaries - a cluster of rural homes with an approximate number of residents and an approximate number of water points with approximate levels of functionality / non-functionality. The parameters of time to repair and distance to an alternative source were based upon inputs from the desk study and expert consultations.

In addition to the iterations of engagement with water service experts familiar with the Triple-S project and the desk study, the model design and agent based model were presented to sector practitioners attending Amsterdam Water Week 2014. Transcripts of those interactions were documented by the researcher. Given the participant's own interests and the incidental nature of conference poster session participation, the information was not deemed of critical added value beyond awareness raising among sector peers about the work of Triple-S Uganda and the value of a systems approach to understanding challenges to sustainable water service delivery and the potential of agent based modelling as a tool.

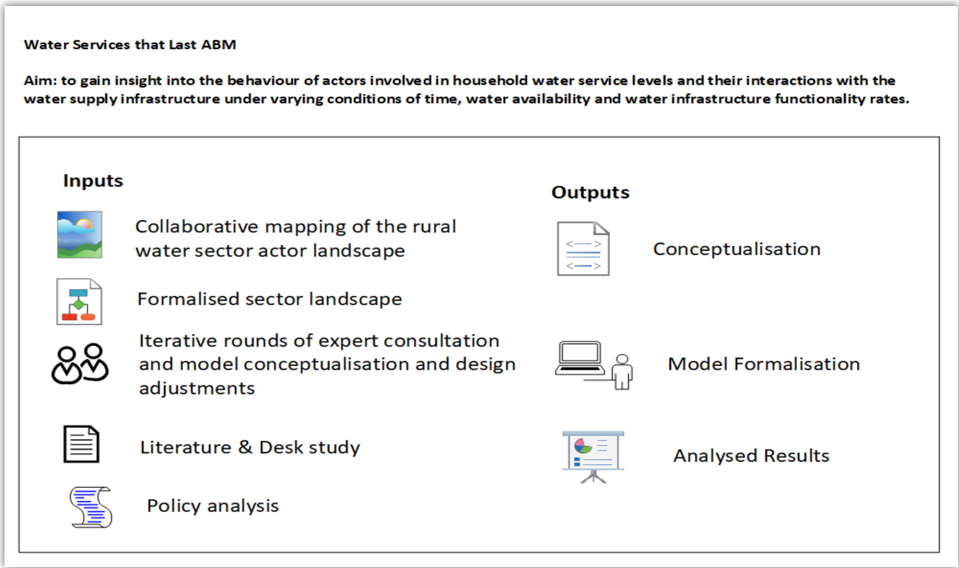


Figure 19. WSL model design inputs and outputs

These iterative rounds of conceptualisation, reflection and modification resulted in an agent based model in NetLogo which was also detailed in an unpublished report. The approach described here is visualised as model design and conceptualisation inputs and outputs in Figure 19.

5.3 System identification and decomposition

The system description, conceptualisation and model narrative of the ***Water Services that Last*** (WSL) model were derived from the results from learning facilitator workshops conducted in Uganda in 2013 and 2014 and from consultations with IRC programme staff and associates. Further consultations were held with rural water domain experts to refine the model narrative and to validate whether the simulated dynamics of rural water services and water supply system functionality in Uganda provided a meaningful representation of the problem of stagnating water services levels.

The WSL model simulates changes in water service levels arising from changes in the number of available water points and changes in time duration between the moment of water point failure, and of reporting and repair events. The purpose of this proof-of-concept model is to explore how water service delivery levels may be maximised and effectuated with a minimum of require resources. The model specifically enables observations of the effects of changes in number of water points on household water service levels. Also, effects from changes in the time-to-repair on household water service levels is possible to observe. The expectation was that the emergent simulated pattern would indicate which adjustments – time-to-repair vs. number of water points vs. longevity/lifespan of water supply infrastructure – would have the greatest effects on household water service levels and to what extent.

The WSL model is a simplification of the system for delivery of water services in rural Uganda as described in Chapter 2 and which zooms in to the level of the parish, a governmental administrative structure which comprises several villages, as this represents the level at which water services are delivered in Uganda.

Figure 20 depicts the multi-level governance structure in which a parish local council (LC2) and village local councils are situated and which, in turn, comprises a number of households.

The Uganda 2014 census indicates that on average, a parish contains approximate 4,335 people (GoU, 2014) with on average 4.8 residents per rural household (GoU, 2014). At the time the model was built, however, data from the 2002 census was used to simulate the local context in which an average parish had approximately 4,644 residents with an average of 6 residents per household.

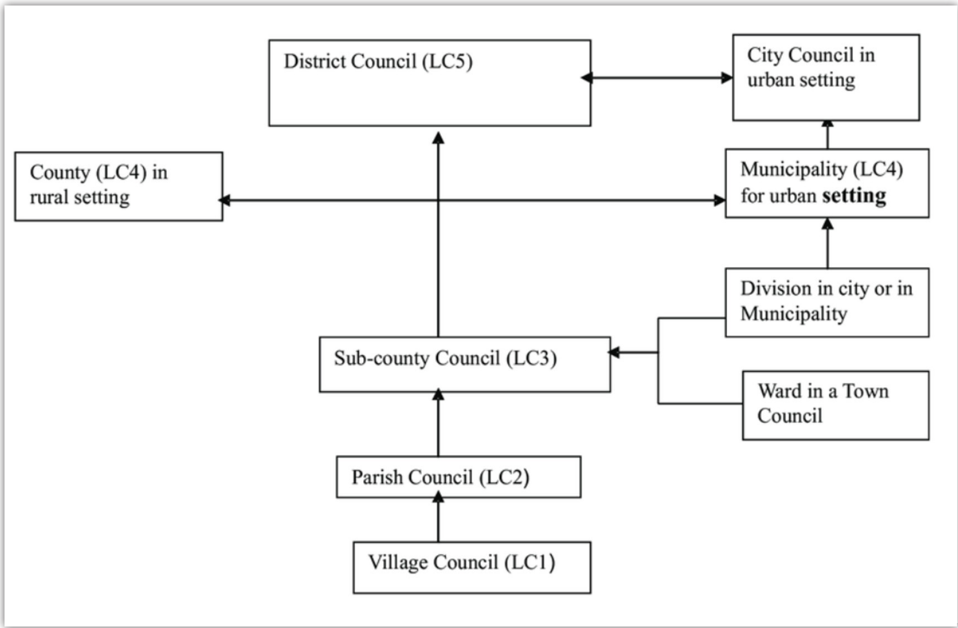


Figure 20. Local Government Structure in Uganda

Source: Adapted from Turyahabwe, N., Geldenhuys, C., Watts, S. & Banana, A. (2010).

5.4 A simplified system conceptualisation

While an extensive system conceptualisation was presented in Chapter 4, in this research step, a simplified conceptualisation was created to explore whether local level patterns of interaction between social and technical agents would give rise to recognisable system level patterns. To test this modelling method's feasibility, households, household water collectors and water points (boreholes with hand-pumps) feature as main agents in the model to enable observation of the effects of water point failure (break down) on households and the overall water service levels accessed by the population in the parish.

Other actors observed in the real world, including parish chiefs, handpump mechanics and health assistants for instance, are omitted to facilitate simplification of the water supply process as the aim is to obtain initial insights into how water point failure affects households.

Water service levels in this model are measured by two of the four nationally determined indicators, namely *access* as measured by the average time required to collect water and *quantity* as measured by the amount of water actually collected by a household on a daily basis (in contrast to the amount required per household per day). Two other key indicators – *water quality* and *reliability of water supply* – while critical measures of sustainable water services – are omitted from this simplified conceptualisation.

In the technical domain, village water points are the main technical actors[3] in this model design. Water point placement is the key variable as it depends upon a range of factors such as preferred locations, the existing number of water points, the cost of water point construction, including the handpump superstructure as well as the borehole well, the number of households to be served in a designated area, etc.

The service level is calculated by the amount of water collected by the day's end and the time it took to collect water. The amount of water considered essential as a basic service level is approximately 15 litres per household resident per day (Batchelor and Moriarty, 2011). If this requirement is not met more than 50% of the time, a household is considered to receive no service. Other levels of service are described below.

From the age of 13, children are often able to carry the same amount of water as adults, approximately twenty litres (Sugita, 2005). In general, younger children are not physically strong enough to carry this amount. The average amount a water collector is considered able to carry on a single collection journey in this model is fifteen litres, plus a random number under six to arrive at approximately 20 litres. Accessibility is measured by the time required by a water collector to reach a water point, collect water and return home.

While the water service levels for access and quantity provide institutions, or rules of play, to which actors adhere, these are not conceptualised according to the ADICO framework set out in chapter 3. This implementation of institutions in the absence of a theoretical underpinning provided the opportunity to examine the arising patterns of behaviour and interaction, thereby establishing the feasibility of this modelling method.

The details of the agents properties and states are provided in Annex B.

5.5 Model Narrative

To simulate how the population may be affected by a change in the variables of time and number of water points the model was built based upon existing conditions in Uganda. These conditions were ascertained in a series of key stakeholder consultation sessions with staff and associates of IRC Wash based in The Hague and to combine these insights with the information about rural water services in Uganda compiled in the literature review and actor landscaping activities.

The model contains an average number of households of a Ugandan parish comprising two or more villages and a representative number of water points. Each

3 An inanimate object such as a handpump is not usually seen as an 'actor' or later as an 'agent' but in the model constructed the pump does indeed have agency, since it is deemed to have properties, states and behaviours that evolve over time based on interactions with social agents and the environment. For example, if a water source dries up, the handpump registers this change in the environment and ceases to deliver.

household has a water collector tasked with travelling out each day to collect water for his or her household.

The model assumes that the time required to pump the basic level of water is approximately one minute as pumps have a capacity design to lift at least fifteen litres per minute (Whitehead, 2001).

At the end of each day, the model calculates the amount of water collected by households. This is compared with the amount of water required per household as determined by the number of residents. The average time required to collect this required amount of water is also recorded.

After a certain amount of water has been collected, water points break down and cease to deliver water supply. Under 'normal' circumstances, a minor breakdown of a pump occurs after 90,000 litres have been extracted; a major breakdown generally occurs after 540,000 litres have been extracted (Osafo-Yeboah, 1994). Only minor breakdowns are considered as, in the event of a major breakdown, pumps generally cease to work completely meaning no service is provided by the water point.

The 'time-to-repair' of a water point is an important determining factor in the level of water service. In Uganda the time-to-repair following a breakdown is approximately 20 days and is included in the model.

Households are assigned a service level colour code denoting different service levels. Green represents a good (acceptable) service level as determined by Uganda's national norms. Yellow represents an average service level. Orange represents a sub-standard service level. Red denotes no service. In other words, both orange and red mean that households did not receive enough water from a safe water source to satisfy their basic daily need. The number of water points and number of days for repair can vary.

This narrative provides a sequence of interactions that results in agents moving and interacting when the model starts to run. This sequence is:

- Water collectors depart from home between 6:00 a.m. and 7:00 a.m. to travel to the nearest water point.
- Upon arrival, provided water point is functional and queuing does not take longer than a collector is willing to wait, the water collector waits in line to collect water.
- The water point assigns each arriving water collector a unique ticket number. A water collector may collect water only once the water point turn-number matches the collector's ticket-number.
- If the water point is not working for any reason, the water collector searches for an alternate functioning water point based on the closest location to the collector's current location as well as to their home. If it is late (+18:30 p.m.),

the collector returns home.

- If the queue at the water point is too long, the collector searches for another working water point closest to their current location as well as their home. A collector only searches for an alternate water point once and returns home, with or without water. If it is getting late the collector returns home.
- If a water collector reaches the front of the queue, the collector collects water for one minute and returns home. The water point registers the amount of water gathered by each collector and the total number of water point users. If the total amount of water drawn from a water point exceeds the amount that point can provide, the water point breaks down.
- When the water collector returns home, the water collected is added to the household's current water balance. The household checks the time duration to fetch that amount of water and the household water balance. At the day's end, a household calculates its service level on the basis of this information.
- When a water collector returns home, he/she checks whether the household water balance is sufficient to meet household needs. If not, the water collector travels out again if time permits. If there is sufficient water, or the time is past 18:30 hours, the water collector remains home until the following morning.

This sequence of actions and interactions is depicted in the process chart in Figure 21.

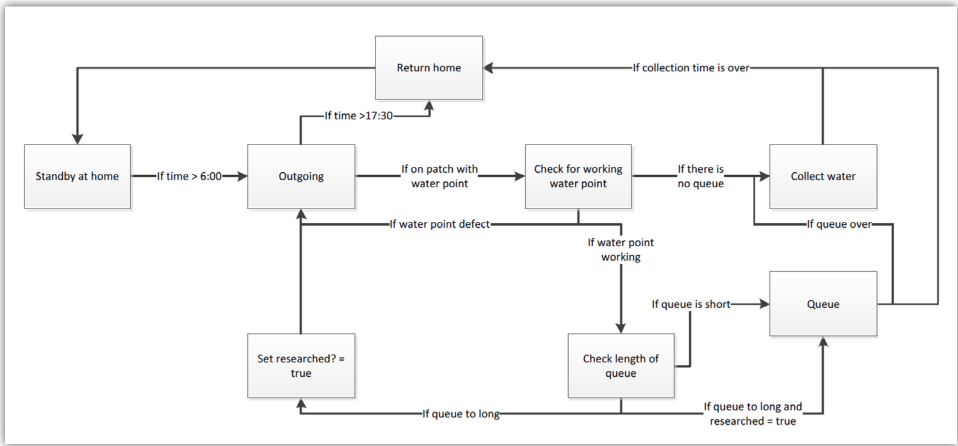


Figure 21. Sequence of water collector activities

Source: S.Tielens, 2014.

5.6 Experimentation and data analysis

Following a round of verification to ensure that the model agents and dynamics are delivering reasonable plausible behaviours and patterns, a series of experiments were implemented. These experiments, conducted *in silico* (i.e. a computer model), test how different numbers of water points and different repair times effect the system various scenario's in the simulated environment.

5.6.1 Experimentation set-up

The model ran for a time period of 120 days, or 108,000 ticks (900 ticks, or 15 hours, per day) to observe how the service levels were effected. A water point breaks down after approximately 90,000 litres of water have been drawn. Time to repair is on average 20 days following the breakdown. A run time of 120 days was selected as water points generally experience break down between 10-20 days of operation - the time it takes for approximately 90,000 litres of water to be drawn, and a further 20 days passes until the water point is repaired. The 120 day run time would accommodate at least three cycles of this sequence of water delivery, break-down and repair.

The random starting conditions of the experiment simulate water points already in use prior to the start of the run providing a more realistic real-world situation and enables the model to run steadily from the outset. Households and water points were randomly placed in clusters making it possible to compare water service levels across different household locations and the water points that serve them. In the random setup, each household has a random amount of water, each water point has a random amount of water (so breakdowns occur randomly) and a random number of water points is already broken. The moment a water points fails was also randomly selected. Each experiment was run ten times to observe how the outcomes varied and determine whether any proper conclusion could be reasoned based on the results.

5.6.2 Data Analysis

Five scenarios, set out in Table 4, were devised for testing and experimentation to examine options for achieving maximum water service delivery levels with the minimum require resources.

The first scenario represents the real-world scenario in Uganda anno 2014 where a parish has approximately 20 water points and an average time-to-repair of 20 days. The outcome of this scenario is an average of 62.33% of the population with access to safe water. This is close to the 64% access rate provided in Water and Environment Sector Performance Report in 2013 (GoU, 2013).

The second scenario entails a total of 20 village water points combined with a shorter time-to-repair of 10 days. The outcome is 87.75% of the population with access to safe water supply.

The third scenario entails an increase in the number of water points to 30 and a time-to-repair of 20 days. In this scenario, 90.57% of the population has access to some level of safe water supply. While the number of households with access to a 'good' service level increases only marginally, levels of access to 'average' safe water supply has decreased as did the levels of those with ‘bad’ access levels.

In the fourth, and final, scenario a greater number of water points – 25 – and a time-to-repair of 15 days are simulated. This scenario does not result in an improvement in comparison with scenario 3 (30 water points and 20 day time-to-repair). In comparison to scenario 2 (20 water points and 10 days to repair), the average number of households with no service level has decreased and the average service level has increased. As the overall rate of access to safe water sources for households and communities is critical, arguably more so than the average service level percentages, scenario 4 is considered to represent a more desirable outcome than scenario 2.

Scenario	1	2	3	4
Average number of households with service level 4 *<50% of daily household requirement = ‘no service’ level*	293.80	118.15	73.60	82.25
Average service level	3.09	2.96	2.91	2.99

Table 4. Average households with no service and service level of the households per scenario.

Source: Adapted from Tielens, 2014.

In other words, the tests indicate that variation in the number of water points, including the availability of additional functioning water points, has a greater effect on service levels than variation in the time to repair of broken water points. This availability of back-up water points, coupled with above average access to safe water sources would help to ensure that communities are able to maintain service levels 1 – 3.

5.7 Conclusions

Under the conditions set out in this model, community water service levels as well as access to safe water improved with an increase in the number of water points and a decrease in the time-to-repair of broken water points. The tests indicate that a variation in the number of water points bears a greater effect on water service levels and number of households with access to safe water than a variation (reduction) in the time-to-repair.

This model explores options for delivering water service levels with varying levels of resources. The resources include a combination of infrastructure in the form of water points and time required to repair broken water points. The model results suggest that, to maximise service delivery levels, sufficient back-up, or additional, water points are required in each village to ensure citizens can access a water point within 5 minutes of their residence, even in the event of a water point break down at a given water point. This is significant as community water supply is rarely planned or financed to accommodate redundancy in the local water supply system through the construction of reserve infrastructure to mitigate break down. The results of this model could serve in planning and deliberation about how to allocate resources towards maintenance and repairs versus the need for investment in reserve infrastructure.

This simplified model could be extended a more accurate approximation of each value using data from the Uganda Water Atlas to simulate a parish, or cluster of parishes (sub-county) or even district level administrative zone. Data from more recent years that represent variations in the available water resource following from climate change patters would provide useful simulations for considering financial and construction policy alternatives. The number of household residents and the number of water collectors per household may be more accurately represented as most households have more than one collector. Lastly, extending the number and types of agents would add value to subsequent models by provide more complex patterns of interaction system dynamics. The aim here, however was to simulate a simplified system conceptualisation to establish the feasibility of this modelling method.

6

Case 2 | The Mobiles 4 Water (M4W) model

Essentially, all models are wrong, but some are useful.
— G.E.P. Box & N.R. Draper (1987, p.424)

If you don't like something, change it.
If you can't change it, change your attitude.
— Maya Angelou (1928 – 2014)
American poet, singer, memoirist and civil-rights activist

In this chapter…

…the Mobiles for Water (M4W) model is described. Built to specification and based upon the actor landscape set out in an earlier research phase, M4W introduced additional an added level of complexity. More agents represented and in addition to travelling to collect water, agents now monitor water point functionality and can choose to communicate a water point's status with other agents.

This model incorporates policy and project design to experiment with different policy scenarios. The potential role of ICT tools in monitoring water point functionality and the rules-of-the game that policy and decision makers have their disposal can be tested using the M4W model to study potential system level effects.

The agent-based model conceptualisation detailed here was co-developed as part of the course-work conducted by M.Jaxa-Rosen and R.van Staveren based upon the case study specifications set out by the author. The full report is available on Zenodo (DOI: 10.5281/zenodo.4763629). The model conceptualisation is available in 4TU.ResearchData (DOI:0.4121/14713995).

6.1 Introduction

Mobiles 4 Water (M4W) was a multi-actor partnership active in rural districts in Uganda during the course of the Triple-S project. The partners involved in M4W's conception and implementation included the Ugandan Ministry of Water and Environment, non-governmental and academic research institutions including IRC Wash, The Netherlands Development Organisation (SNV), Makerere University College of Computing and Information Science, WaterAid and local government actors including district water officers, handpump mechanics and community development officers (CDOs).

Launched in 2011, M4W aimed to improve functionality rates of rural water points by reducing response time for repairs in the case of water point failure (Abisa, et al., 2013). The concept entailed the use of low-cost information and communication (ICT) solutions, namely mobile telephones, to monitor and communicate about water point functionality. The intended system users were community members and water user committee members who were aware of a water point failure, but not necessarily able to diagnose the cause of the breakdown.

The primary aim of creating an agent based model of the M4W approach was to test whether such an intervention could be usefully coded and modelled, and if so, using what model specifications? The secondary aim was to obtain insights into the conditions under which the M4W initiative could successfully lead to improved water service levels by reducing the response time in cases of water point failure. The research intention was to identify potential scenario options for improving the effectiveness of the M4W intervention.

6.2 Collaborative Model Design Approach

The M4W model conceptualisation and design process followed a similar collaborative process to those described in Chapters 4 and 5.

During Triple-S project meetings and multi-actor participatory workshops held in Uganda between 2012 and 2014, the M4W initiative and the challenges it faced in going to scale, were selected as an action research initiative, or experiment.

The aim of the agent based model conceptualisation was to obtain insights into the conditions under which M4W could lead to improved water service levels (as nationally determined) by reducing the response time to water point failure.

With the collaboratively created sector landscape map as a starting point, expert consultations with colleagues from IRC and the Triple-S Uganda initiative provided additional insights that informed the choice of the M4W action research initiative as the subject of an agent based model. In addition to the empirical knowledge of the researcher, a expert consultation meeting was held with approximately 15 IRC and Triple-S team members in December 2013 at IRC's offices in The Hague including colleagues joining via an online meeting platform from Uganda and Bangladesh. Following an introduction to this model conceptualisation by the researcher, the model was presented by the student researchers Jaxa-Rosen and van Staveren. The questions and discussions, including detailed feedback from IR staff were documented by the researcher.

From the qualitative feedback on the main model assumptions, actionable points were implemented in a subsequent version of the model conceptualisation. A key point of feedback was the value in being able to run the model with the M4W initiative / institution 'turned off' to observe arising patterns in the absence of this initiative. The expert feedback resulted in the use of the social network as a means of knowledge dissemination about functional and non-functional water points. A second key feedback point resulted in the set up of spatial distribution was amended so that population clusters would have water points placed both within and around the clusters. A final assumption that was amended pertained to the water service levels. In the final conceptualisation, the calculation of water service level was adjusted to reflect the non-linearity of water quantity as a function of distance (the initial assumption was a linear relationship between these factors).

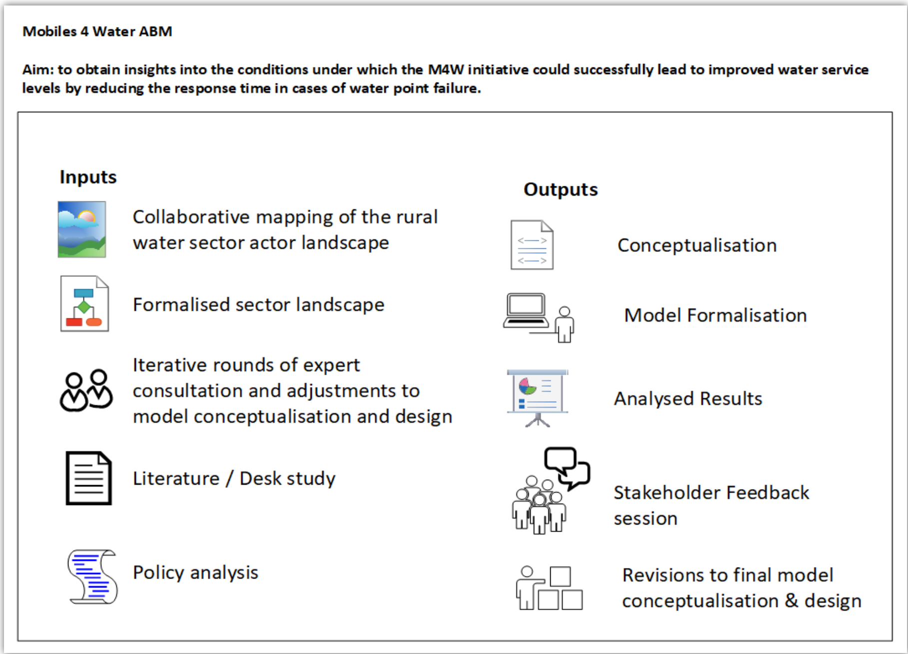


Figure 22. M4W model design inputs and output

In addition to expert consultations, desk research on prevailing institutions (after Crawford and Ostrom: norms, policies share strategies) as well as national water services delivery arrangements in Uganda and empirical information about the M4W project were compiled from empirical, theoretical and policy sources of information. The MWE Water Supply Atlas informed the choice of district and parish for simulation in the model design. The national water service norms were derived from existing sector scoping studies (Nimanya et al., 2011). The set up of the M4W action research initiative as a set of rules in the conceptualisation was derived from Triple-S Uganda literature documenting the operations of M4W. These sources enabled the model conceptualisation - from a non-dynamic map of the actor landscape - to a dynamic model in which social and technical agents are observed to act and interact giving rise to the macro level pattern of water service levels.

6.3 System Description

Here the system in which the problem occurs is described and decomposed for the purpose of building a structured, rigorous and reproducible agent-based model for experimental and policy analysis purposes.

Given that 30% of rural water infrastructure is non-functioning at any given point in time in Uganda, rural residents commonly turn to other available alternative sources to meet their water needs. These sources are largely unprotected surface sources such as springs, streams, rivers and lakes.

Water service providers, who are tasked with delivering safe water, require real-time information about the functioning of the water infrastructure so they can gain insight into service levels being accessed in the districts, parishes and villages they serve.

The Mobiles 4 Water (M4W) initiative was conceived to test the role of ICT, and specifically mobile telephone facilities, in facilitating information diffusion. The programme was implemented in Lira and Kabarole provinces in Uganda.

As depicted in Figure 23, M4W was designed to enable water users to use their own mobile telephones to report water point breakdowns or other water supply issues. An ICT-based system to send, receive and track these notifications was centrally managed by the consortium of researchers, development partners and local and national government actors. The information gathered was stored in a central data base at Makarere University and made accessible to actors throughout the entire water supply system hierarchy from national to district level. One aim was to create an information source that contained the ‘right’ information in the ‘right’ formats for use in national water service monitoring and in local-level decision making about resources allocation, leading to more effective and efficient use of resources and improved water service levels. The expectation was that accelerating the flow of information about water infrastructure break down would lead to shorter time-to-repair and subsequently higher levels of services.

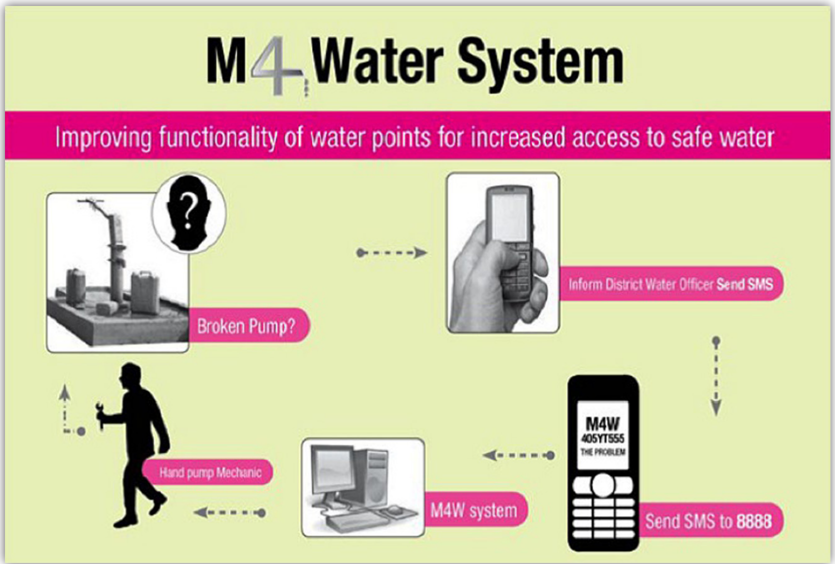


Figure 23. M4W System conceptualisation

Source: Abisa, et al., 2013.

The M4W system was designed to work as follows: a user who finds a non-functioning water point sends an SMS text message containing the unique identification (ID) number of the water point to the central M4W system (Figure 24 and Figure 25). Under the system it was also possible to report the breakdown by telephone.

Figure 24. Water Points with unique M4W identification code, Uganda, 2013

Source: IRC Wash, 2013

The central system stores the notification information, making it available to all system users. Among other key actors, handpump mechanics (HPMs), or HPM associations, may access this system. Upon receipt of a notification of a non-functional water point an HPM travels to the water point, makes the repair and receives payment from the water user committee (WUC) – the body responsible for regular maintenance and operational expenses. To cover the costs of such repairs, the WUC collects monthly fees from water users.

In 2014, consortia members made an assessment that M4W was not functioning as envisaged. Water users were not reporting enough faults through SMS text or telephone calls for issues to be logged in the central system in a timely manner. Additionally, WUCs were not collecting water user fees on a consistent basis. As a consequence, even when information was logged in the central system and an HPM arrived to make a repair, no money was available for payment or spare parts. As HPMs are private sector actors who need to cover their costs, in the absence of payment, they were leaving after diagnosing the breakdown without the water point being repaired.

Figure 25. Handpump mechanic affixing sticker with unique water point identifier and instructions.

Source: P. McIntyre, 2013

The initial hypothesis was that water users had low-willingness-to-pay tariffs as water is considered a freely available natural resource. When a water point is not functioning, or water tariffs are unaffordable, rural residents may meet needs from alternative, often unprotected, water sources. Consequently, WUCs cannot collect sufficient financial resources from user fees to cover water point maintenance costs. In turn, people are further disinclined to pay for sub-standard water services.

This scenario provided the basis for the model narrative in section 6.6. The environment, including external factors that influence the agents but cannot be influenced by the agents, is also described. As with the *Water Services That Last* model presented in Chapter 5, for the M4W model a number of concepts, actors and behaviours were identified as central to the narrative of the problem scenario and form the core of the M4W model:

- Concepts underpinning the model: user preference for clean water, user attitude towards the requirement to pay for water and levels of trust in other actors dependent on previous transactions.
- Actors: water users, Water User Committees (WUCs), handpump mechanics (HPMs) and the District Water Officer (DWO). Real-world technical artefacts are modelled here as agents: water points (safe) and water sources (unsafe).
- Behaviours: using water, paying for water, talking to people about water services, fixing water points, paying for repairs and installing new handpumps
- Interactions: talking to others, paying for water and repairs, reporting issues to HPMs
- Agent states/properties: bank balances, water service levels, attitudes towards other agents (primarily for transactions), preferences for water, knowledge about sources, status (functional/non-functional)

An overview of agents, their properties and (inter)actions is found in Annex C.

6.4 Model formalisation

Households in rural Uganda organise for at least one person per day to make the trip to a local water point. Therefore one 'tick' here represents one day. In Table 5, household ability to meet basic daily water needs is mitigated by access to water where access is determined by distance to a safe water supply. Users water service level was assumed to vary as a linear function of the distance to a water point.

Service level	**Access measure**	*Needs met*	**Level of health concern**
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

Table 5. Health-based requirements for water service level

Source: Howard, Bartram, & others, 2003

However, following feedback from domain experts, the calculation was adjusted to reflect that the relationship is actually non-linear. While water consumption tends to plateau at around 15 liters per capita per day for distances between 100m and 1000m (or a travel time of 5 to 30 minutes), the amount of water consumed decreases significantly as travel time and distance increase, as evident in Figure 26.

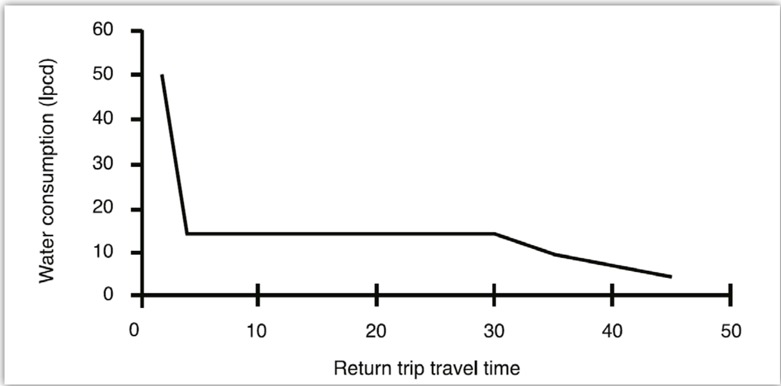


Figure 26. Daily water consumption per capita as a function of travel time

Source: WHO, 2003

In the rural context described here, the significant increase in water collection provided by "on-plot" service is less relevant; the model design was adjusted to reflect the minimum service level definition given for Uganda by Nimanya et al. (2011), corresponding to clean water within 1.5 km.

The service level is quantitatively approximated in the model as follows:

	Distance (m)	Service level rating
No service	> 1500	0
Intermediate	1000	0.5
Full service	< 100	1

Table 6. Adjusted water service level calculation in the model

Source: Jaxa-Rosen & Van Staveren, 2014. P.10.

The calculation was implemented as a simple quadratic curve fit in the model. Given the importance of these indicators, further work should incorporate more detailed data about local water collection - including explicit knowledge of the quantity of water gathered by each user.

6.5 Environment and spatial layout

The environment consists of phenomena that influence the agents but which the agents themselves cannot influence. The model :

- Gives all agents a location (which influences the distance between users and water points and sources and gives all water points a WUC)
- Creates social networks of the water users and HPMs
- Gives income to the water users and DWO
- Generates different types of water points (with different properties)
- Allows water points to break down

The actions and interactions of the agents have a clear spatial dependence: HPMs move between water points, while the service level and water point choice of water users is affected by geographic distribution. The size and layout of the environment play a determining role in model outcomes. An appropriate geographic boundary was chosen by selecting an area representative of the eastern half of Rwiimi sub-county in Kabarole District. Figure 27 shows Kabarole's location in Uganda, Rwiimi's location in the district and a more detailed map of the sub-county.

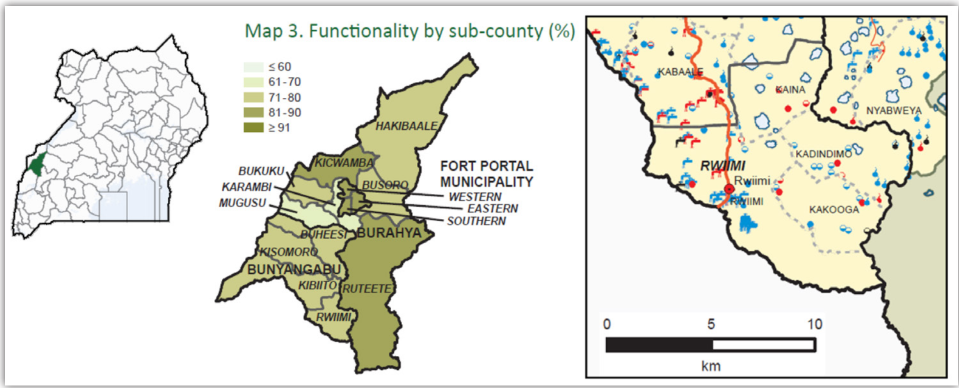


Figure 27. Location of Rwiimi sub-county, Kabarole District, Uganda

Source: Uganda Ministry of Water & Environment, 2010.

In 2010, Rwiimi sub-county had the lowest access rate in the district, with 69% of the population having access to point water sources (GoU, 2010). Table 7 summarises water service data for the sub-county.

			% access	% functional	Protected springs			Shallow wells			Deep boreholes		
Admin Unit	Population	Population served	Rural	Rural	Functional	Non functional	Total	Functional	Non functional	Total	Functional	Non functional	Total
Rwiimi	28,300	16,948	69	77	10	1	11	16	6	22	3	5	8

Table 7. Water service level for Rwiimi sub-county in Kabarole district

Source: Government of Uganda, Ministry of Water & Environment, 2010

This may be explained by the poor ground water potential in the area, which affects the technical and economic feasibility of new water points.

Given the computational and data requirements involved in a full simulation of the sub-county, the sub-county (which covers an approximate area of 77 km2 with 28,000 inhabitants) was further subdivided for simulation purposes. A square area of 36 km2 with the same average density of water users and water points of each type was conceptualised and formalised in the model.

Furthermore, in order to limit the number of agents in the simulation, each water user in the model represents small neighbourhoods of 5 households of 5 persons each (i.e. 25 people), clustered in a random arrangement of "villages". The baseline spatial conceptualisation simulates 540 water users, corresponding to a population of 13,500 persons. This population is served by 20 water points proportionally distributed between each type of point water source. Finally, the location parameters are adjusted to obtain a realistic initial access rate.

This method for setting up the environment is intended as a first approach to modelling the dynamics of the system; given the importance of geographic parameters in the context of water services in general, and M4W in particular, a full sub-county-level simulation should integrate GIS data to more accurately represent water point locations and population clusters.

6.6 Model Narrative

The next steps include writing the model narrative that sets out which actor undertakes which actions at which point of time. The model narrative is, in essence, an easily readable, detailed description of what happens in the model between every unit of time – or 'tick'. The narrative is used to create the pseudo code and both were iteratively updated as new relevant information was received from key informants. The narrative set out below, in terms of the initial contextual setting and the sequence of activities of different actors in order for households to obtain the required amount of water to meet their needs, are described in detail in Annex D.

Initially the researchers considered the possibility of representing the DWO constructing new water points with a randomly chosen water point "project" proposed each quarter, provided the DWO had sufficient funds. This routine was not implemented in the experimentation phase to reduce the amount of exogenous factors in the model and simplify interpretation.

The decision structure in Figure 28 provides an overview of the behaviour and interaction patters and sequences for all actors involved in the model on the basis of the rules set out above.

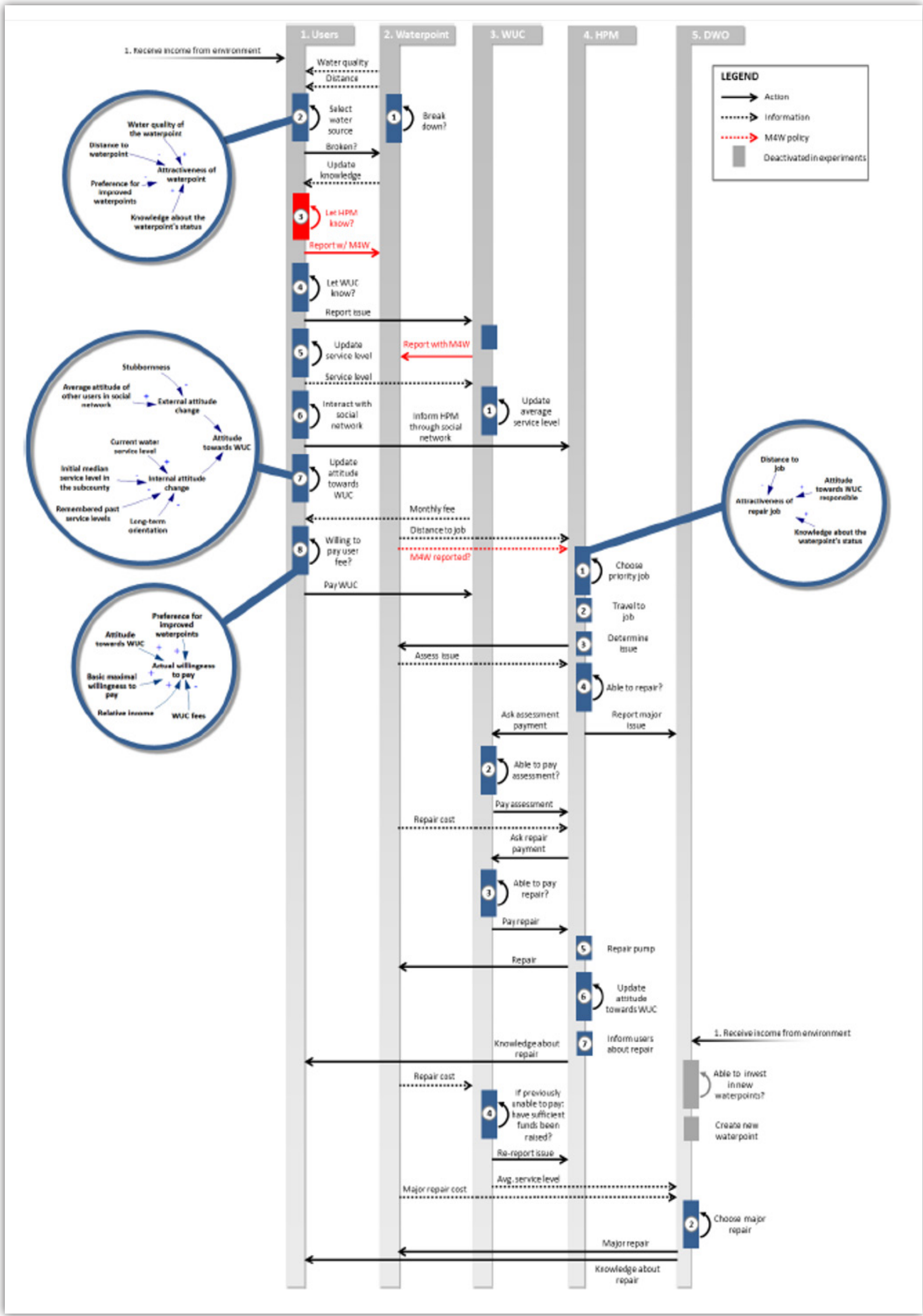


Figure 28. Graphic representation of model narrative

Source: Jaxa-Rosen and Van Staveren, 2014.

6.7 Experimentation and Data Analysis

To examine the emergent patterns, a series of experiments were conducted 'in silico'.

- a social network experiment to examine the social network parameters on the overall performance of the system in terms of the dissemination of information about broken water points and reductions in time to repair.
- an experiment on user attitude was set up to examine effects of the attitudes of other users and the base, current and historic service levels of users on whether or not users adjusted their attitude to the water user committee.
- an experiment on income and payment examines user willingness to pay for water point maintenance and the effects on water service levels.
- an experiment where the Mobiles 4 Water intervention is implemented to observe system level changes in time to repair and service levels.
- an experiment related to a policy to stimulate use of safe (protected) vs. unsafe (unprotected) water sources is implemented to examine user behaviour and choices when confronted with longer travel times to access safe water.

Each experiment and set of results provides interesting avenues for analysis by decision makers. Here, the results and analysis of the Mobiles 4 Water experiment are provided.

6.7.1 M4W experiment set up

Upon receiving notice of a failed water point, the HMP travels to the water point and interaction with the WUC commences. The model uses the social network to distribute knowledge about functioning and non-functioning water points. The time required for this knowledge to disseminate and reach the HPM depends upon the degree of interconnectedness between the HPM and the water users.

The underlying expectation of the Mobiles 4 Water intervention is that the system as conceived would enable users and WUCs to update information about waterpoints in a central system also accessible to the HPM. The expected result is quicker HPM response times, shorter time-to-repair rates and higher user water service levels.

The experiment to test the effectiveness of this intervention design, was setup for 40 repetitions with the parameter settings set out in Table 8:

Variable	Value
Mobiles 4 Water system	Off
Number of safe water points	20
Fraction of unsafe water sources	0.8 (16 unsafe sources)
Maximum distance between user and water point	2.2 km
Number of population clusters	15
Users per cluster	36
Max radius from cluster	0.9 km
Base willingness to pay	3000 shilling
WUC-Monthly payment	600 shilling
Number of HPMs	1
Max radius for WUC	1.6 km
Chance of global link	20%
Total social links per user	15
Social network local radius	1 km
Daily social interaction	With 15% of social links
Relative effect of social interaction	1
Relative effect of change in service level	1
Relative effect of absolute service level	0.5
HPM attitude increment	0.2
HPM negative experience bias	1.5
Major breakdown interval	1825 days
Minor breakdown interval	60 days
Weibull shape parameter	2.5

Table 8. Parameter settings M4W experiment

A full factorial sweep was conducted whereby the model is run repeatedly combining the different parameter settings with either the Mobiles 4 Water intervention either set to ‘on’ or ‘off’. In addition to these parameters, the following KPI were saved as model output:

- Mean user attitude towards WUC
- Mean user service level
- Mean HPM response time
- Mean waterpoint down time

- Number of non-functional waterpoints
- Number of users with service level = 0

6.7.2 Results and Analysis

When the option to report a broken water point via the Mobiles 4 Water system is activated, a positive effect on both water service levels and on down time of water points is observed.

Figure 29 displays the service level with (in green) and without (in red) the M4W intervention activated. In the experiment, the M4W option is activated after 180 steps in order to allow for the start up activities of the model. Recall Table 5 in which the adjusted water service level calculation placed an intermediate level of service at 1000 meters travel distance, or 0.5 service level rating.

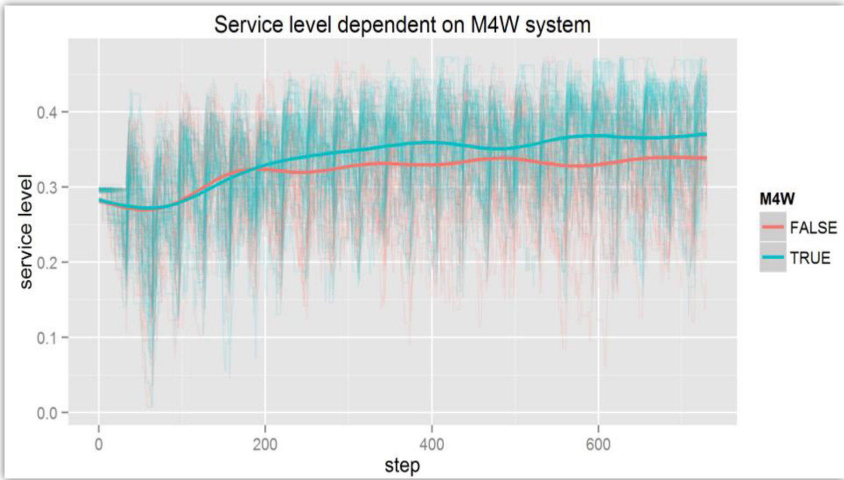


Figure 29. Effect of M4W intervention on water service level

Source: Jaxa-Rosen and Van Staveren, 2014.

The average service level without M4W, depicted in red, is around 0.34. Following activation of the option to report a broken water point using the M4W system, results in green depict an increase in average service levels to around 0.36.

While these service levels remain below an intermediate level of service (0.5 in Table 13), the activation of the M4W option does result in a higher average level of service under the conditions set out in this experiment. Figure 30 depicts the density of average water service level distribution further confirming the positive effect of M4W on the overall system performance.

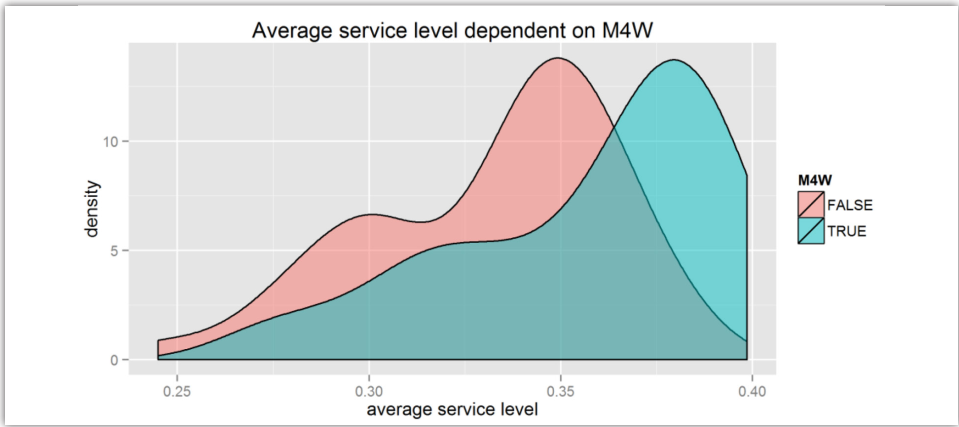


Figure 30. Density of average service level distribution

Source: Jaxa-Rosen and Van Staveren, 2014.

A similar positive pattern is observed in Figure 31 with regards to the indicator of water point down time whereby the activation of M4W is associated with a decrease in the down time of water points.

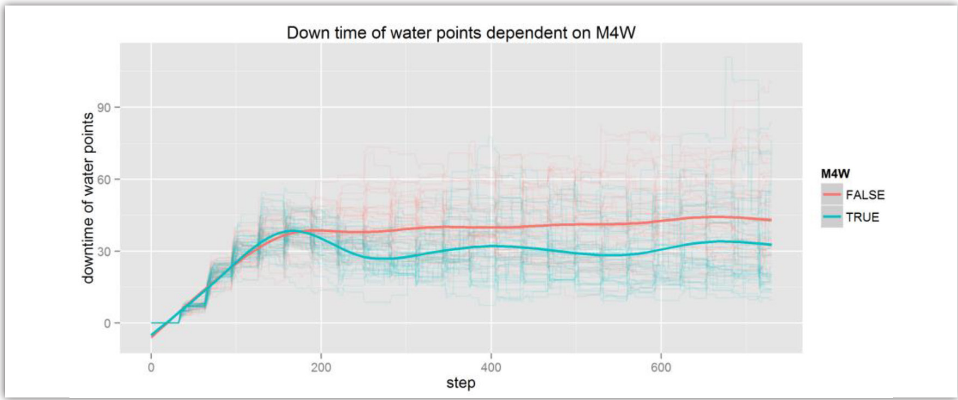


Figure 31. Water point down time

Source: Jaxa-Rosen and Van Staveren, 2014.

The distribution is more clearly revealed in a density diagram as in Figure 32.

Here too, a positive relation is observed with a higher density of runs with shorter down times represented in green following the activation of the M4W intervention.

While these results and analysis are not predictive, they do demonstrate the potential for experimenting with policy interventions under different conditions related to the overall scenario of rural water services. In this manner, policy interventions such as the Mobiles 4 Water programme can be implemented in order examine potential system levels effects such as changes in water service levels and water point down time.

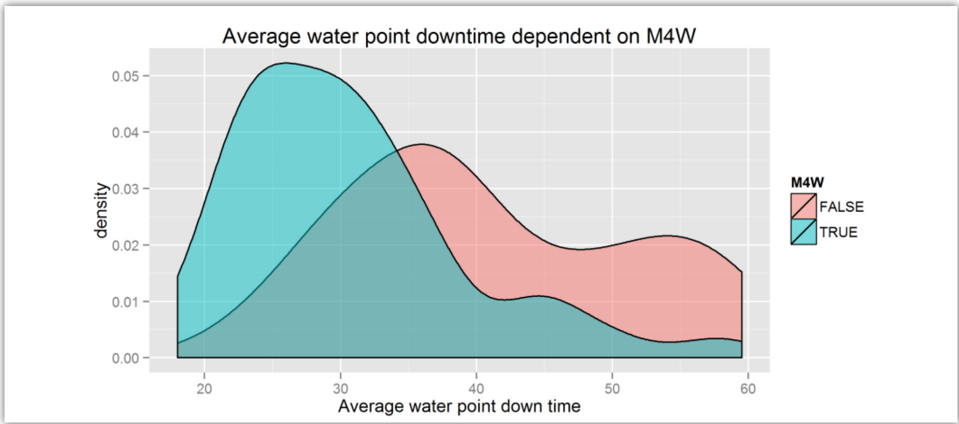


Figure 32. Average down time of water points with and without M4W

Source: Jaxa-Rosen and Van Staveren, 2014.

The full set of test results are openly accessible in 4TU.ResearchData's repository (DOI: 10.4121/14714028).

6.8 Stakeholder Feedback

Model validation is the process of assessing whether the model is fit for the purpose for which it was built – that is insight into the dynamics of a complex system and/or answering specific research questions. Domain expert were consulted throughout the model building phase to test assumptions made during the creation of the agent based model.

Early in the verification stage, when the model building phase was considered finished, a consultation meeting was held at IRC Wash in The Hague with experts from the rural water supply domain either present in person, or via teleconference. The main model assumptions were presented and sample model runs were executed. During feedback, the opinion of domain experts was that water user decision-making on how to spend their limited financial resources is far more complex than the initial design. The cost of sending SMS text messages to the central system, income levels, willingness to pay and the monthly water fees are in combination important model parameters. This raised the need for a re-design of those decision rules. These refinements are already included in the model description given above in this chapter.

Domain experts said that it would be valuable to be able to observe the model with the Mobiles 4 Water initiative 'turned off'. This would make comparison possible between the arising system dynamics with and without the Mobiles 4

Water intervention. The modification devised to address this was the introduction of a user's social network as the key mechanism for dissemination of knowledge about functional and non-functional water points.

Some assumptions about spatial distribution were rejected which led to a new location setup based more closely on population clusters with water points placed in and around the clusters. Finally, experts believed that the service level had not been calculated appropriately. Rather than being linearly dependent on the distance and the 'safe' status of a source, the service level was recalculated using the assumption presented in Table 6: *Adjusted water service level calculation in the model* in Table 6.

The validation provided directly actionable insights and helped to ensure the model was more closely aligned with the real-world setting. The outcomes of the rural water domain expert consultation meeting were significant and led directly to a revision of the model verification, experiment design and set up. Modifications based on the experts' feedback were incorporated following the consultation session in an iterative participator modelling approach. These modifications are already incorporated in the description of the model given above.

6.9 Model Limitations

User decisions on whether to send an SMS text to a central number are presented as simple decision rules, while these little and seemingly inconsequential decisions have a lot of complex causes in real life and large consequences. Model results can only be usefully interpreted by keeping in mind the range of in-built assumptions set out in the model formalisation.

Deliberate choices have been made by the modellers included the decision to look at the M4W system from a local perspective, thereby excluding governmental organisations from higher levels of the national water governance structure.

Given the complexity of agents' interactions in the model, it was only feasible to run the model for 730 ticks (2 years), excluding long term developments such as the implementation of new water points which take place on an annual basis in most districts and parishes.

Stakeholder consultation also revealed many complex cultural issues. For example, it came to light that some water user committees may not dare to collect money from users with high social status. Accurately representing the full intricacy of the complex, contextually specific, social structures present in rural Uganda would require further field research using inter-disciplinary methods to surface these details and convert them to a set of replicable rules. Whether these complexities need to be modelled or it is sufficient that knowledge of context-specific 'rules of the game' can be used when interpreting model results, is a consideration to be handled on a case-by-case basis.

6.10 Conclusions

This project set out to gain more insights into the inner workings of the Mobiles 4 Water system and the reason why the system does not function in an optimal way.

The modelled system seems to represent an important feedback mechanism between water tariffs and water service levels. Water users with low service levels are less likely to pay for water services which results in low WUC financial balances / incomes and consequently, insufficient funds to pay for maintenance. This over time leads to non-functional water points, lowering water service levels accessed by users. An important 'systemic' improvement would be to increase water user knowledge about the importance of maintaining water points and maintenance costs. Without money gathered through water tariffs, eventually no water points will be functional.

Moreover, increasing the understanding that water user committees are not private entities with a profit aim could be beneficial. Money generated through user fees is meant to cover both operational and maintenance expenses thereby leading to increased service levels. The poor, or non-functionality, of water points should therefore not serve as a reason to withhold monthly water fees. Rather, low water point performance, framed as an incentive to increase one's regular payment of water fees, could result in sufficient money to cover the recurrent costs of maintenance and repair. For insights into intangible issues such as the role of trust between and among agents, an additional round of conceptualisation and revision of the model narrative and formalisation are required and could provide useful insights into how to further foster trust in the community based management model.

Rates of user fees are a related issue. Fees set at too low an amount result in low maintenance levels and service levels that decline over time. Fees that are set too high run the risk of insufficient funds as people cannot afford to pay their contribution (Hofstede, Hofstede, & Minkov, 1991). An alternative policy mechanism could be a means-based sliding water tariffs scheme, as observed in some countries. Converting this into an institution that is implemented in an experimental scenario in an extension of the current M4W model would enable decision makers to examine the effect of different tariff schemes on nationally-set water service levels and their ability to ease the burden on the poorest.

The implementation of the M4W telecom solution in the model resulted in higher service levels and lower average time-to-repair for non-functioning water points than the social diffusion of information solution alone. In turn, higher service levels are associated with an increased rate of user willingness-to-pay fees, resulting in water points remaining functional over longer periods of time. In this scenario, the Mobiles 4 Water is preferred over organic knowledge diffusion that is dependent upon one's social network.

6.10.1 Reflections and insights from both the Cases 1 & 2 models

The models in Chapter 5 and 6 provide several valuable insights and indicators for subsequent research steps. These two models provide valuable insights into how to conceptualise the system and simulate this description in an agent based model. However, to be able extend, modify or otherwise reuse these models, a coherent theory is required to have consistent patterns of agent behaviour.

This section highlights some of the key insights and their implications for in the context of this research project.

6.10.2 Conceptualising agents who learn and adapt

The ***Water Services that Last*** and ***Mobiles 4 Water*** modelling processes both resulted in detailed, yet slightly different, conceptualisations, narratives and pseudo-coding to simulate the technical and social agents interacting and adapting their behaviour patterns according to fairly simple sets of rules.

The WSL model simulated agents at the most local level of water services delivery providing insights into how water service levels are affected by interactions between social agents (households and water collectors), technical agents (water points) and policy artefacts including policies on water point coverage rates and average time-to-repair norms currently in effect in rural Uganda.

The M4W model simulates an increasingly complex system and narrative. The degree of complexity was increased through the introduction of additional agents that are found across more governance / administrative levels of the water sector. The simulation includes more elaborate rules that guide agent behaviour and the aspect of information dissemination and agent ability to learn and adapt are more explicitly scripted into this model.

Both models establish a means to describe, encode and thereby simulate the process of single agents and groups of agents learning, making choices and adapting their behaviour and strategies accordingly. In both cases, learning arises from interaction with other social agents, with the technical agents (water supply systems) or with institutions such as water point functionality and water service levels. These conceptualisations can be modified on the basis of domain expert feedback to arrive at simulations even more closely resembling the real-world scenario. This outcome seems promising as it indicates that the models could provide a valuable policy analysis tool.

6.10.3 Collaborative model design | local knowledge & domain expert feedback

Contextually specific information is required to more accurately explain and simulate realistic agent behaviour and decisions. Complex social norms are not captured in this model and require further inquiry to understand and accurately represent in a simulated environment.

An important consideration of a collaborative modelling exercise is which implicit institutions are critical to understanding the problem scenario and for decision taking at policy level.

Interpretations of the model must consistently apply the assumptions upon which the model formalisation (narrative and conceptualisation) are based.

6.10.4 Rural Water Services | Multi-actor, multi-level action arenas

The simplicity of the ***Water Services that Last*** model provided the insight that social, technical and institutional phenomena could be meaningfully simulated using a structured approach to model design and implementation. The choice was made with this model to focus on a relatively discrete segment of the rural water supply sector to create a valid simulation of how interactions between people, water infrastructure and a set of simple rules could affect a simplified expression of the Ugandan water service levels. The reality of this scenario is far more complex, involving far more actors, distributed across different levels of the rural water sector, the essence of the relationships and scenarios depicted, along with the arising macro-level pattern of the services levels is otherwise difficult to reduce to their essence and experiment with in real-world settings.

Having a basic model that can be extended to include more agents, both technical and social, from different levels along with more complex expressions of agent behaviour and the introduction of varying policy mechanisms would allow for experimentation with more complex scenarios.

6.10.5 The relationship between information and water service levels

In both models, agent behaviour is reliant upon reliable information about water point functionality and other issues such as household water service levels, the cost and duration of time-to-repair repairs as well as the location and functionality of alternate safe water points. These issues are known from literature and practice in rural water service to impact significant difference in people's water service levels. In the ***Mobiles 4 Water*** model, this is extended to insights about people's social networks – a key mode of information transmission. One's social 'connectedness' was observed to have an impact on the service levels.

Information about finances for water service delivery and maintenance, in the form of water tariff payments, the rates of water tariffs, the costs of repairs, the amount of funding provided by national grants, etc. is an essential resource for actors with a mandate to keep water services flowing.

The introduction in M4W of the social network resulted in interesting insights. In the scenario without the M4W telecom system, the social network had a significant influence on service levels. In this scenario, strong, active social networks contributed to accelerated knowledge diffusion about water points functionality and subsequently higher service levels following reduced time-to-repair.

A social network's functioning is dependent on unpredictable parameters such as one's number of interpersonal connections, the location of those connections and the amount of social interaction between users from their own villages and the social interaction between villages as HPMs may live in another village. Dependency upon these uncertainties for something vital as the daily water supply is an undesirable scenario.

6.10.6 Next steps

The models described in Chapters 5 and 6 incorporate agent learning and adaptation in the simulated environments. The M4W goes further in exploring the concept of social learning. We see here that in the absence of a centralised ICT solution (the M4W telecom solution) that the 'old school' dissemination of knowledge among local-level agents through social networks simulates how information about water point functionality is exchanged and learned.

The insight that is still lacking following the development of two relatively simple models, however, is how agent learning and information exchange between and across levels of the water sector system might be conceptualised and encoded in a rigorous, consistent manner. A formalised, consistent representation of these processes would be valuable for examining other policy interventions in a reproducible manner. Having a fit-for-purpose system description and narrative that can be systematically adapted or expanded to include additional actors, rules and levels of sector governance in a consistently replicable manner, would serve not only to reduce the time and potentially the cost of model development, but also provide sector learning platforms with useful, replicable and reusable boundary objects developed specifically to represent collectively defined mental models about existing problem scenarios and possible promising solutions.

An underlying theory that explains the phenomenon of social learning would provide useful insights for policy and decision-makers into factors that drive agents to change their behaviours and how this gives rise to new institutions (in the 'rules of the game' sense) that promote sustainable services.

In Chapter 7 a more systematic and more complex system description in implemented. The model narrative and design incorporate theories about social learning as well as about how information (institutions) might change over time as it moves through a socio-technical system under different conditions of learning.

7

Perspectives on learning in multi-level, multi-actor water service systems

As a net is made up of a series of ties, so everything in this world is connected by a series of ties. If anyone thinks that the mesh of a net is an independent, isolated thing, he is mistaken. It is called a net because it is made up of a series of interconnected meshes, and each mesh has its place and responsibility in relation to other meshes.

— Gautama Buddha (c. 563/480 – c. 483/400 BCE)
Monk, philosopher and teacher

Look for the helpers. You will always find people helping.

— Mr. Fred Rogers (1928-2003)
Television personality, musician, puppeteer and writer

In this chapter…

…The design and outcomes of an agent based model built to examine the financial allocation policy for rural water supply under varying conditions of learning practices is presented. The increase in complexity lies in the combination of a real-world institution – namely the national financial allocation formula applied in the period 2012-2014 to national and sub-national-level water services planning in Uganda. Specifically the manner in which district-level agents might learn from one another and the impact of this dynamic on district water service levels was simulated. Extending the model conceptualisation to include varying agent learning styles under varying conditions reflects a more realistic pattern of contextual variation we might expect to observe in the real world.

Experiment results indicate that when Districts have less restricted conditions to determine financial allocation ratios at a decentralised level, water service levels, measured in terms of the national norms and numbers of operational water points, is higher. Also, varying inter-District learning styles deliver variable water service levels.

These results offer policy-relevant insights into adaptive management practices grounded in social learning approaches in socio-technical systems, under the conditions set out in the model design. This combination of intangible elements was considered by key stakeholders as a valid, useful simulation that is replicable and adaptable to other contexts.

This chapter presents the case description of the researcher as conceptualised in an agent based model developed by Felix Knipschild in the course of his MSc thesis project. The model specifications are openly available in the education repository of Delft University of Technology

[http://resolver.tudelft.nl/uuid:55c225d5-5e75-4cd0-8097-715108eee172].

7.1 Introduction

A key concern of policy makers and practitioners is the potential outcome, or impact, of a policy or intervention. The model presented in this chapter explores how social learning might occur around the interactions of a real-world policy and what outcomes might flow from spending decisions.

As with other forms of public services, financial considerations play a fundamental role in sustainable water services. Policy and operational decisions about the allocation of financial resources and their potential impact on a system's overall performance are particularly challenging given the many unpredictable factors involved. The principles and practice of adaptive management, discussed in chapter 3, are proposed as a means to manage large scale socio-technical systems in the face of unpredictable future circumstances. Adaptive management entails monitoring and learning about signals of changing circumstances, identifying valid alternative routes towards the envisaged goal and assessing the capacity to navigate the revised course, while keeping the goal – in this case nationally determined water service levels – in sight.

The model simulates changes in water service levels arising from varying financial policy options under very different archetypal social learning and adaptive management styles. A brief contextual background to the model narrative is provided. Thereafter the model specifications are described followed by the findings from the *in silico* experiments conducted in the simulated system.

7.2 Collaborative Model Design Approach

As with the model conceptualisations and designs in Chapters 4 - 5, the Perspectives on Social Learning model conceptualisation process entailed a series of iterative steps to generate the model inputs and outputs visualised in Figure 33.

The aim of this final model conceptualisation was to simulate the arising system dynamics in terms of water service levels arising from varying financial policy institutions (policies) under distinctly different archetypal learning and adaptive management styles. This final research step benefited from work presented in earlier chapters such as the sector landscape which had undergone rounds of decomposition, formalisation, stakeholder validation and implementation in previous models. Nonetheless, in this research step, additional sources of theoretical and empirical information were gathered using mixed methods to inform the design of this more complex model conceptualisation.

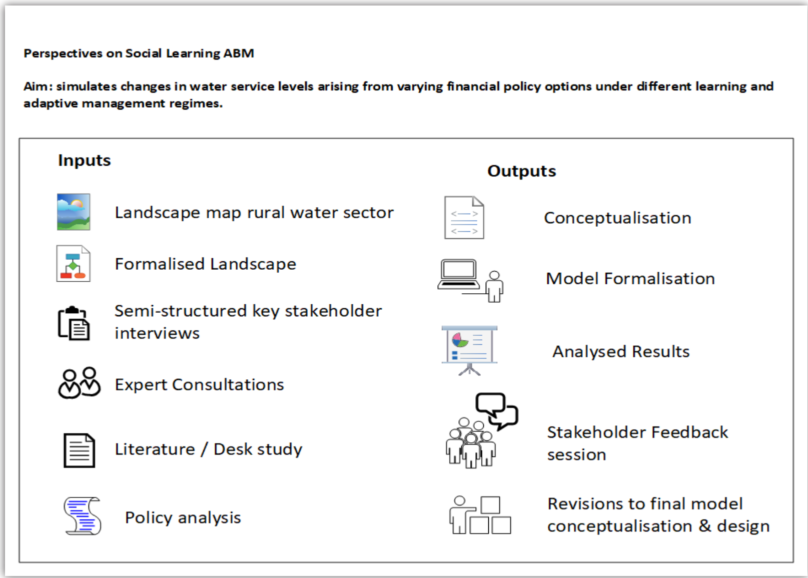


Figure 33. Perspectives on Social Learning model design inputs and outputs

The Triple-S programme design choice to focus on sector learning as a means for delivering sustainable rural water services informed the choice to delve into theory about adaptive management and sector learning. Also, having observed in previous models the role of information (of users, HPMs, DWOs, etc) on the macro level pattern of water service levels, theory about how information evolves and is transmitted between agents was examined. From the domain of policy, seven different sources of information were incorporated into the model conceptualisation. Contextually specific information about the prevailing financial, technical and regulation institutions in Uganda was gathered from MWE's Water and Environment Sector Performance Reports (2010, 2014, 2015), the Sectoral specific schedules / guidelines for 2012/13, the national water sector Financial Allocation Formula and the District Implementation Manual. Empirical information was gathered from Triple-S Uganda and other scoping studies (Nimanya et al., 2011; Biteete et al., 2013 and Boulenouar, 2014).

Semi-structured interviews were conducted at two points in time. In the conceptualisation phase three semi-structured interviews were held with the IRC Uganda Country Direct, Africa Regional Manager and Regional WASH Advisor Uganda. During the model validation phase a total of five semi-structured interviews were held; two researchers with knowledge of national water sector dynamics, systems sciences and modelling, but with no direct knowledge of the Triple-S project; two semi-structured interviews were held with the Regional WASH Advisor of IRC Uganda and IRC's CEO / Triple-S Project Director. The transcripts of these interviews were reviewed and categorised along key themes with relevant inputs to the conceptualisation being highlighted and interesting, but not salient empirical insights gathered from the open-ended responses of interviewees being noted, but not further operationalised.

The researcher, in her role as a Triple-S team member, was involved in the interview format design and selection of interviewees. Following the interviews by an MSc candidate and student intern, the review of the responses and categorisation of replies was collaboratively conducted. This process led to model design choices about information flow across the multi-level governance structure, varying goals of Districts in real world and for instance also the possible reluctance of District Water Offices to report above average results due to the risk of receiving a lower financial allocation of the District Water and Sanitation Conditional Grant from the national level in a subsequent financial year.

The learning and adaptive management styles implemented in the model design were developed for the purpose of this model. While they were informed by the literature about social learning, adaptation in water governance systems and evolution of information in social systems, they are not derived from either the theory or the empirical experience in Triple-S, but rather chosen as a means to encode learning in a dynamic system model.

The qualitative feedback from the stakeholder semi-structured interviews provided insight into key assumptions about the system description, the drivers of learning in the water sector and policy challenges to delivery of sustainable water services. This feedback was incorporated in adapted iterations of the model conceptualisation through changes to system description and model parametrisation choices prior to the implementation of the model in NetLogo. Following these steps to gather and assimilate various sources of information using mixed methods, a key choice was made to conceptualise the District Water and Sanitation Conditional Grant and district water service level variation as the central institutions about which District level agents would learn. These two institutions were selected as the literature points to the importance of financial resources for sustaining water infrastructure and services and empirical information from the Government of Uganda, Triple-S Uganda and other sector experts points to water service levels as the salient metric for determining the sustainability of a service. The interconnection between these two institutions is plausible, but not easily investigated over long periods of time for all 111 Districts in the Republic of Uganda. Information gathered and assimilated from the collaborative sector mapping, the scoping studies and policy documents, stakeholder consultations and interviews confirmed the value of investigating how learning at District level about the affect of different financial allocations on water service levels in other Districts in Uganda.

The final analysed results emanating from experiments implemented in simulated rural water service model were presented to IRC and Triple-S staff for reflection and discussion in a final project presentation in 2014.

7.3 Inter-District learning about financial allocation choices

Uganda has set goals to achieve stated water service levels for its rural population (GoU, 2019). Over time, however, a pattern of service slippage, where previously achieved levels of services start to decrease, is observed (Bey et al., 2014; Nimanya et al., 2011). Slippage indicates a move away from achieving the aim of sustainable water services for all people living in rural communities, and it arises from a myriad of intractable challenges and the reality of providing sustainable services in a dynamic, decentralised, multi-level, multi-actor space with high degrees of uncertainty. In this context, an iterative approach to foster collective reflection and collaborative action by concerned stakeholders is desirable. This iterative process enables stakeholders to collectively identify challenges and their origins, identify and test possible solutions, learn about what works and adapt solutions as needed in repeating cycles of adaptive management.

The District Local Government, in its role as water service authority in Uganda's governance arrangements, is tasked among other things with the responsibility of distributing financial resources (money) to pay for new infrastructure construction and for major repairs and rehabilitation for water supply infrastructure. The annual District water services planning process is a bottom-up process in which specific needs for new infrastructure, repairs and rehabilitation are gathered from villages and parishes, compiled at Sub-County level and submitted upwards to District Local Government for compiling into a District plan that is then submitted to the national level. At national level the District plans are reviewed and District Conditional Grants are distributed to District local governments for expenditure along nationally set ratios of approximately 70% for new infrastructure and 30% for repairs and rehabilitation.

Given the sector's strong formalised learning ethos, the aim of the agent based model was to gain insight into whether and how changing institutions – in this case varying financial allocations – and different learning styles within and between Districts give rise to more sustainable levels of water services over time. The underlying belief was that Districts that are more inclined to learn from other Districts with higher water service levels, would choose to replicate the financial allocations of those Districts in their own District.

Subsequent sections describe a systematically designed model that simulates the decentralised system for rural water service delivery and the patterns of water service levels arising from agent behaviour under varying learning styles.

7.4 A national financial allocation ration | the institutional context

During the period 2008-2014, local government administrators in Uganda were obliged to adhere to specified financial allocation ratio set out in the District

Water and Sanitation Conditional Grants. These ratios required Districts to spend proportionally more money on the construction of new water infrastructure than on major maintenance and rehabilitation for existing water infrastructure. The ratio was a minimum of 70% of total budget to be allocated to the costs of constructing new water supply infrastructure with the remaining 30% divided over costs related to software activities (community mobilisation, training, etc.) to a maximum of 8%, rehabilitation of boreholes and piped water schemes to a maximum of 13%, construction of sanitation facilities to a maximum of 3% and supervision, monitoring and district water office operational costs up to a maximum of 6% of the total budget (GoU, 2012).

Districts were not permitted to deviate from this ratio even in the event that locally conducted needs assessment indicated that another course of action would lead to higher water service levels. Various studies (Bey et al, 2014; Biteete et al., 2013; Matyama, 2015) made a connection between this policy directive and stagnating water service levels. While it would be ideal to experiment with different financial allocation ratios in different districts with varying local conditions over longer periods of time to identify an 'optimal' ratio, such an experimental approach is neither possible, nor necessarily equitable, in real-world settings for a myriad of reasons, not the least of which is that there remain many un(der)served citizens in Uganda and the urgency of delivering sustainable services to them is critical. Moreover, as new infrastructure is built, the new infrastructure will require regular maintenance. While the population of under-served and unserved people remains dauntingly high in the rural areas, a fixed allocation in favour of new construction overlooks the increased requirement, in total terms, for financial resources to maintain greater numbers of water points and related infrastructure. In other words, the more new infrastructure that is built, the higher the total amount of money that is required to maintain the expanded water supply system. Fixed ratios do not reflect this shift in system dynamics and requirements. The model therefore offers the possibility of adapting allocation ratios to observe the effect of a relaxation, or other adaptation, of the nationally set allocation ratios, on District water service levels – a policy assessment that is difficult to test rapidly in a real world setting.

The Ugandan financial allocation ratio consists of three ratios for a certain expenditure: a ratio for CapEx, a ratio for CapManEx and a ratio for unspent budget. The boundaries set out by the MWE in the District Conditional Grant regarding this allocation ratio are detailed in Table 9.

	Definition	Short	Boundaries (% of DCG)
X	Capital Expenditure	CapEx	70 - 100
Y	Capital Maintenance Expenditure	CapManEx	0 - 13
Z	Unspent Budget	Unspent	0 - 30 (100 - X - Y)

Table 9. Conceptualisation of the District Conditional Grant

Source: Knipschild, 2014.

In this policy mechanism, unspent budget returns to the national coffers. If this happens, it means that a district has invested less than possible in its water infrastructure. A district with a low unspent budget ration may indicate a district delivering a high level of performance. The optimal ratio for unspent budget would therefore be 0 indicating that the budget has been completely used to cover CapEx and CapManEx expenditures. For the ratio for CapManEx it may be reasoned that a higher ratio is probably more beneficial for the water service levels in the long term. The maximum allowance for CapManEx budget is 13% of the total budget and therefore an optimum of 0.13 may be assumed. The optimum ratio for CapEx would then to be one that spent all of the balance: the best behaviour of a system may be observed with a CapEx ratio of 0.87. The optimal ratio, under the conditions and assumptions of this model, in the ABM is therefore [0.87 : 0.13 : 0]

7.5 Conceptualising sector learning and evolving institutions

In the system conceptualisation set out in Chapter 4, a theoretical framework based upon memetics was developed to explore how agents might gather, exchange and modify information about water service levels. The language of institutions – ADICO – was used to describe the actions and interactions of agents. The socio-technical agents described in that conceptualisation were the central dynamic agents involved in information exchange. Their micro-level interactions gave rise to macro-level patterns of water service levels. In this extension of that design, agents now exchange information through the processes of *selection*, *replication* and *variation*.

The institution under consideration is the financial allocation ratio used to disburse national-level financial resources to district local governments to finance water supply, including maintenance and minor repairs of infrastructure. This chapter examines how learning about different applications of the financial allocation might come about, focusing on how the units of information about different allocation rations and water service levels evolve under different learning regimes. Different learning styles of the social agents – *rational*, *myopic* and *random* – are described as the 'rules' as information about financial allocations is selected and spending ratios are replicated or varied. This combination of learning styles, different institutional interpretations and the principles of evolution provides an opportunity to observe the effect of varying learning regimes on district water service levels.

7.6 System identification & description

7.6.1 Learning processes | selection, variation, adaptation

This section elaborates on the concepts used to conceptualise the learning processes and methods in the model as were set out in Chapter 4.

In the process of learning, agents make choices about whether or not to take up new information and incorporate it into their future behaviour, choices and decisions. In order to conceptualise this process of learning, the processes of selection, replication and variation are applied to represent the learning process taking place between and among agents in the model.

In this model, a rural water supply sector institution was identified, namely the nationally determined *financial allocation ratio* implemented by districts. This piece of information represents a district-level policy choice within nationally set limits. The processes of selection, replication and variation offer a means to conceptualise the process by which information about "good" or "bad" financial allocation ratios is transferred among and between agents as it is taken up, applied and modified by individual agents. The conceptualisation is further elaborated in th model narrative, which tells the 'story' of the procedures that are encoded in the agent based model. The narrative detailing what each agent does, when, why and to whom, is available in Annex E. The narrative in turn informed the *pseudo-code* which represents the steps of the narrative about how agents learn about the affect of varying financial allocation ratios on water service levels. Different styles of learning are also applied as options that have been built into the model that may be implemented or not for experimentation purposes.

7.6.2 Learning methods | rational, myopic, random

Not only do agents select, replicate or vary information in their daily activities, they also have different methods by which they learn. In order to conceptualise the method of learning, the concepts of *rational*, *myopic* and *random* methods are applied as 'rules' that determine the method by which information is selected, replicated or varied by agents in the simulation.

Each method is observed in the simulated rural water system. For instance, *fully rational* represents learning at the national scale, where a good or effective policy from one district is signaled by the Technical Support Unit (TSU), communicated to MWE and subsequently communicated to all other districts in the form of a law or undertaking. The *myopic* method represents learning at the regional scale, where districts learn from each other about the effectiveness of policies through participation in regional learning platforms, such as learning fora or WASH alliances. The *random* method represents learning between districts, where one district communicates with one other district but the exchange is not formally facilitated through a platform or directive.

7.6.3 Combining learning processes and methods

Combining the learning processes and methods described above makes it possible to explore different scenarios by which processes of replication and variation of information might take place.

The **replication** process contains conceptualisations about learning methods in the rural water supply sector. Three different learning methods are identified in the sector, each with a different number of institutional levels involved. The three learning methods described above – taking place at inter-district, regional and national levels, represent routes across institutional levels by which districts may learn about a policy outcomes in other districts.

The **variation** process examines alternative conceptualisations of how an allocation is replicated by a district. In the first replication there is no variation - districts simply make a perfect copy of the allocation ratio they replicate. In the second method, districts slightly adjust the ratio with a random fraction towards the allocation ratio they used themselves in the previous year. The second method represents either a slight communication error between districts or the rational choice of a district to adjust the ratio to their own situation.

These combinations of learning processes and methods represent simplifications of how actual human learning and social learning take place as one means for examining arising dynamics when this set of rules and styles are applied.

7.7 Model set up | time and procedures

Table 10 provides an overview of the model's variable parameters and their sources is given in.

Parameter	Units	Value	Source	Comment
Districts	number	110	Directorate of Water Development and Ministry of Water and Environment [2016]	Excluding Kampala District (due to no rural characteristics)
Delivery Capacity Water Point	Litres per day (L/D)	6000	Directorate of Water Development and Ministry of Water and Environment [2016] F.A.Q., Biteete et al. [2013, p. 24]	All are shallow wells with hand pumps
Population growth rate	% per year	3.6	Biteete et al. [2013, p.1]	
Target Quantity	Litres per person per day (L/P/D)	20	Biteete et al. [2013, p. iv]	
CapEx price	USD	2300	Biteete et al. [2013, p. iii]	
CapManEx price	USD	600	Biteete et al. [2013, p. iii]	

Mean lifetime Water Point	Year	6	Moriarty [2016]
Standard Deviation Life time Water Point	Year	1.5	Moriarty [2016]
Simulation Years	Year	20	

Table 10. Model Parametrisation
Source: Adapted from Knipschild, 2014.

7.8 Model formalisation

The model described here has a number of salient features that warrant a detailed description given their fundamental role in the model design, set up and performance. These include water quantity, the variation process and time and procedures. The model conceptualisation is available in 4TU.ResearchData's repository (DOI: 10.4121/14714037).

7.8.1 Water Quantity

The first salient element is the calculation of water quantity per person implemented in the model. This calculation, based upon Uganda's national norms and standards, is used to determine whether a district water service performance can be classified as *good* or *bad* once the district's learning and selection processes have been activated.

The calculation of water quantity per person is made by multiplying the number of functional water points with their assumed delivery capacity and divide by a district's population. To arrive representative data for this calculation, actual data was used to make reasonable extrapolations about functional water points, delivery capacity and total water quantity delivered per district.

The initial parametrisation of district water quantity is based upon water infrastructure data made available by the Government of Uganda's Ministry of Water and Environment, Directorate of Water Development (GoU, 2015). Data on the total number of water points and the number of functional water points, disaggregated by district and infrastructure type, is combined with national standards for the number of people a given water infrastructure type should provide with a given quantity of water. All water infrastructure in the model is assumed to be a shallow well with a hand pump. Here too national standards (GoU, 2015, Annex IV) state that a shallow well with a hand pump has sufficient delivery capacity to provide 300 people with 20 litres of water per day.

The number of functional water points – disaggregated by type and district - is multiplied by assumed delivery capacity resulting in a total quantity of water (in litres) delivered in a district. This figure is used to calculate both the water quantity per person by dividing the total amount of water delivered by a district's population, and the number of shallow well water points to be simulated. Lastly, the total number of shallow wells is calculated based upon the rate of functionality per district (GoU, 2016). These calculations serve as a basis for the initial simulation conditions. During the initial and subsequent simulations, similar calculations are used to calculate water quantity as a means of tracking district performance over time.

7.8.2 Variation Process

The set-up of the variation process is also a feature of note in this model. In this process, a choice is made between making a perfect copy or introducing a variation on the selected financial allocation ratio. The latter represents both the possibility of an unconscious mistake in copying a financial allocation ratio as well as the conscious adjusting of a selected ratio to better suit one's own situation. For the introduction of variation, a calculation is made. The ratio the district used in the previous tick is considered the 'old' ratio, the ratio a district selects and replicates for use in the next tick is the 'new' ratio. Only the ratios for CapEx (capital expenditure) and CapManEx (capital maintenance) are considered in the formula.

7.8.3 Time and procedures

In a time step of one year, all dynamics and granularity of events are aggregated, looking in particular at how policies are transferred between districts and how this influences the outcome of system behaviour. One year is a useful time scale as the policy of interest is re-evaluated on a yearly basis in the local and national learning platforms such as Sector Performance Reviews.

Simulations are run over a period of 20 years. A water point's average lifetime is 6 years which means that it is possible to observe a period of 3 to 4 infrastructure life cycles. This makes it possible to observe the effect of different learning regimes over a period of time sufficiently long enough to observe patterns emerging. In the 20 years of a simulation a number of steps and procedures are repeated every tick (in this case, one year). Agents' actions and the order in which they are performed every year are as follows:

Return budgets: All residual unspent budgets of districts from the previous year are returned to national government. This is the cumulative of unspent budget that is not spent on either CapEx or CapManEx.

Calculate Water Service Levels: Districts calculate the water service level per person in their areas. This is a function of the number of water points, the functionality percentage of the water points, the delivery capacity of a water point and the population. We assume each district has complete information about the state of infrastructure in its area. The water service levels per person are used to construct the ranking for the selection procedures.

Selection processes: Districts are ranked according to their water service level per person. If the districts are categorised as *fully rational*, this ranking is made at national level and includes all districts. If the districts are categorised as *myopic*, the ranking is made within regions. Hereafter, the districts make three assessments: whether they are 1) the best performing district or 2) in the bottom half of the ranking, and 3) do they perform above national set target quantity? The first assessment is used in the replication procedures. The second and third assessments form the selection mechanism: the allocation ratios of district in the bottom half or below target quantity *cease to exist*, the ratios in the top half of the ranking and above target quantity *live on*.

Replication processes: Districts whose allocation ratio *lives on* replicate this ratio and use it again next year. Districts whose allocation ratio *ceases to exist* replicate the allocation ratio that is used in the previous year by the best performing district, i.e. the top ranked district. They replicate either the ratio of the best performing district in the nation (method: *fully rational*), the ratio of the best performing district in the region (method: *myopic*), or the ratio of a random other district (method: *random*).

Variation processes: Only districts who have replicated an allocation ratio of another district follow this procedure. If the variation method is *perfect copy*, the districts simply replicate the ratio they selected to replicate. If the variation method is *random fractional*, districts move a random fraction from the ratio used in the previous year towards the ratio selected for this year.

Ageing of district and water points: The population of a district grows in line with its "population growth rate". After each tick, operational water points add a year to their age. When they reach their calculated expected lifetime they fail and become non-functional and the age counter is reset to zero. Thereafter, for each tick in the model, non-functional water points add a year to their non-functional age. When this counter reaches 5, the water point is considered abandoned and the WP-agent dies.

Districts calculate budgets: All districts calculate their budgets for CapEx and CapManEx from the allocation ratio multiplied by the budget in the District Conditional Grant.

Districts spend CapEx: Districts spend their CapEx budget, by determining the number of water points that can be constructed within their allocated budget and creating that amount. The water points start delivering services to the districts. Districts calculate how much budget remains from their allocation, transferring the residual budget to CapManEx.

Districts spend CapManEx: Districts calculate how many water points they are able to repair within CapManEx budget and repair that maximum number. Any unspent CapManEx is transferred to the *unspent budget*.

7.9 Experimentation

The model conceptualisation examines the effect of different archetypal learning styles under varying conditions on water service levels that users receive. Experiments exploring how learning in Uganda's rural water supply system might occur under varying conditions, and the effect of different learning styles on water service levels, are described in this section.

The first step was to identify a performance indicator to assess how well a district is performing. The water service level selected is *water quantity per person per day* (L/.p/d) delivered in a district. Two criteria were adopted to judge how well an allocation ratio performs. First, a ranking of all districts based on their water service level, ranked from highest to lowest. Second, the national water quantity target is taken as a threshold value for "good" performance. These criteria are implemented uniformly across each experiment. The experiment set-up examines the effects of selection, replication and variation processes. The different methods are combined in a set of scenarios and the experiment tests whether different methods for replication and variation result in different system behaviour and water service levels. The experimental design is depicted in Table 11.

Replication method	Variation method	
	Perfect Copy	Random Fractional
Fully Rational	Experiment 1	Experiment 2
Myopic	Experiment 3	Experiment 4
Random	Experiment 5	

Table 11. Experiment Design

Source: Adapted from Knipschild, 2014.

For random replication districts (those which choose an allocation ratio from a random other district), the two variation methods (perfect copy and random fractional) are considered as a single scenario because adding a random variation to the random process does not result in different outcomes.

Simulations are run in the agent based model using the NetLogo *Behaviour Space* function which is an environment to set up simulations and determine output variables. In total, 500 simulations are performed, 100 runs for every scenario. Processes that occur randomly are included in the model. For example, water point failure or the initial allocation ratio of the districts, require multiple simulations of the same scenario to increase confidence about the average behaviour of the system. Many output variables are gathered in the simulations, including outputs to analyse district performance, regional performance and performance aggregated at national level. The analysis of the output of the experiments is presented in the next section.

7.10 Results and Data Analysis

In this section, experiment results in this simulation of rural water services in Uganda are presented and discussed.

Results show that, under the conditions of this model, particular approaches to inter-district learning result in higher water service levels. Moreover, the results from the experiments conducted in the agent based model simulation indicate that when Districts have less restricted conditions for locally determining financial allocation ratios (as opposed to nationally determined ratios that they are required to adhere to), the performance measured in terms of the national water services indicators and in terms of operational water points improves.

Under the prevailing policy conditions at the time of the study, districts were bound by the MWE to invest most of the financial allocation in CapEx to further its policy to increase the rate of water supply coverage at district level. The results of the *in-silico* experiments here suggest, however, that this policy restriction hampers progress on district water service levels. The simulations demonstrate a higher rate of functionality, a higher total number of water points and a higher average service level in the experiments with loosened restrictions for choices about allocations of financial resources for CapEx and CapManEx.

7.10.1 Initial Simulation Conditions

The initial conditions of the model are based on the actual situation in Uganda during the study period. District-agents in the model are similar to real Ugandan districts in terms of general characteristics that affect the water quantity level: population size, total water quantity delivered in a district, functionality rate of water points and a water point’s delivery capacity are randomly selected from possible real-world options.

All data are sourced from government sources used to monitor water supply and services progress in rural Uganda (GoU, 2016). While initial budget allocations in the model may vary from real-world district and over time, the model is based on the allocated budget in the Financial Year 2015/16. Model behaviour is expected to progress in a stable fashion, as the financial allocation from national level to district level is assumed to grow at the same rate as the rate of population growth. Expected behaviour may be stable as districts find a balance between investments and infrastructure failure. One might expect to see different values to which a system tends to evolve based on different methods for learning, as discussed in section 7.9

Figure 34.a shows the average performance of all 100 districts in Uganda for all 500 simulations over a period of 20 years. In the first five to six years, the average performance of districts in all simulations shows a steep drop from about 19 litres of water per person per day to 13-16 litres of water per person. Following this steep drop however, the system stabilises.

Over the first 5 years the quantity of water in the simulation remains fairly uniform between districts, after which time the spread increases to between 12 and 18 litres per person per day. A box plot of the system behaviour in Figure 34.b shows the average water service level stabilises over time around a water quantity of 14 litres of water per person per day (L/p/d). A small number of runs are considered outliers at quantities of around 12 and 18 L/p/d.

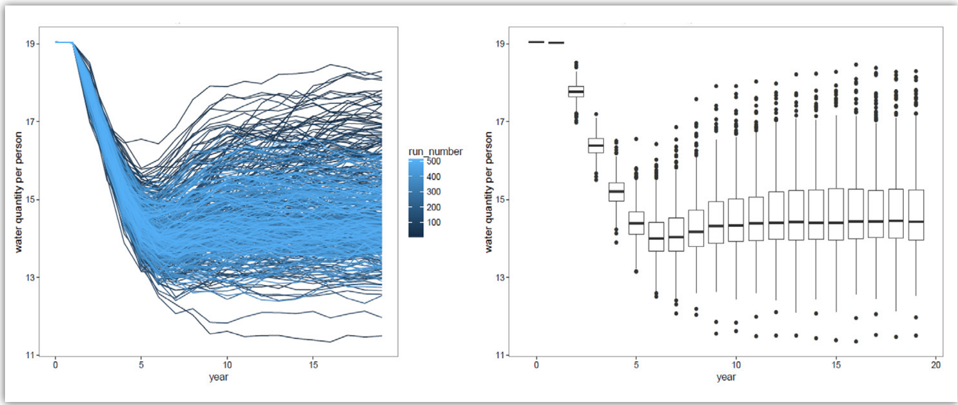


Figure 34. Average performance of 500 simulation runs over time.

A single line represents the average water service level of 110 districts over a period of 20 years in a single simulation run
(a) Average national performance of all simulations (b) Average performance and spread over time

Source: Adapted from Knipschild, 2014.

The initial conditions in the simulations show a water quantity level of approximately 19 litres of water per day, compared to the national target of 20 litres of water per day. Model behaviour stabilises after 5 years at approximately 14-15 litres of water per person per day. National coverage in Uganda is estimated at 65% (GoU, 2015). In the conceptualisation of the water service level, this results in a water service level of 13 litres per person per day where 100% is 20 litres per person per day.

Regarding the steep drop from the initial conditions and the stable behaviour after the initial five years period, it is possible to extrapolate the stable behaviour over a long period of time. The initial steep decline may be an artefact of how the system is modelled, rather than an actual system pattern. This is explored through performing a sensitivity analysis on initial budget and service level estimates based on empirical data.

If it is assumed that initial conditions reflect real life, a stable level means districts spend just enough budget to keep pace with the rate of infrastructure breakdown and the rate of population growth. As district budgets grow at the same rate as population growth, it is further assumed that the district budget and the infrastructure failure are in balance.

Infrastructure failure in the simulations reflects assumptions (based on real life) about the expected lifetime of water points and the investment costs for CapEx and CapManEx. District budget in the simulation arise from assumptions about the District Conditional Grant (DCG) and its growth. As water supply services are financially intensive, both assumptions can have a large effect on the level at which finances and failure rate are found to be in balance. In an additional experiment, the sensitivity of the level at which the simulations stabilise at different budget levels is tested. Figure 28 shows how sensitive the model output is to initial DCG budget changes. The DCG budget is varied by -10%, -1%, 0%, +1% and +10% with a total of 20 simulations (20 years) shown. Here only the end points are shown.

Figure 35 shows that when DCG budgets vary greatly (plus or minus 10%), the simulation outcomes in terms of water per person increase as the budget increases. The middle three plots show the same behaviour as the outer two plots. Each run is based on 20 simulation runs, which is too few to obtain a good representation with a difference of 1%. The simulations show a median water quantity of 13 litres when the districts receive 10% less budget and around a median water quantity of 17.5 litres when districts receive 10% more budget. This indicates that the model's behaviour is sensitive to assumptions about financial parameters. Other parameters may also influence the level at which the model becomes stable.

In the previous section, it was assumed that the initial district conditions were correct. This assumption is revisited to consider why initial conditions might be inaccurate and to explain the quick decline exhibited in the initial five year time period. District data is based upon data sourced from the Directorate of Water Development of the Ministry of Water and Environment (2016) which also employs a number of assumptions. The Ugandan government uses heuristics to determine the number of people a water point type serves. For instance, a shallow well is determined to have the capacity to deliver 300 people with 20 litres of water per day

(GoU, 2015, Annex iv). This heuristic rule is implemented in the model. However, if this input information is inaccurate, then the model's initial conditions are also inaccurate.

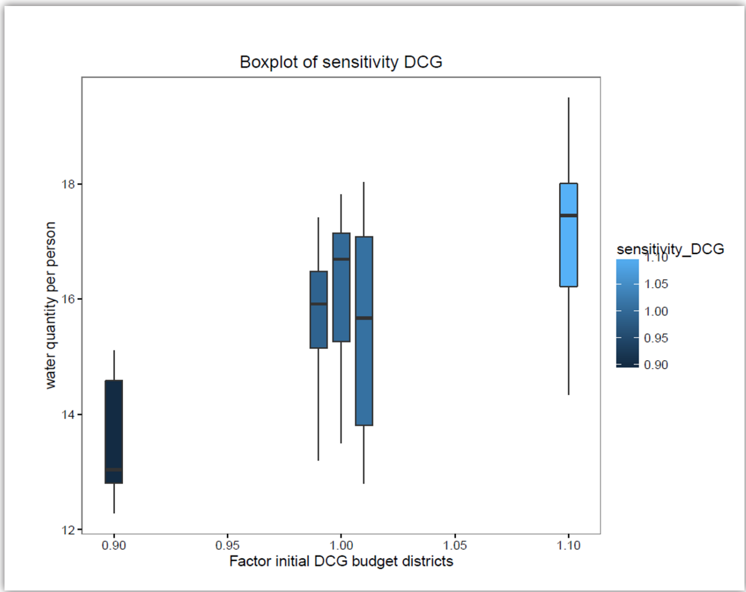


Figure 35. Sensitivity analysis of initial District Conditional Grant allocations - initial allocations are multiplied by the x-axis factor

Source: Adapted from Knipschild, 2014.

Another important test was to check the model for modelling artefacts. this entailed examining the use of district water service levels at the end of one run as the input for a new run whereby districts start at the level at which they became stable in the previous run. In subsequent tests, the number of water points is varied to match the water service level achieved at the end of the previous run. A total of 50 simulations are performed, 10 for every scenario for replication and variation to ensure a similar representation as the initial model run to test the original settings. The detailed description of these tests and analysis are provided in Annex F.

In summary, the average district performance shows a steep decline followed by slight recovery with a stable state over a long time period. At the outset, districts have a certain water service level and a certain rate of water point functionality. The financial allocation they receive combined with the policy that guides spending decisions results in water service levels that cannot be maintained. A timely repair is less costly than rehabilitation, or the installation of a new, water point.

Possibly the maintenance budget in the simulated scenario is too low to maintain current service levels, indicating that there may be other budgetary sources in the real world which are not represented in the model. Funding through overseas development aid programmes for new infrastructure may go unrecorded resulting in insufficient domestic budget allocations for CapManEx. This in turn could result in a failure to maintain the desired rates of water point functionality based on the initial conditions. This scenario is plausible given the disincentive arising from the budget allocation policy that mandates budget allocation reductions to districts that perform above the national average in subsequent financial periods.

In reflecting on the extent to which the behaviour is an artefact of the model or a result of the initial data used, it is proposed that both the level of stabilisation and the initial conditions are not entirely accurate. The aim is, however, not to predict the future state of rural water supply in Uganda, but to explore policy alternatives under varying conditions in different scenarios. Any inaccuracy is not therefore considered to invalidate the pattern of outcomes observed.

7.10.2 Analysis of Scenarios for Replication and Variation

This section analyses scenarios for replication and variation. The replication and variation methods are first reviewed prior to the review of the five possible scenarios for interactions between replication and variation methods as described in 7.5.3.

7.10.3 The process of replication

In this section we explore the dynamics that arise in general system behaviour under different methods of replication. Each simulation run follows a similar pattern with an initial drop in performance rates observed in the tests for model artefacts. The level at which the simulations become stable is spread over a significant range. It is therefore reasonable to posit that the replication method may influence the level at which performance stabilises.

The expectation is that the *fully rational* learning method results in better performance, as effective policies in allocating the financial ratio spread over a wider range of districts. However, a sub-optimal allocation ratio may, in practice, have outcomes that are considered very good, for instance when initial conditions of a district applying that specific ratio had high initial water services levels. This may result in an ineffective, or bad, policy being spread to many districts that copy the sub-optimal allocation of the high performing district. The *random* replication method is assumed to perform the poorest among the three learning methods, as the other two learning processes take place at higher scales by replicating better outcome districts, while in this case districts choose a district at random. The *myopic* replication method, which is limited to one region, is assumed to perform somewhere in the middle with a less prolific spread of lessons, or information, than in the *fully rational* method which is not limited by the regional boundaries. The actual outcomes of the different replication methods is visualised in Figure 36.

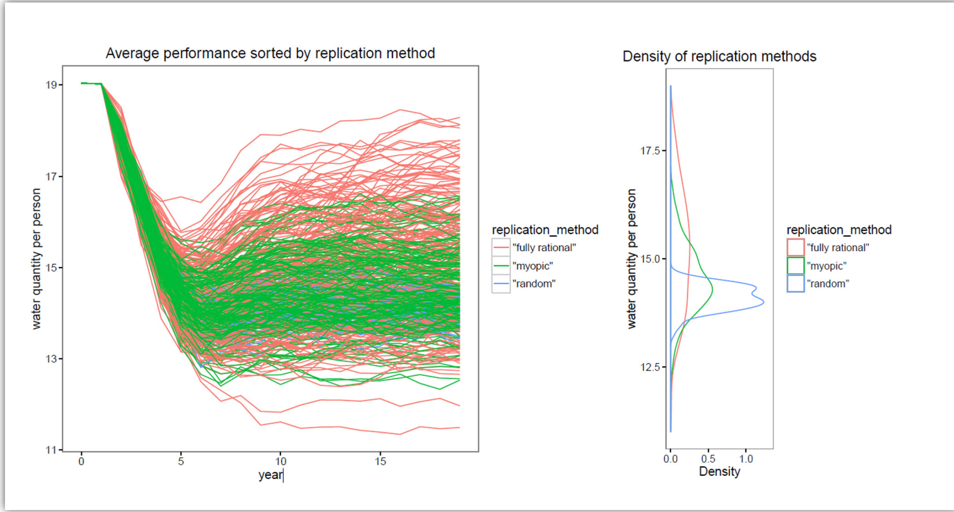


Figure 36. Average performance by method of replication.

Left: all runs. Right: the density of runs ending at a certain water quantity level after 20 years.

Source: Adapted from Knipschild, 2014.

In the runs depicted above, red denotes the *fully rational* method, green the *myopic* method and blue the *random* method. Green, *myopic,* runs are visible in the centre of the range. The *random* method is barely visible and, at the extremes near the top and the bottom, some simulation runs with the *fully rational* method are visible. Figure 36.b plots the end values of the simulation runs which end up at the same water quantity level whereby the density plot shows a larger deflection for the *random* and *myopic* methods.

The *fully rational* method seems to result, on average, in a higher national average water quantity of the districts. However, the *fully rational* method also shows poor outcomes. The *myopic* replication method is similar to the *fully rational* method, but the effects are less extreme perhaps due to the fact that policy choices affect a smaller area. The *random* method depicts interesting, fairly stable, behaviour.

None of the learning methods perform exceptionally well, nor do they perform exceptionally poorly. All runs end between a level of 13 and 15 litres of water per person per day. Figure 37 visualises the end point of all simulation runs.

The *fully rational* replication method performs better than the *myopic* method which, in turn, performs better than the *random* method. This is significant as the 95% confidence intervals of the median of the plots do not overlap.

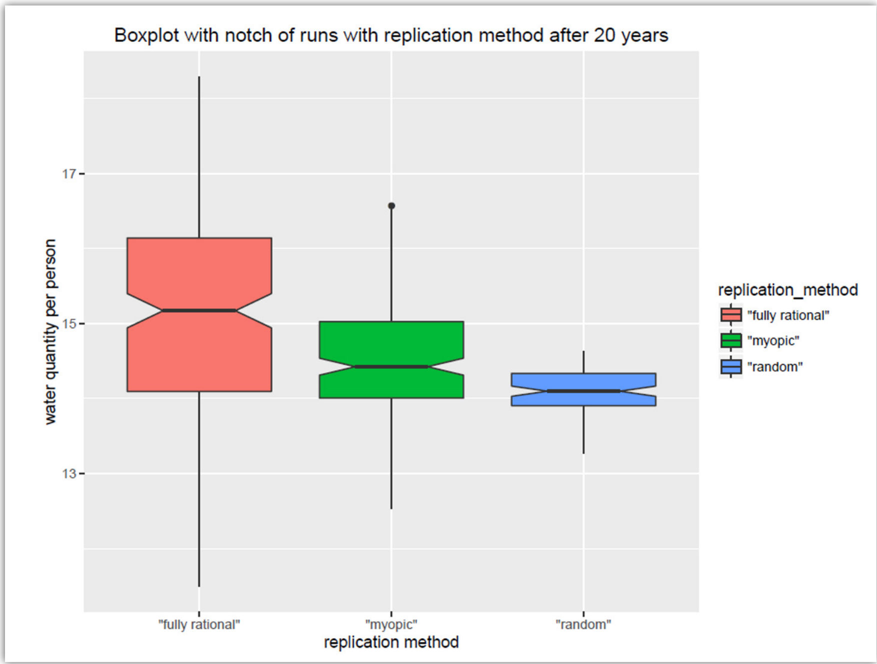


Figure 37. A notched box plot of replication methods

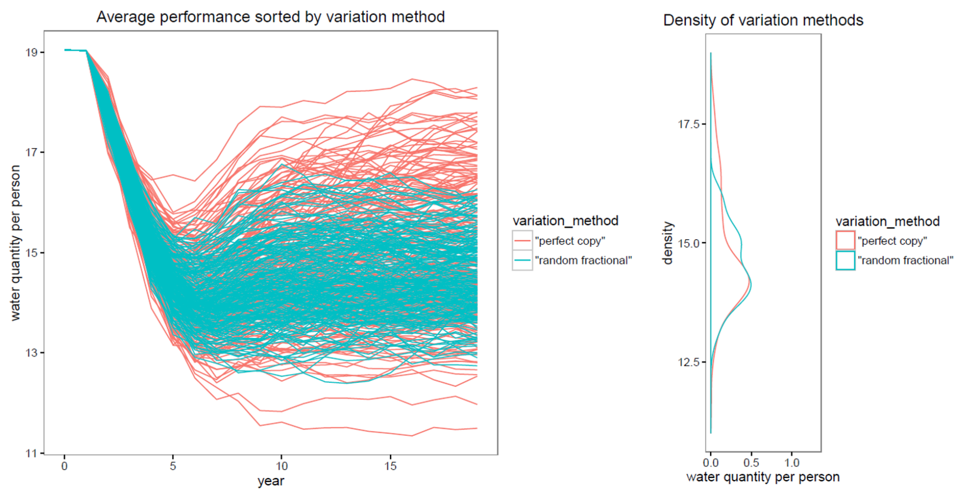
Source: Adapted from Knipschild, 2014.

A second observation is that there is a wide spread of outliers in the *fully rational* method (between 12-18 litres) which declines as the scale moves towards the more random, local level (between 13-17 for the *myopic* method and between 14-15 for the *random* method). Outliers in the *fully rational* method arise as the model is sensitive to initial conditions, i.e. the allocation ratio of a district that performs well with a good allocation ratio (e.g. zero unspent budget) spreads over at least half of the districts in a single year. The initial ratio of the districts is determined on a stochastic basis, randomly chosen within the set boundaries for CapEx and CapManEx for every district in each simulation. The effect of a good or bad initial condition is limited to one region in the *myopic* method and has almost no effect in the *random* replication method reducing the spread of outliers.

7.10.4 The process of variation

On the methods for the variation process of learning, two options exist: a) districts make *perfect copies* of the selected ratio and b) districts slightly adjust the selected ratio (*random fractional*). The latter presents two possibilities – an unconscious mistake in copying a ratio or a conscious choice to adjust the ratio to the local context. The expectation is that the *perfect copy* results in more extreme behaviour, as extreme allocation ratios are mimicked. The *random fractional* is expected to result in more moderate system behaviour, as variation is added to extreme allocation ratios.

In Figure 38, the same graph types as in the replication experiments are depicted. One shows the average district performance over time, colour coded by variation method. The other shows the outcome density of simulations after 20 years, again colour coded by variation method.



(a) Performance coloured by variation method (b) Density of runs after 20 years

Figure 38. Average water quantity level by variation methods over time.

Source: Adapted from Knipschild, 2014.

On the left, all runs are depicted with both extremely good and extremely bad runs resulting from the *perfect copy* (in red) method. The *random fractional* (in green) method runs demonstrate more moderate performance. On the right, in the density plot analysis of runs ending at specific water quantity levels, the conclusion is less clear. The two plots do not differ much with both below a water quantity of 12.5 L/p/d. At the level of 15 L/p/d the methods diverge slightly with more *random fractional* runs and a greater spread of ***random fractional*** runs over the higher levels in the *perfect copy*. This analysis seems to be further supported by Figure 39.

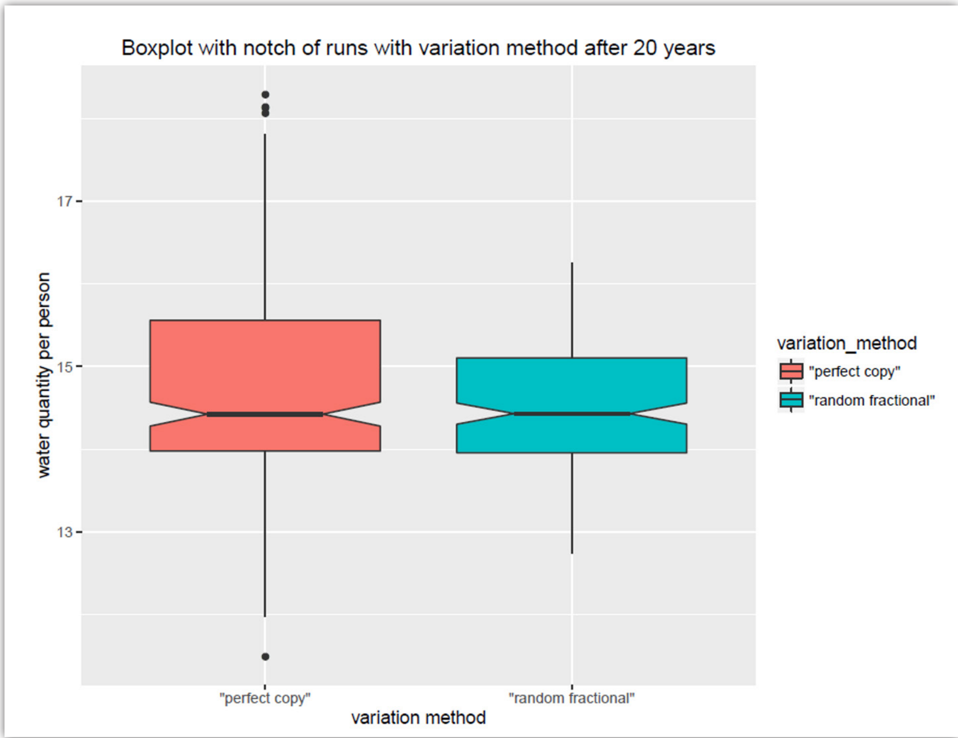


Figure 39. Average performance and spread of water quantity by variation method
Source: Adapted from Knipschild, 2014.

The medians of the two runs are similar, but the outliers of the *perfect copy* method are spread over a larger range than the *random fractional* method: (12-18 compared to 13-16). This may indicate that as districts decide to adapt a policy they have imitated, they are less likely to encounter extreme scenarios. With these insights we posit that the *random fractional* variation method performs better than the *perfect copy* method. While the median is the same, the spread is smaller, resulting in a more moderate pattern of system performance. Here, the effects of the replication and variation methods on the average system behaviour have been simulated and analysed separately. What happens when these factors are combined? The results are visualised in Figure 40.

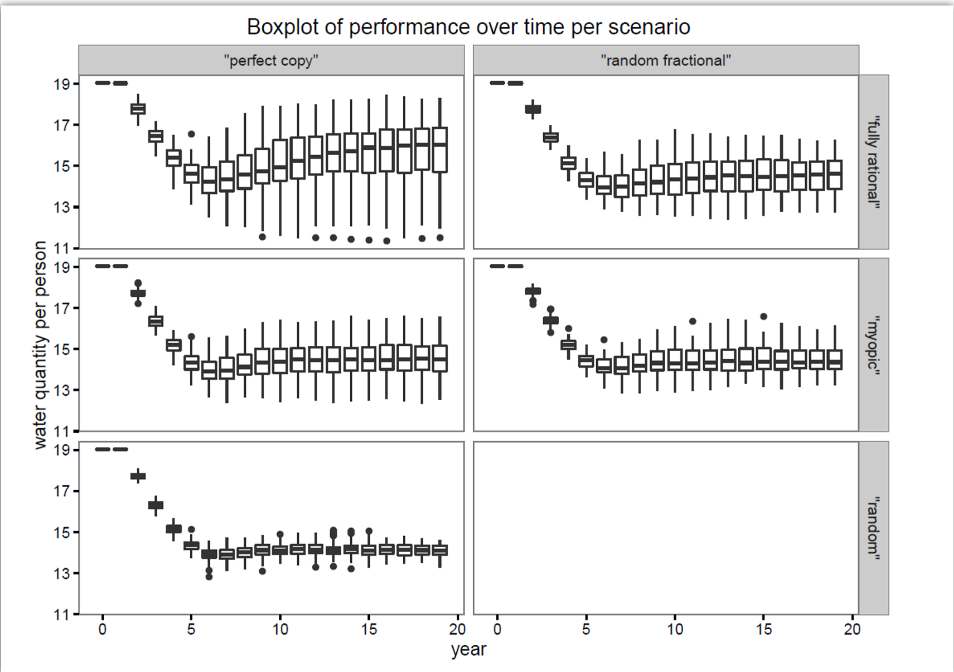


Figure 40. Performance over time per scenario over 20 years

Source: Adapted from Knipschild, 2014.

Figure 33 depicts five experiments, each represented by a box plot of the average behaviour under the conditions for replication and variation as specified in the scenario over a period of 20 years. All simulation runs are separated according to their methods for replication and variation. Each box represents a one year run of the model.

The difference between the left and right graphs is the variation method: *perfect copy* on the left, *random fractional* method on the right. From top to bottom, the variation in replication method is depicted: fully rational, myopic or random. In the top left scenario (*fully functional* + *perfect copy*), the greatest range of endpoints of the simulation has the highest median. The *fully rational* + *perfect copy* scenarios differs from the *random fractional* counterpart in that the range of the simulation runs is higher and the median performance is higher: 16.5 compared to 15. In the *myopic* method similar conclusions may be drawn. The median of the *perfect copy* + *myopic* scenario is higher than its *random fractional* counterpart. The difference here is, however, minimal: 14.5 compared to 14. The spread of the *perfect copy* + myopic scenario is greater, (induced by model sensitivity to initial conditions) which is similar to the *fully rational* + *perfect copy* scenario. In the *random* replication method the spread is smallest with a median that is the lowest among the five scenarios.

In this section standalone and combined analyses of different learning processes and methods for replication and for variation were presented. These were operationalised in a model run under varying conditions. The aim was to illustrate the diversity of policy insights that model-based policy analysis can offer to decision makers.

7.10.5 **Allocation Ratio**

The focus in this section is on the institution, the financial allocation ratio, and insights arising from modelling design choices and experimentation runs.

Implicit within the implementation of the policy in the simulation are learning and exchange arising from communication between district level agents. This section examines whether the simulated districts are observed to learn how best to implement the allocation ratio.

Attention is also given to whether an allocation ratio considered "good" results in improved water service levels. As explained in Section 7.3, the optimal ratio, under the condition, and assumptions of this model [0.87 : 0.13 : 0]. A good allocation ratio is assumed to result in the highest district performance measured in water quantity. It is reasonable to expect that districts, through experience and communication about their allocation ratios, gradually learn to implement the best allocation ratio in their own context. That said, districts have different starting conditions and it may be difficult to determine whether they have learned and implemented the best allocation ratio, rather than a ratio, good or bad, of a district which had good starting conditions such as a high number of functional wells.

Figures 41-43 depict the relationship between the allocation ratio of the best performing district and the average performance of the system in terms of water service levels. The x-axis of the scatter plots present the allocation ratio of the best-performing district for CapEx, CapManEx or Unspent respectively over a 20-year national ranking. The y-axis indicates the average water quantity delivered by the 110 districts. A regression line is plotted to show the fitted relationship. The shaded area shows the 95% confidence interval.

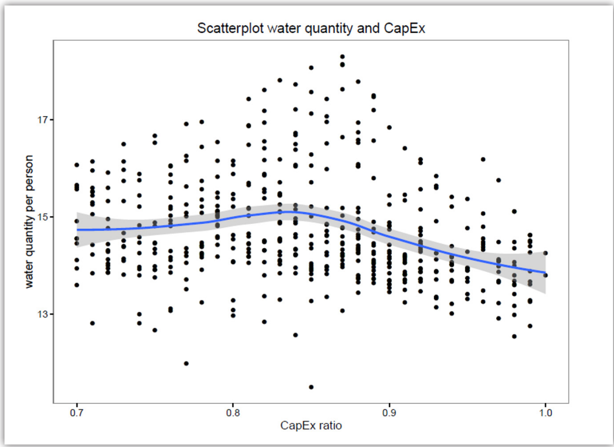


Figure 41. Ratio for CapEx at t=20 and corresponding water quantity

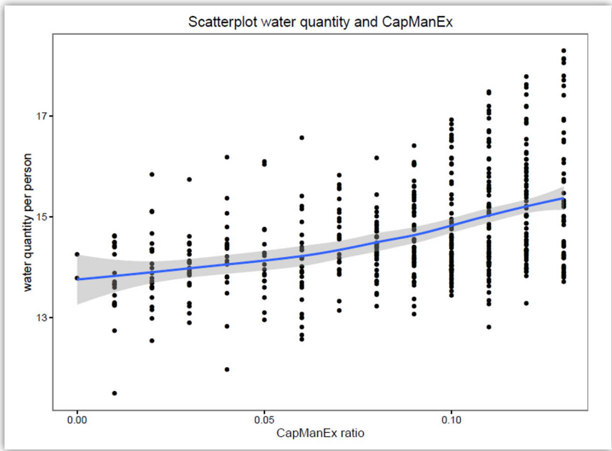


Figure 42. Ratio for CapManEx at t=20 and corresponding water quantity

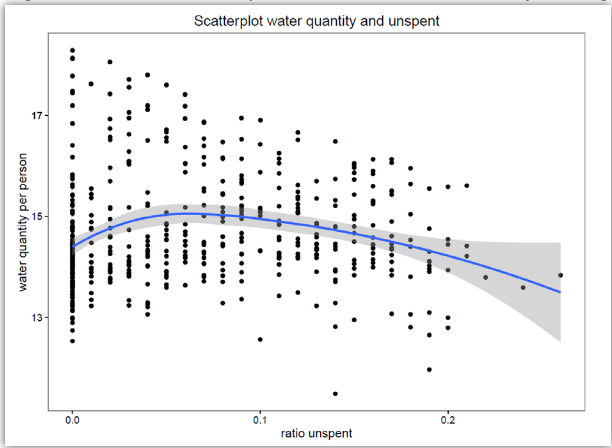


Figure 43. Ratio for unspent at t=20 and corresponding water quantity

Source Fig. 41-43: Adapted from Knipschild, 2014.

Each point depicts the output of a single simulation run including the average system level performance and the corresponding ratio of the best performing district amongst them. The shaded area around the line shows the 95% confidence interval of the regression line.

Starting with the CapEx ratio in Figure 41, the regression shows an optimum around a CapEx ratio of 0.85. The highest outliers are around 0.87, the artificial ratio optimum. For the density, no significant difference is evident at first glance. Figure 42 depicts the CapManEx ratio. A first point of interest is that the regression line indicates an upward trend, stopping at 0.13, the boundary CapManEx allowance in the ratio. Secondly, there are more data points as the ratio increases. This may indicate that districts learn it is better to increase budget allocations for CapManEx. In Figure 43, the regression line indicates an optimum around 0.08 with outputs higher when unspent ratio is lower. Also, data points are denser at 0, but not necessarily higher. Lastly, almost no runs leave more than 20% unspent budget, indicating that districts learn to spend the money appropriately, further supporting the notion that districts learn and adapt. Progress towards the artificial optimum of the allocation ratio is observed, although it is not entirely clear which districts are responsible for spreading and having the best allocation ratio. In the graph of the CapManEx ratio an upward trend is clearly observed with a higher ratio for CapManEx of the best performing district indicating that those districts on average perform better.

7.10.6 Districts unchained

In this experimental run, districts are free to allocate the budget with no restrictions. The 13% maximum for CapManEx and 70% minimum for CapEx boundary conditions are excluded from the simulations. The expectation is that the average district performance will be higher without restrictions as compared with simulations where restrictions on budget allocation are included. This expectation stems from the steep decline immediately after the start of the initial simulations and assumed in section 7.9.2 to arise from a decrease in district infrastructure functionality rates. This may indicate that districts do not have adequate budget to maintain the infrastructure given the rate of infrastructure failure, possibly pointing to a need to increase CapManEx allocations. The plausibility of this scenario is underscored by the upward trend in the regression line in Figure 42.

Figure 44 depicts the outputs of runs without restrictions on the allocation ratio. One hundred simulations are performed, 20 for each scenario for replication and variation over a time span of 20 years for comparison with the original experiment. The minimum ratio for CapEx is varied between 0.7 (MWE minimum) and 0 (no restrictions).The maximum CapManEx ratio varies between 0.13 (MWE maximum) and 1 (no restrictions). The output for runs using the allocation ratio default conditions and the loosened conditions are visualised in the matrix in Figure 44.

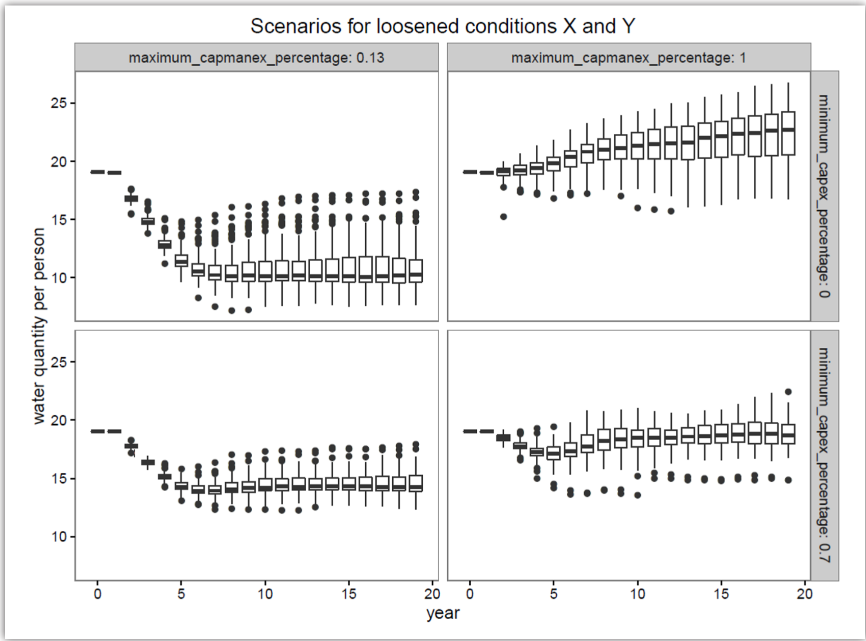


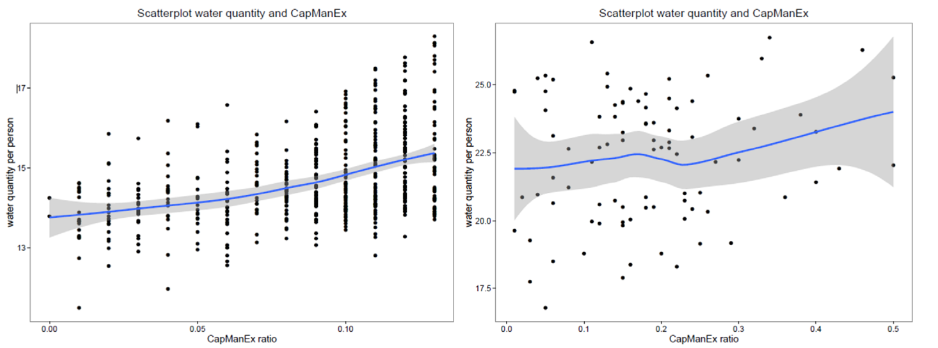
Figure 44. Loosened conditions for allocation ratio.

Source: Adapted from Knipschild, 2014.

In the four box plots of Figure 44 different settings for the CapEx ratio and the CapManEx ratio are plotted against one another. The boxes show the results of 20 simulations plotted over time with specific settings for CapEx and CapManEx. The difference between left and right is the maximum ratio for CapManEx either 0.13 (left) or 1 (right). The difference between top and bottom is the minimum ratio for CapEx - either 0 (top) or 0.7 (bottom).

The plot at the bottom left represents the situation observed in all previous analyses: the CapEx ration is restricted to minimum of 0.7 and the CapManEx ration is capped at 0.13. The plot at the top right represents the scenario where all restrictions are absent: a minimum of 0 for the CapEx ratio and a maximum of 1 for the CapManEx ratio. In the restricted scenario, the familiar drop of the average water quantity delivered by districts is followed by a moment of stabilisation. However, in the unrestricted scenario, there is no drop. Instead, average performance rises slowly and continues to rise over time. Even the most negative outliers remain near 20 litres, where the median grows to approximately 24 in 20 years' time.

Verification is performed to see whether districts actually spend more budget on CapManEx in unrestricted simulation runs with the expectation that the CapManEx ratio exceeds 0.13. In Figure 45, the CapManEx ratio of the restricted run is depicted on the left with the CapManEx ratio of the unrestricted run on the right.



(a) CapManEx ratio in restricted simulations (b) CapManEx ratio in unrestricted simulations

Figure 45. Trend between the ratio of CapManEx of the best performing district and the national average performance.

Source: Adapted from Knipschild, 2014.

This figure indicates is that unrestricted runs perform much higher in terms of water quantity than the runs with restricted conditions for the allocation ratio. It shows the relation between the allocation ratio of the best performing district in the nation and the average performance of the districts. A regression line is plotted to show the fitted relationship. The shaded area shows the 95% confidence interval.

Despite fewer data points in the unrestricted run as fewer simulations are conducted, (as is observable in the shaded area surrounding the regression line), the trend and difference between the experiment results is clear. Even with a low number of runs, the best performing district spend up to 50% on CapManEx.

The analysis of the model outcomes would indicate that the static, or rigid, financial allocation policy results in ineffective allocation of available financial resources. The simulations with flexible, unrestricted, allocation ratios demonstrate that with the same amount of budget, the average performance of districts rises to a median of 24 litres after 20 years, compared to a median of 15 in the restricted variant.

Two further simulations are conducted in the model environment: one with restrictions on the allocation ratio and one run without restrictions. First, the average functionality of the water infrastructure is analysed. The expectation is that the functionality in the unrestricted runs is much higher, as the amount of budget for investments in maintenance grew, as observed in Figure 43. The average functionality of water points in the districts resulting from the two runs is depicted in Figure 46.

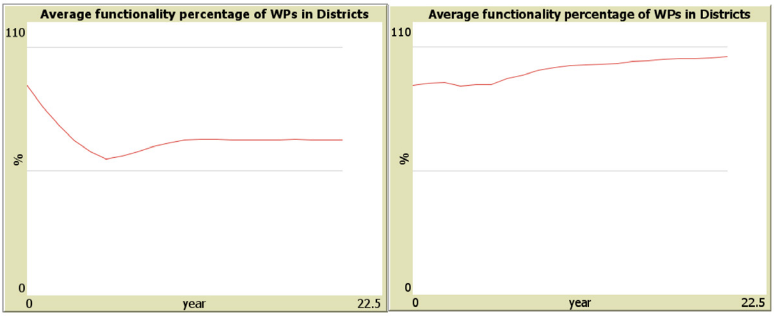


Figure 46. Difference between a run with restrictions on the allocation ratio and a run without restrictions.

Source: Adapted from Knipschild, 2014.

The red line indicates the average performance where the grey lines represent the y-values 100 and 50 to support interpretation of the figure.

The left-hand figure indicates that the rate of functionality of water infrastructure is key to understanding the behaviour of the average district level water service levels. The figure on the right depicts the simulation results in the absence of restrictions on the allocation ratio. The average percentage of functional water infrastructure increases in a similar way to the average performance of the districts. Unrestricted decision making does however leave decision makers with a trade-off between serving everyone with low levels of service versus serving some people with higher levels of service.

The final analysis consists of the same two runs as represented in Figure 46. The analysis is elegant in its simplicity: count the functional and non-functional water points after 20 years for both simulations. The result is presented in Table 12.

Factor (measured at t=20)	Restricted run	Unrestricted run
Operational water points	107.860	183.109
Non-operational water points	63.500	4.500
Total number of water points	171.360	187.609
Functionality percentage	63%	96%
Average water quantity	14,5	24

Table 12. Water point data of two simulation - one restricted run and one unrestricted run, measured after 20 years

Source: Adapted from Knipschild, 2014.

Though this represents just a single simulation, the indication is that not only are the average performance of the districts and the average functionality of the water infrastructure better in the unrestricted simulation, but that the unrestricted simulation also results in more water points overall.

The percentage of non-operational infrastructure is lower, the total number of water points is 10% higher and the amount of functioning water points is 80% higher in the unrestricted scenario compared to the restricted scenario. In the unrestricted scenario, it is possible that fewer water points are built, but as all water points are maintained and repaired within five years (after which time defunct water point are often abandoned) the result is higher water service levels.

7.11 Conclusions

This chapter presented alternative methods by which districts might share information and 'learn' from one another in the sense of copying best practices and decision making about how finance is allocated between constructing new water points and repairing or rehabilitating existing water points. These decisions affect the balance between providing a service to people who currently have no service, and preventing those who currently do have a service from losing it.

Some tentative conclusions that can be drawn from this are that when districts 'learn' from each other by copying the spending ratios of better-performing districts this does not, over 20 years, lead to an improvement in water quantity per person per day. This may not be due to the process of replication itself. In any scenario where water points fail at a rate faster than they are replaced or repaired, outcomes in terms of water per person will decline.

What the model outcomes do suggest is that 'learning' (***copying***) from the widest pool of districts (***fully rational*** method) is better overall than learning from a narrower range of districts (***myopic*** or ***random*** methods) when the median outcome is considered. Those that adopt the fully rational method have all the 'best' results but also have some of the worst results, reflecting a wide range of outcomes. Those that strike out by using the fully rational method may do so because they copied the allocation ration of a district that was successful due to having started with favourable conditions and prospered despite poor choices on financial ratios. Policy makers might use modelling to consider whether the current multi-level, multi-actor system arrangements fosters learning platforms adequately throughout all levels, including at regional and sub-regional levels in a country with decentralised, deconcentrated arrangements for water service delivery.

8

Conclusions, Discussion, Future Research Directions

You write in order to change the world...if you alter, even by a millimetre, the way people look at reality, then you can change it.

— James Baldwin (1924-1987)
Novelist, playwright and activist

I've learned that I still have a lot to learn.

— Maya Angelou (1928 – 2014)
Poet, singer, memoirist and civil-rights activist

In this chapter…

…following a brief review of the structure and substance of this dissertation, a set of conclusions related to the main research questions articulated at the outset of this research project are presented.

Thereafter, the contributions of this research and its conclusions are offered followed by reflections on the limitations and directions for future research.

The dissertation concludes with a summary by way of an epilogue taking note of promising indications about transitions currently underway in Uganda policy and governance arrangements for rural water services.

8.1 Introduction

The real world challenge under examination in this thesis is the stagnation of rural water service levels below Uganda's nationally set norms and standards. This dissertation sets out an iterative participatory process of developing a series of increasingly complex models to study this challenge. From an initial round of qualitative, on-the-ground/empirical actor and issue landscape mapping and analysis, we moved to detailed agent based models, to examine the effects of various proposed policy interventions. This progression required the development of a language to describe the complexity of a multi-actor, multi-scalar action scenario in which micro- and macro-level interactions and rules (both formal and informal) give rise to patterns. This language made it possible, in turn, to build agent based models for the purpose of policy analysis and ultimately, under varying social learning regimes, a new achievement in both the domains of water policy analysis and the field of agent based modelling.

The challenge of delivering sustainable rural water services is discussed from various perspectives in Chapters 1 and 2. This background informs the theoretical framework formulated in Chapter 3 and underpins subsequent choices about how to describe and structure agent behaviour in the models in chapters 4 - 7.

The two agent based models detailed in Chapters 5 and 6 examined different sustainable water services challenges and served as a 'proof of concept' for the iterative process of system analysis, presenting model designs and results to key stakeholders as well as incorporating key stakeholder feedback into subsequent versions of the models.

The introduction of a conceptual framework for the evolving process of water service delivery in rural settings is detailed in Chapter 4. The conceptual framework not only achieved a highly detailed description of the system including the behaviours of the socio-technical agents, but also provided the means to develop a more complex model that incorporates financial policy challenges with social learning regimes (methods and processes) as well as water service levels in a simulation of a multi-level, multi-actor water governance system in Chapter 7.

What is the sum contribution of the research that has been presented to this point? What higher level insights can be distilled from the models, their results and the participatory model creation processes for water services, participatory modelling practice and model-led policy analysis? And under what conditions do these hold true? What territory does this work not cover? Lastly, how could this work potentially be extended, or adapted, in further research? These questions are addressed in this final chapter.

8.2 Conclusions | Revisiting the Research Questions

This section is organised into three key sets of conclusions. These include a section on high-level policy insights arising from the results of the *in silico* experiments, conclusions about participatory model-based policy analysis and the applicability of the Institutional Analysis and Development framework in modelling institutional change in the water sector.

Research Question 1: ***What system-level insights do complexity sciences offer for the analysis of water services policy and implementation measures in the Republic of Uganda when a policy intervention, selected through a collaborative action research approach, is simulated in an agent-based model of the rural water sector?***

The model results described in this dissertation were generated from implementing models conceptualised based upon action research activities of the Triple-S Uganda project and the national and district level policies in effect in Uganda in the period of 2008 - 2016. Each model was elaborated upon and adapted following the initial collaborative sector landscaping mapping conducted by the researcher with the Triple-S Uganda team followed by desk study to further ground the empirical evidence in relevant theory found in scientific literature. Rounds of expert consultations and semi-structured interviews and feedback sessions were the conducted to ground the iterations of model conceptualisation in the empirical experience of key stakeholders. The aim of this research approach was to adapt the narrative and code, ensure design choices reflected real world circumstances and that the policy challenge was examined thoroughly and accurately.

Commencing with the last model first, one notable finding that warrants immediate attention is that under the parameters and assumptions set out in the *Perspectives on Social Learning* model described in Chapter 7, the implementation of the most open learning regime for selection, replication and/or variation of financial allocation ratios across all possible districts, resulted in higher water service levels.

It is not possible to claim that the results are unconditionally accurate or universally applicable. They are also not predictive. That said, the experiments run in the model described in Chapter 7 provided a series of results related to the varying learning regimes and financial allocation ratios encoded there.

From the *Water Services that Last* model, presented in Chapter 5, a main insight is that additional 'back up' village-level water point infrastructure – at numbers above what is considered a minimum requirement to meet households' daily needs – delivers marginally higher levels of water services than a decrease in the time-to-repair in the absence of any other measures to address stagnant water service levels.

This model is relevant for policy discussions and decisions about capital expenditure on new infrastructure, capital maintenance expenditure decisions around the operations and maintenance requirements of rural water infrastructure. It is also potentially relevant to the higher level policy transition, now underway in

Uganda anno 2021, about departing from point source as the preferred rural service delivery technology to networked piped water supplies to all settlements in the country. Such an ambitious undertaking is not achieved in the short term. Policies and governance arrangements related to financial, infrastructure and maintenance choices are required to ensure rural water service levels continue to increase. This in parallel with the need to expend attention and resources to finance and guide the transition to household-level networked piped water connections for everyone, everywhere in Uganda.

The results from the *Using Mobile Phones to Improve Water Service Levels* (M4W) model presented in Chapter 6 pointed to the availability and regular flow of information across horizontal and verticle levels as a key factor in efforts to improve district water service levels. The model provides insights into sector policies related to water point maintenance, the introduction of information and communication technologies in a context of high mobile telephone market saturation combined with low levels of disposable income as well as the suitability of market-driven mechanisms for maintaining rural infrastructure. Simply stated, if a water committee does not have the financial resources to pay for assessment and repairs by the hand pump mechanic, a broken water point is not repaired - whether or not the information about repair status is transmitted at local or to national level agents.

Information about a water point' s status, compiled and updated in real time, is relevant to track in a national log, or record. However, in the absence of national-level support for an otherwise well-designed and carefully implemented intervention with results pointing to its potential suitability for wider implementation and scaling up to national level, initiatives such as M4W that are implemented with and by committed development partners, may be relegated to the category of another well-conceived, but not broadly supported donor-driven programme. The dialogue among policy- and decision-makers could then focus less on questions about whether a specific tele-communications based solution is appropriate, but rather on whether the national water sector – from rural users up through the Ministry of Water and Environment – has the interest, institutional capacity and 'bandwidth' in the form of a broad base of support coupled with human and financial resources, to take up and implement proposed innovative solutions that meet policy challenges and user needs. Reflecting on the underlying assumptions about various stakeholders' roles, responsibilities and the required investments for innovations to succeed, with the support of an agent based model to analyse various scenarios, reveals factors that may limit potential success, before committing to an intervention.

The results of the final model reported upon here *Perspectives on Social Learning,* described in Chapter 7, demonstrate that deliberate processes and methods to foster learning horizontally across all districts result in higher water service levels, when compared with scenarios where learning takes place by chance or when district actors limit their learning to information from neighbouring districts. The emergent macro-level result is an overall pattern of higher water service levels - closer to the nationally determined norms - when information flows effectively at the local level of implementation. This insight about the importance of information flows, combined with knowledge about the value of the learning platforms at different governance levels, underscore the importance of well-resourced and curated inter-district information exchange, learning and adaptive processes.

Research Question 2: ***How is it possible to conceptualise institutional interactions in the rural water services sector from a complexity sciences perspective in an agent-based model based upon collaborative model conceptualisation processes?***

The second research question asked how to describe and conceptualise institutional change in a complex socio-technical system. A main result of this research project is a language used to build a series of models that systematically conceptualise and simulate a policy challenge and various policy solutions in a complex adaptive system. The language is used to build a simulation of the problem scenario of failing water service levels and the behaviours agents involved in water services delivery.

The language, rooted in theory from the complexity sciences, and used to conceptualise, build and implement three models as experimental devices, generated results which offer policy- and decision-making stakeholders potentially useful insights in their deliberations. While more process-oriented in its presentation, arriving at a language for conceptualising the models required several developments and principles addressed below.

The research commenced with and built upon sector landscape analysis and mapping processes that involved key actors from the rural water supply sector in Uganda. The perspectives established from the landscaping activity were subsequently analysed and validated with key stakeholders at intervals in the research process. Garnering this input, diversity of perspectives and expertise of key sector actors provided a rich basis for the system conceptualisation and agent-based models. Collaborative mapping and analysis yielded conceptual insights into the structure and relationships of the rural water system, and also provided the team of learning facilitators in Uganda with strategic and actionable insights into their levers of influence and access to key policy and decision making at national, regional and local levels. The change processes they were driving gained a new perspective as their work in the rural water sector of Uganda, which had largely felt and seemed to be ‘behind the scenes’, was rendered visible and tangible through the process of mapping the ‘system’ through which policy change travels. This process of collective sense-making and awareness raising, made it possible to document several additional knowledge products and share results among key sector stakeholders grappling with the question of how best to facilitate sector learning – and at what cost.

The mix of collaborative methods and tools used in this initial research step are commonly used in development cooperation programmes for strategic planning and analysis. These collaborative methods of analysis, planning and strategic management, designed to maximise the inclusion of a wide range of perspectives, are found in many other sectors including corporate and organisational management and change, the complexity sciences, technical public administration, climate change and adaptation sciences, energy transition, etc. These methods are commonly applied in an effort to generate shared narratives that support multi-actor change interventions to navigate through complex problem spaces towards promising solutions.

The research process revealed that these methods and tools are suitable for gathering fundamental information about a system, its agents and their (inter-)actions, and the formal and informal rules and institutions guiding agent behaviour, as well as the aims and goals higher-level stakeholders consider to be driving their efforts to deliver change.

Describing and building a model using iterative processes of information gathering, analysis and sense-making, using methods that are familiar to stakeholders such as collaborative mapping and analysis methods, contributes to the development of a shared tool to visualise and analyse a policy challenge. Integrating familiar methods for mapping and analysis in this manner helped foster confidence in the resulting agent based model, a fairly new simulation tool in the context of planning and management of rural water services, and thereby also the model results and analyses.

Research question 3: ***What is the potential of computer based (in-silico) testing of policy scenarios in an agent based model for insights into actionable strategies for delivering systemic change based upon social learning?***

This research created robust *in silico* simulations that stakeholders could use, in concert with other models and sources of information, to support decisions about sustainable water services in rural Uganda.

A series of models and model designs that are increasingly more complex, in terms of the system description and the problems they are designed to address was built. To make this step, a theoretical framework and conceptualisation were devised to examine how micro-level institutions may change over time leading to macro-level, socio-technical system change.

Following the principle of parsimony, the models are as simple as possible. It is tempting to model 'the whole system' once a highly detailed description, as set out in Chapter 4, is achieved. However, this is not always necessary to arrive at valuable insights about water service levels, the value of additional water points or the potential role of mobile telephone technology in monitoring water point functionality in remote regions of the country. Efforts to deliver a complete and perfect model may distract from more important modelling challenges and dialogue among stakeholders about these pressing issues. A model that is a simple as possible, but as complete as necessary can support this dialogue.

A model design resulting in a simulation is adequate when the problem, or policy challenge, is clearly defined and the choices and assumptions underlying the model are well documented and understood by policy- and decision-makers who will use the model to explore the problem space and potential solutions. Of not-insignificant importance is the sense-making and data analysis once a model has generated results. Collective analysis of the relevance, validity and applicability of experiment results is best achieved through high-quality, representative participatory processes involving key stakeholders representing concerned domains as inclusively as possible.

In keeping with the principles of inclusive adaptive management and the passage of time, it is reasonable to expect that new or different policy challenges will emerge. To serve as useful boundary objects, model narratives and designs will require new collaborative iterations and modification to support adaptive management processes. Such modifications may entail the addition of new or different actors, a change in the formal or informal rules-in-use to enable observation of changing micro- and macro-level patterns, or the inclusion of new forms of interaction and connectivity between and across the multiple levels and scales of governance. With information garnered from the actor and issue landscaping activities for guidance, the model description set out in Chapter 4 can be modified in all of these ways to support adaptation to newly emerging policy challenges in the context of Uganda.

A similar actor and issue landscaping activity in Ghana was conducted in the 2013-2014 period. The results of that exercise, coupled with a desk review of prevailing institutions, key stakeholder consultations and model design steps could serve as the basis for a comparable series of models exploring the same or similar, but contextually specific, problem descriptions. While all elements require attention when ensuring model robustness, the modeller's thorough understanding of context and access to key stakeholders with deep insight into the prevailing local dynamics, policy challenges and 'rules-in-use' is arguably the greatest determining factor of whether a model will provide meaningful policy insights.

Such a model-based policy analysis approach to informing decision making processes may help to manage available resources more effectively while building the requisite broad base of support among key stakeholders. Policy- and decision-makers can use collaboratively designed agent based models to probe different scenarios under which a solution or intervention will succeed or not succeed. Models can support multi-actor decision making platforms to decide whether the necessary institutional bandwidth is available for a given undertaking. This is valuable learning. It has the potential to help water sector actors avoid what is sometimes referred to as the graveyard of defunct water supply infrastructure built through donor-driven projects. It may also help in terms of knowing where to direct time and money for large-scale awareness raising and community engagement campaigns and the accompanying advocacy and promotion materials to promote behaviour changes. These are common elements of large scale technical infrastructure improvement programmes aiming to deliver impactful, innovative initiatives at community level. Testing all of these 'moving parts' across horizontal and vertical scales, over long periods of time under varying conditions, in a simulated environment prior to large-scale role out can illuminate underlying assumptions about the various roles and actions of actors and the arising macro-level pattern.

8.3 Contributions

There are additional insights and observations, beyond the conclusions presented above, that warrant mention here.

This dissertation draws from the disciplines of complexity science, policy science, social science and computer-based modelling to obtain insights into how large scale change in a socio-technical system such as a rural water services might arise. The language developed here as a means to describe a complex adaptive system makes it possible to codify and experiment with different policy mechanisms and implementation alternatives through the use of advanced modelling techniques. This represents a contribution to the domain of research into computer-based modelling as the openly published outputs document how policies and agent behaviours may be translated to code in a systematic manner and can be extended or used to build new models of other water service delivery policy options or social learning approaches in Uganda and elsewhere.

The research contributes to the domain of water services by providing insights into policy and practice in the rural water sector. Insights from the *in silico* experiments provide insights into how financial allocations policies may be adapted in light of dynamic changes to local needs and realities related to water services. The models can serve as boundary objects that empower sector policy makers to examine and experiment with policy alternatives under varying conditions and over long period of time – a unique potential given the time required to achieve lasting institutional change.

The research contributes to academic research into the concept and practice of social learning and its potential to promote change in socio-technical systems. Social learning is promoted for its role in delivering change in problem arenas with 'wicked' and intractable challenges. Modelling, as a form of boundary object creation can help to coalesce diverse stakeholders across different sectoral scales to generate meaningful insights into wicked problem scenario which do not easily lend themselves to scientific research in a real world setting.

A further key insight is that institutional change takes time and it remains challenging to know what resources should be committed to which new promising idea in the face of future uncertainty. In the models built in a bottom-up fashion for this research, the factor of time required to achieve the desired meta-level patterns of sustainable water service levels, confirms findings from other research that institutions, in this case financial allocation policies, require decades as opposed to three to five year cycles to achieve their intended policy goals. Moreover, in the meantime, unpredictable changes arise in the system on an ongoing basis potentially rendering the initial policy goal as unattainable or no longer necessary.

Adaptive management requires appropriate tools and methods for dealing with uncertainty in responsive as well as strategic ways. The collaborative policy analysis modelling process itself may be considered a demonstration of how adaptive management can work with its iterative cycles of information gathering, experimentation and adaptation.

Here too, however, the factor of time factor also holds true for the collaborative modelling process. Significant time is required to foster and generate meaningful models that are inclusive and representative of key stakeholders' views and experience. A personal reflection is that the dividends of investing in adequately-funded, professionally-facilitated sector learning processes that encompass well-connected multi-actor platforms across horizontal and vertical lines, may be intangible but are justifiable as a means for overcoming system inertia through fostering social learning.

The development of boundary objects brings with it temporal and budgetary considerations. Time is of the essence as the scope of the challenge to deliver safe water to all citizens is pressing. Building rigorous, useful models requires significant time and content inputs from domain experts as well as resources to ensure analysis and sense making of results is conducted in a valid and robust manner. The interconnections across scales, supported by co-created boundary objects, makes integration of perspectives, priorities and perceptions about promising solutions less daunting when cycles of iterative analysis, planning and adaptation involve a (reasonably) stable cast of actors who share a common goal.

Uganda is in the fortunate position of having embedded a sector learning approach that includes a broad range of sector actors and which is representative of the broad range of views and wishes this constellation of actors. In other national contexts, sector learning processes often remain based on project funding-cycles which are shorter than the time frames in which large-scale outcomes and systemic change may be reasonably expected. It is important to hold rapid, yet concerted and inclusive social learning processes that align with the strategic and practical agendas of key stakeholders. These objectives may seem at odds with one another yet there is potential to organise learning processes for greater effective outcomes in rural water services. Concerted, professionally-facilitated cycles of adaptive management based upon nationally-defined monitoring processes which in turn feed timely and relevant information into sector learning platforms that are inclusive and representative foster the balance between the need for information loops that deliver both rapid cycles of information as well as the consistent flows of information to inform mid- to long-term information needs.

8.4 Limitations and Directions for Future Research

8.4.1 Modelling

Further research conducted using the products of this project should commence with a round of rigorous validation of the model designs and experiment results. This step conducted with committed problem owners would deliver richer insights into how useful these models are, as well as tips into what modifications / extension are required to enhance their value in policy making to increase water service levels. At the very least a thorough reflection on what contextual parameters have changed in Uganda in the intervening years since the completion of the final model in 2016 would add value.

The iteratively designed conceptualisation and models presented here may be adapted to simulate other problem scenarios in similar steps of increasing complexity. The models may be extended to model socio-technical-environmental systems, to reflect other, or additional, policy interventions, to depict a more complex actor landscape or the effects of agent learning about the availability of natural resources on domestic water services levels / policy decisions. The effects of learning about the natural resource on water services levels could be explored in an IWRM or conflict mitigation focused initiative.

A promising future direction would be to enhance the models built in this project through integrating and/or aligning them with other modelling approaches that address other facets of the problem of stagnating water service levels. These problems could be more effectively explored if the models in this project were linked to other kinds of models (systems dynamic models, social networking and GIS), using other forms of participatory and experiential learning in collective analysis, planning and assessment. Such multi-model ecologies have the potential to provide a more complete perspective without having to 'panel beat' a single model to simulate the whole system.

In times of humanitarian crisis, responders and decision makers must devise an emergency response based upon imperfect information. These circumstances entail multiple actors working together to address rapidly emerging circumstances. Having base case models ready for rapid modification and extension can provide useful decision making support in uncertain times.

Additional issues, or factors, may also be encoded in an expanded version of any of the models presented here. For example, the models can be modified and extended to include indicators about ground water levels and the natural environment in an effort to extend the work to encompass a socio-technical-environmental system perspective.

8.4.2 Water provision

The water sector is currently oriented in pursuit of the Sustainable Development Goals (SDGs). Locally contextual models offer the greatest value at national and local levels by adhering to national norms and standards. There is merit to the idea of substituting the water service levels currently used in Uganda with indicators used to track the SDGs, as a tool for supra-national bodies to explore policy options for achieving universal access to water, sanitation and hygiene services.

One of the initial aims of this research project was to develop a didactic model of the social learning process of the rural water sector in the Republic of Uganda. The model was intended to serve as a boundary object for collective reflection with key decision makers and financiers about the value of dedicated, well-resourced and professionally facilitated sector learning processes.

The tenets of scientific modelling practice – actually the products of any co-creation process – require stakeholder validation of model narratives, experiment design and results. In this research, project conceptualisation and model validation were conducted in an iterative manner incorporating consultation with key stakeholders at key moments in the model design and results validation. The end of project and a shift in interest among the key research partners meant that the model validation process was limited to a less broad representative range of key stakeholders in later research stages.

8.4.3 Open science

In keeping with the FAIR principles, all research outputs, from the original co-creation workshops of the Learning Facilitators in 2013 through the model designs, are made openly available to the international research community for further development, exploration, expansion and modification. This application of open science principles to the sharing of this work is an achievement in addition to its contribution to scientific research and its value development cooperation and policy making. Openly available and reusable the results may be replicated and extended for other policy scenarios / problem arenas. The README files and metadata about the models and requirements for reproducing them provide future researchers with insights into the key decisions taken in the coding and model building and experimentation processes.

The skills required to build computer generated simulations and agent based models are becoming more widely taught and available with each year. Specific initiatives to raise the capacity level for coding and computer programming – including in Sub-Saharan Africa – have proliferated in recent years and include coding labs and meet up cafes, open coding workshops, Software Carpentries and

Girls who Code among other ICT initiatives in Africa. The expectation is that this modelling method increasingly becomes a standard tool used by sector planners and policy makers. The open access resources provided by this research project can help those wishing to extend existing models, or build new models with additional requirements.

8.4.4 Learning

A concluding reflection on learning in multi-level, multi-actor systems: investing in and sustaining learning processes and mechanisms that engage committed stakeholders delivers more sustainable results. In the *in-silico* experiments conducted, agent learning and adaptation takes place both with and without extra stimuli to promote and support exchange of information and best practices. That said, when learning is promoted and takes place as a result of access to more complete information about best practices and alternative solutions to challenges, we observe in the models that the result, over time, is higher water service levels.

The initial sector landscape map collaboratively created at the outset of this research project underscores the fact that Uganda has a fairly sophisticated sector learning process and mechanism in place with effective national and regional dynamics. Over the past decade increased attention and resources have been invested in strengthening the learning platforms and mechanisms of the District and sub-District levels of governance in Uganda and forging robust connections between these levels and the regional and national levels. This provided a valuable case example for conceptualising and modelling linkages between platforms and sub-national levels dedicated to learning and adaptive management, as well as a means to identify aspects of the learning mechanism that could be further strengthened and embedded in a broader perspective on sector adaptive management approaches.

8.5 Epilogue

The real world challenge under examination in this thesis was the stagnation of rural water service levels below Uganda's nationally set norms and standards. This dissertation set out an iterative participatory process of developing a series of increasingly complex models to study this challenge. From an initial round of qualitative, on-the-ground/empirical actor and issue landscape mapping and analysis, we moved to detailed agent based models, to examine the effects of various proposed policy interventions. This progression required the development of a language to describe the complexity of a multi-actor, multi-scalar action scenario in which micro- and macro-level interactions and rules (both formal and informal) give rise to patterns. This language made it possible, in turn, to conceptualise and build increasingly complex agent based models for the purpose of policy analysis under varying learning regimes. The developed model conceptualisation process and language have the potential to be adapted for different water service delivery models ranging from self-supply, to community-based to utility-provided supply models. This represents a new achievement and provides promising decision support in the domains of water policy analysis and agent based modelling.

Through the Sector Strategic Investment Plan (2018-2030) and the 100% Service Coverage Acceleration Project (SCAP 100), the Republic of Uganda is currently moving towards changes in rural water service delivery in terms of legal and institutional arrangements, infrastructure and technology choices, organised at a more aggregate level of service provision with a utility or other form of professionalised entity providing services to several communities or districts. This signals a significant departure from the community managed model of service delivery studied in this work. This thesis will offer decision makers a means to create shared perceptions of such new arrangements and collectively assess the potential sustainability of promising solutions over the long-term. The generic modelling language and process discussed in this thesis thus contributes to the urgent international challenge to ensure sustainable water services for everyone everywhere.

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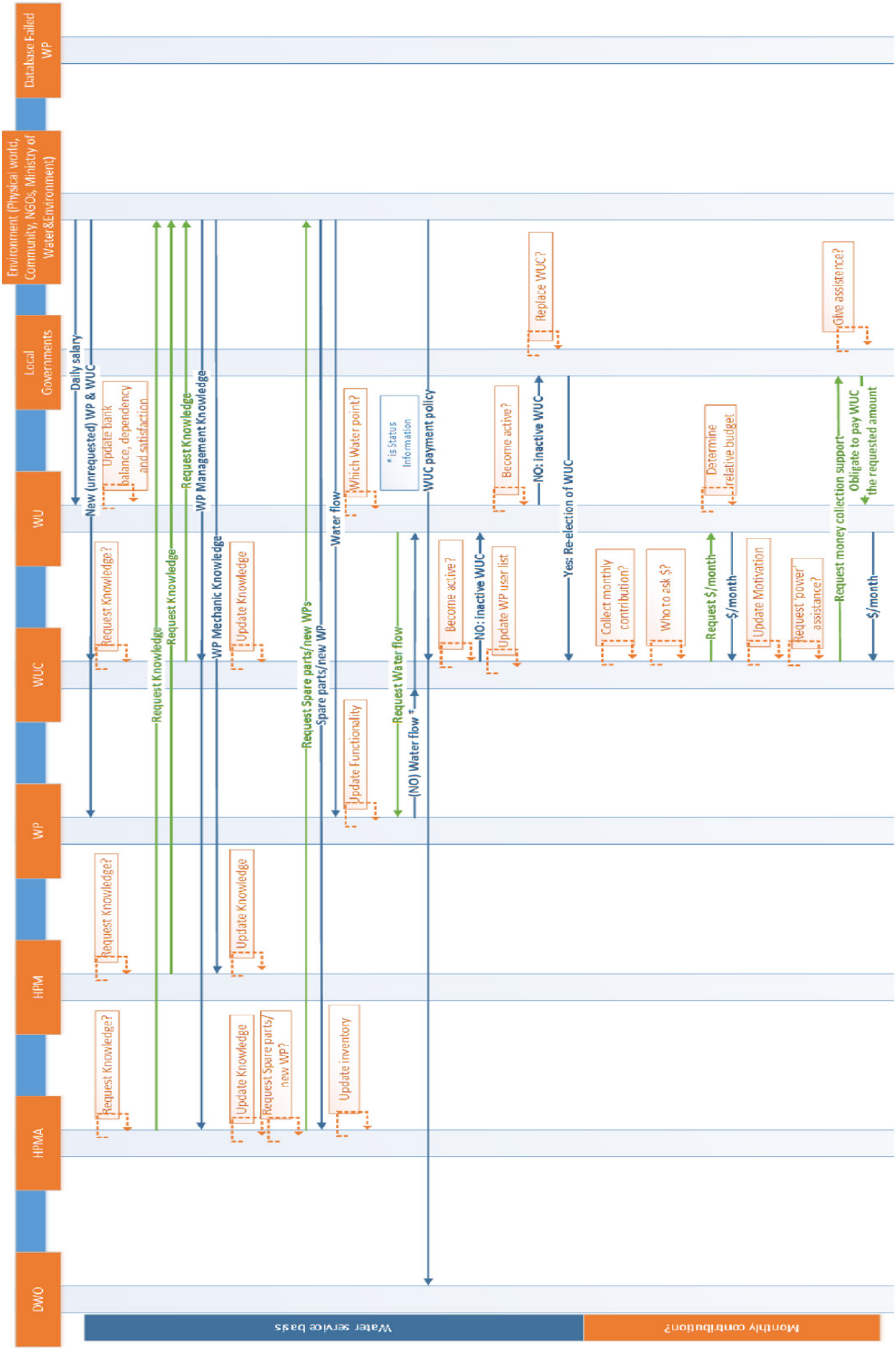
Appendices

Annex A: Pattern of Interaction in the Model Design

(Enlarged Figure 18,p.99, source: Van Tongeren, 2014.)



Appendix B Water Services That Last Model | Agent Properties & States

Agent Properties

The three agents depicted here are:

- Handpumps
- Households
- Water collectors

Each agent contains a number of properties. A property is a variable that the agent carries and can change according to the status of the agent, such as the amount of water they carry or the number of residents in a household.

Every agent also has global variables ('globals') which other agents can read. In this model, the globals are:

- The number of days the model is running
- The current time of the day
- The volume of water that can be taken from a pump after which the pump will break down
- The number of pumps that are already broken when the model starts running
- The question of whether a household has enough water
- The possibility of giving the model a random set up

A given geographical location (a 'patch') has the following properties:

- Household density within a given radius
- Either 0 or 1 household on the patch
- Either 0 or 1 water point on the patch

Households have the following properties:

- A certain location - a patch on which they are located
- Amount of water at the household
- A service level (indicated by colour coding of green, yellow, orange or red)
- Number of residents
- Water required per household
- The number of times household agents travel to a water point to collect water
- The start, end and duration of the collection of water

Water points are key infrastructure agents have the following properties:

- A certain location (a patch[4] on which they are standing)
- They are either working or defect
- An exact time when they broke down
- They count the number of water collectors that show up to get water
- They identify the number of the collector next due to get water
- They count how many water collectors are waiting at the pump
- They count how much water has been taken

Water collectors have the following properties:

- A home from which they depart and return to after water collection
- A walking speed
- A status indicating which water collection action is occurring at a given moment: collecting water, standby at home, waiting in queue etc.
- The location of the water point to which the water collector travels
- The time required to collect water
- The time the collection is finished
- A ticket number received upon arrival at a water point
- The amount of water a collector carries homewards
- The maximum time the collector is willing to wait at a water point
- Occurrences where it is necessary for a collector to travel in search of an alternate water point if the queue is too long at the initial / previous one.

Agent States

Agents have different statuses during the model runs. Water collectors status indicates their current activity: outgoing, arriving, queuing, collecting, redirecting, returning, standby at home. If a water collector is moving from his house to a water point, he/she is outgoing, if he/she is waiting at a water point, he is queuing etc.

Household status indicates the experienced service level as categorised in section 5.4: green, yellow, orange or red.

A water point's status reflects intensity of use – sometimes referred to as water point 'crowding'. If there are fewer than sixty water collectors at a water point during the day, the water point turns green. For more than sixty users, the water point turns yellow. If there are more than 120 users during the day, the water point turns orange. If the water point stops working it turns red.

In this model only the water collectors are dynamic as they can move within

4 A patch is an area of ground. In this model each patch is 25 meters wide.

the limits of this parish, the boundaries of the simulated 'world'. The time frame in which they move, is from dawn (06:00 hours) until 18:30 at which time they return home. By 21:00 hours every water collector has returned home and sleeps and this is deemed to be the end of the day. The model therefore runs 15 hours per day and does not continue to run during the night. The model uses units of time referred to as 'ticks'. In this model every 60 ticks represents one hour and a day is 900 ticks (15 hours x 60).

The environment of this model, the "world" that is created, is an average parish in Uganda, with an average number of residents per household. As stated above in 4.2.1 the 2002 census data shows a parish contains on average 4,667 residents comprising 774 households at an average of six residents per households (Uganda Bureau of Statistics, 2002). The number of households and water points can be changed to explore different situations such as larger villages or even a city.

Water points are the only water supply resource depicted in ***Water Services that Last***. In principle, a single water point should, by design, provide 300 people with a water service level of 15 litres per person, per day. If households, at the end of the day, experience 'no service level' this means that the water collector would choose to collect water from unprotected sources of water including springs, rivers, or lakes. In other words, without factoring in alternate, unimproved water sources, a parish requires approximately sixteen functioning water points to ensure that all its residents receive the nationally determined water service levels.

Each household agent has only one water collector. The passage of time in the model is measured in ticks. The time of the day and number of days are calculated and displayed on the model interface. Several variables that may easily be modified or built upon to explore different scenarios include: the time-to-repair of a broken water pump, the amount of water that may be drawn from a pump before it breaks down, the number of households, the number of clusters, water collector's time-to-collect, the number of failed / broken pumps, the average speed of a water collector and the radius of household clusters. Lastly, the size of the model is 600 patches by 600 patches. As each patch is 25 meters wide this results in a 15 square kilometre model world.

Appendix C Mobiles 4 Water | Agent Properties

Water users

- Income
- Money balance
- Willingness to pay
- Knowledge of time of last payment
- Mobile phone
- WUC responsible for the water points
- Attitude towards their WUC
- Preference for clean water points
- Knowledge about water points and water sources
- A source that he/she is currently using
- Water service level
- Knowledge about past service levels
- Stubbornness
- Social network

Water user (inter)actions

- Use water
- Pay for water
- Let HPM know about breakdowns
- Let social network know about functional/non-functional sources

WUCs have

- Money balance
- Users they are responsible for
- Water points they are responsible for
- Monthly fee collection
- Performance (average service level of users)

WUCs (inter)actions

- Collect money
- Pay HPMs for assessment
- Ask HPMs for repairs
- Pay HPMs for repairs

HPMs have

- Money balance
- Attitude towards WUCs
- Attitude change rate
- Negative experience bias
- Favourite job
- Assessment fee
- Knowledge about water points
- Social network

HPMs (inter)actions

- Assess water points
- Fix water points
- Receive money for assessments

DWOs have

- Income
- Budget for major repairs
- Budget for new water points
- Knowledge about service levels of users

DWO (inter)actions

- Pay for major repairs
- Install new water points
- Pay for new water points

Water points (clean) have

- Type
- Construction cost
- Cost of repairs
- Time between breakdowns
- Water quality
- Status (functional/non-functional)
- Type of breakdown (minor/major)
- Breakdown assessed by HPM
- Water users

Water sources (dirty) have

- Water quality
- Status
- Water users

Appendix D Mobiles 4 Water | Model Narrative

Initial environment setup

A water service delivery area is described with:

1. A given number of population clusters is distributed randomly on the grid, with users distributed randomly within a given maximum radius of the centre of each cluster. This loosely represents the geographical distribution of villages at a sub-county level
2. A given number of water points is distributed randomly between population clusters, and located within a given maximum radius of each cluster
3. A given number of non-improved water sources is distributed randomly on the grid
4. WUCs are created sequentially at the location of each water point that is not already covered by the activity radius of an existing WUC
5. A given number of HPMs is created at a location adjacent to a random population cluster
6. The district water officer is placed at a random location as his/her geographical location is irrelevant
7. Agent properties are set for water users, water user committees, HPM, DWO, water points and water sources
8. Social networks of users and HPM are established , based on a given number of desired total links and a desired fraction of global links with users beyond a given radius. The social network setup follows the work from Holzhauer, Krebs and Ernst (2012) who describe an algorithm that lets agents pair up with a group of agents that live fairly close as well as a few more distant agents.

Water User

1. Receive daily income from environment and updates money balance
2. Travel to water point or other source based on knowledge about working water points, distance to water points, and attitude towards other sources

   a. If water point is broken: Update knowledge about working water point

   b. Decide on going to another water point or other water source, based on attitude towards water from other sources

   c. If water source is working, tap water and leave

Following the M4W policy, if a user finds a non-functional water point:

3. Decide on reporting the breakdown through a SMS/call with the M4W

system, based on willingness to pay, mobile phone ownership, attitude towards WUC

4. If unable/unwilling to pay, decide on letting WUC know about the non-functional water point based on attitude towards WUC; the WUC is then assumed to automatically report the water point in the M4W system
5. Update user's service level based on the water quality of the source, the distance to the source, and whether or not it is overcrowded compared to the average number of users per water point
6. Interact with a given fraction of user's social network, letting him/her know about the status of the priority source, and about the status of another randomly chosen water point known to be broken
7. Update attitude towards WUC based on three components:
   a. External attitude change is based on the difference between the average attitude of the user's social network and their own attitude, divided by the user's stubbornness
   b. Internal attitude change is based on the sum of an absolute perception component (taking the difference between the user's current service level and the initial median service level of all users in the sub-county), and a relative perception component (with the difference between the user's current service level, and the average of remembered past service levels over a given "memory").
   c. Both of the above components are then divided by the user's long-term orientation, which decreases the rate of change.
8. Pay WUC based on the basic maximum willingness to pay, user's income relative to the population average, WUC fees, attitude towards WUC, and preference for water points.

Water Point

1. Each day, calculate the time elapsed since the last minor and major break-downs, and determine whether or not to break down based on a Weibull distribution with a given shape parameter, and median durations between minor and major breakdowns

Water User Committee

If water user reports break down:

- Report issue to HPM by indicating that the water point is ready to assess (covered in action 1.4)

1. Recalculate average service level of users under the WUC's responsibility

2. Upon request of HPM for payment for assessment :

   a. When balance is high enough: pay for assessment

3. Upon request of HPM for payment of a minor repair:

   a. When balance is high enough: pay for repair

4. If a non-functional water point under the WUC's responsibility was previously assessed but left unrepaired due to a lack of funds, and the WUC has successfully raised enough funds for the repair:

   a. Inform HPM that water point is ready to be reassessed and repaired.

Handpump Mechanic

1. Receive breakdown alert from M4W system or notification of a breakdown through the HPM social network; choose a priority repair job to respond to, based on distance and attitude towards WUC responsible.
2. Respond to priority repair job (if any) and travel to the water point
3. When arriving:

   a. Determine type of failure and (in the case of a minor breakdown the HPM can repair) the cost for repair:

      i. Ask the WUC whether it has sufficient money to pay for the assessment

         1. If WUC has sufficient money balance:

            a. Assess the water point and positively adjust the HPM's attitude towards the WUC

         2. If WUC has insufficient money balance:

            a. Still assess the water point, but negatively adjust attitude towards the WUC

4. If the water point needs repairs for a major breakdown (too complex to fix immediately by the HPM):

   a. Report major breakdown to DWO

5. If the water point has a minor issue and can be repaired by the HPM:

   a. Ask WUC about further action:

      i. If WUC decides to repair:

         1. Make repair
         2. Receive payment
         3. Inform users that water point has been repaired

ii. If WUC decides not to repair: do nothing

6. Adjust attitude towards WUC positively or negatively, based on outcome of the repair interaction
7. Go to next repair job on HPM's list.

District Water Officer

1. DWO receives a given income every 90 days (to simulate a quarterly release of funds corresponding to the District Water and Sanitation Conditional Grant), with a certain percentage being allocated towards the rehabilitation of existing sources
2. If HPM has reported major breakdown:

   a. Check available repair funds

      i. If available funds are greater than the rehabilitation cost of one or more water points with a major breakdown:

         1. Basic policy: Pick the broken water point which has the lowest rehabilitation cost; ask WUC responsible to contribute an amount equivalent to the cost of a minor repair (or its money balance if funds are insufficient). Repair the water point and inform users about the rehabilitation.

         2. Alternate policy: Prioritise the broken water point which belongs to the WUC with the lowest average service level, but which the DWO can still afford to repair; proceed with repairs as with the basic policy

Appendix E Role of Social Learning | Model Narrative

The actions of the agents and the order in which they are performed every year are as follows:

Return budgets

All residual unspent budgets of districts from the previous year are returned to national government. This is the cumulative of unspent budget that is not spent on either CapEx or CapManEx.

Calculate Water Service Levels

Districts calculate the water service level per person in their areas. This is a function of the number of water points, the functionality percentage of the water points, the delivery capacity of a water point and the population.

Each district is assumed to have full information about the state of the infrastructure in its area. The water service levels per person are used to construct the ranking for the selection procedures.

Selection processes

Districts are ranked according to their water service level per person. If the districts are categorised as fully rational, this ranking is made at national level and includes all districts. If the districts are categorised as myopic, the ranking is made within regions. Hereafter, the districts make three assessments: whether they are 1) the best performing district or 2) in the bottom half of the ranking, and 3) do they perform above national set target quantity? The first assessment is used in the replication procedures. The second and third assessments form the selection mechanism: the allocation ratios of district in the bottom half or below target quantity cease to exist, the ratios in the top half of the ranking and above target quantity live on.

Replication processes

Districts whose allocation ratio lives on replicate this ratio and use it again next year. Districts whose allocation ratio ceases to exist replicate the allocation ratio that is used in the previous year by the best performing district, i.e. the top ranked district. They replicate either the ratio of the best performing district in the nation (method: fully rational), the ratio of the best performing district in the region (method: myopic), or the ratio of a random other district (method: random).

Variation processes

Only districts who have replicated an allocation ratio of another district follow this procedure. If the variation method is perfect copy, the districts simply replicate the ratio they selected to replicate. If the variation method is random fractional, the districts move a random fraction from the ratio they used in the previous year towards the ratio they have selected for this year.

Ageing of district and water points

The population of a district grows in line with its "population growth rate". After each click, operational water points add a year to their age. When they reach their calculated expected lifetime they fail and become non-functional and the age counter is reset to zero. Thereafter, for each click in the model, non-functional water points add a year to their non-functional age. When this counter reaches 5, the water point is considered abandoned and the WP-agent dies.

Districts calculate budgets

All districts calculate their budgets for CapEx and CapManEx from the allocation ratio multiplied by the budget in the District Conditional Grant.

Districts spend CapEx

Districts spend their CapEx budget, by determining the number of water points that can be constructed within their allocated budget and creating that amount. The water points start delivering services to the districts. Districts calculate how much budget remains from their allocation, transferring the residual budget to CapManEx.

Districts spend CapManEx

Districts calculate how many water points they are able to repair within CapManEx budget and repair that maximum number. Any unspent CapManEx is transferred to the *unspent budget*

Appendix E Role of Social Learning | Tests for Model Artefacts

Tests to examine whether the steep decline of the average performance is an artefact of the model were conducted in the manner described in this annex.

District water service levels at the end of one run sere as the input for a new run whereby districts start at the level at which they became stable in the previous run. However, the number of water points and the population increased as the districts developed over the initial 20 year period. The water quantity delivered per person per day is a sum of the population, the total number of water points and the functionality percentage of the water points.

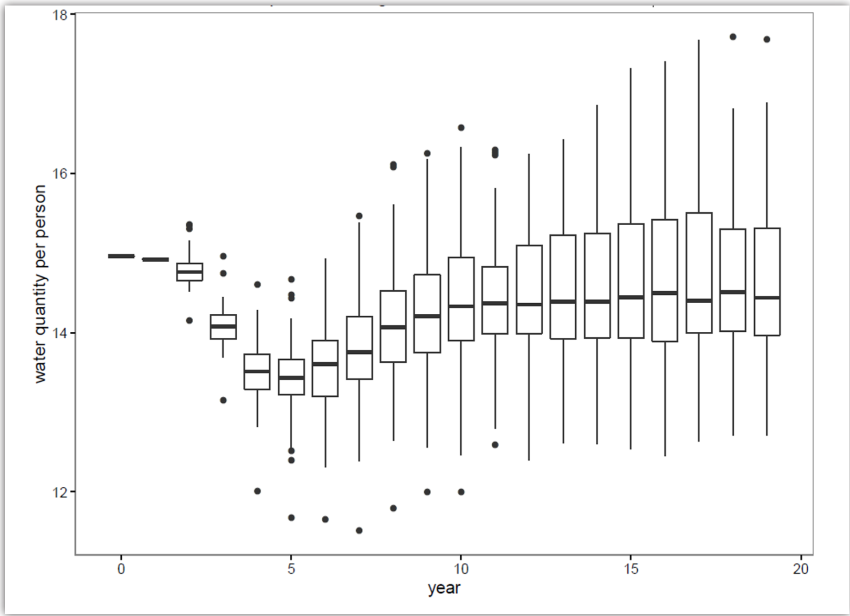


Figure 47. Test with district output as input for subsequent simulation

Source: Adapted from Knipschild, 2014.

In the subsequent test, the number of water points is varied to match the water service level achieved at the end of the previous run. A total of 50 simulations are performed, 10 for every scenario for replication and variation to ensure a similar representation as the initial model run to test the original settings. The results are displayed in Figure 47.

The end point of the first test is the starting point of the subsequent test. Districts therefore start from a lower base than in the first test - 15 litres here compared to 19 litres in the original simulations. During this test, the median of the average district performance declines to almost 13 litres per person per day over 5 years. The decline does not appear to be caused by initial conditions that are too high or too low. The initial conditions are implemented by varying the number of water points in every district. This implies that the district water point functionality rate does not vary, but that more water supply infrastructure is available. Additional simulations demonstrate that the decline of average district performance is similar to the decline in average functionality. The decline in water point functionality rate arises from the fact that many water points break down in the first few years, both in the model and in real life, and apparently more rapidly than repairs can be made as depicted in Figure 48.

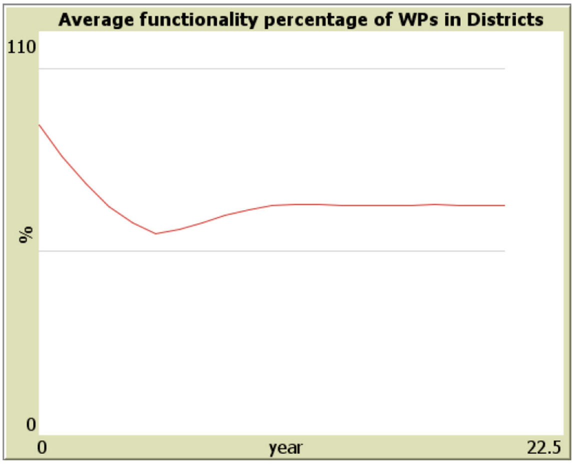


Figure 48. Average district functionality percentage in a single simulation.
The red line indicates average functionality percentage. Grey lines represent 100% and 50%.

Source: Adapted from Knipschild, 2014.

Figure 48 shows an average water point functionality rate of approximately 84% in all districts in the initial set up. Thereafter it declines to approximately 55% in 5 years, increasing again to around 63% in 10 years. This pattern is similar to the average district performance behaviour. The observed dynamic is a model artefact. The assumptions about district's DCG budget, and about the water infrastructure states such as price and lifespan, determine whether districts have sufficient budget to maintain the rates of coverage. It may also, however, indicate an ineffective investment strategy.

In summary, the average district performance shows a steep decline followed by slight recovery and then a stable state over a long time period.

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If I have seen further it is by standing on the shoulders of Giants.

— Isaac Newton (1642-1726/27)
Mathematician, physicist, astronomer, theologian and author

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You must find a way to get in trouble, good trouble.

- John Lewis, 1940-2020
Civil Rights Leader, American statesman

Curriculum Vitae

A California-born native, Deirdre moved to The Netherlands in 1995 and completed a Master of Arts in Development Studies at the Institute of Social Studies in December 1999. That same month she joined IRC as a Research Associate in the Gender and Water thematic group and co-coordinated the Gender & Water Day of the World Water Forum held in The Hague in the year 2000. In the years that followed Deirdre lived and worked as a lecturer and trainer at the National Community Water and Sanitation Centre at the University of Limpopo Province in South Africa under the auspices of the APSO skills sharing programme of the Government of Ireland in cooperation with the Republic of South Africa.

Upon returning to The Netherlands in 2003 Deirdre worked independently before re-joining IRC in 2004 until 2015 and conducted technical advisory as well as action research and training activities in Africa, the Middle East, Asia and Latin America that were commissioned and funded by national governments and development cooperation agencies including Asian Development Bank, Gates Foundation, European Commission, Millennium Water Alliance, Government of Ghana, UNICEF, UN-Habitat among others.

Currently, in addition to working independently as an advisor on collaborative stakeholder analysis and engagement processes in complex multi-actor initiatives in the WASH, energy and academic research sectors, Deirdre works as a communications professional in the field of higher education and scientific research. She also moonlights as a Pilates instructor. In all of these activities, connecting people with evidence-based information to support them to make well-informed decisions remains a central organising principle in all of her work.