Addressing stakeholder conflicts in rural South Africa using a water supply model

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Abstract
A system dynamics modelling approach is adopted to deepen understanding of the effects of operational management on the performance of the Greater Kirkwood water supply system in South Africa. Currently, the interrupted operation of the system has led to perceptions of systemic social injustice on the part of citizens and contention between the municipality responsible for supplying water to the citizens and the Water User Association responsible for delivering untreated water to the municipality. The model is used as a means of exploring the technical constraints of the water supply system, and of supporting discussions between stakeholders about contentious issues, and the ways they can address these issues. Research on the utility of the model as a means of supporting strategic conversations between stakeholders (cf. Howick & Eden, 2010) is ongoing

Key words: water management; socio-technical system; conflict resolution; strategic conversations; soft systems methodology

1. Introduction

Following the apartheid era, the democratically-elected government of the Republic of South Africa undertook to ensure that all citizens had access to basic water services. This was a significant challenge given that the water resource and water services were no different from the other resources and services in South Africa, which were inequitably distributed across racial groups in a purposeful and designed manner. In particular, the technical supply of water services was primarily designed for the white minority. From 1996 onwards numerous changes at a national level resulted in a complete restructuring of water policy and legislative frameworks. The changes relevant to water services include: the Constitution of 1996, which positions access to water as a basic human right for all; the Water Services Act of 1997, which separates provision and regulation in a decentralised manner; the National Water Act of 1998, which legislates a *basic human needs* reserve that comes before all other allocations in the country, and the policy of *free basic water*, which was formalised in 2001.The Constitution differentiates three spheres of government, namely national, provincial and local government (Juta's Statutes Editors, 2010), with the responsibility for service delivery residing in the 'local government', or municipal, sphere. One of the service delivery duties of the local government is to ensure the provision of water and sanitation services to all users within a municipal jurisdiction. The Sundays River Valley Municipality (SRVM), located within the Lower Sundays River Valley sub-catchment, within the Eastern Cape province of the Republic of South Africa (*Figure 1*), is struggling with this task.

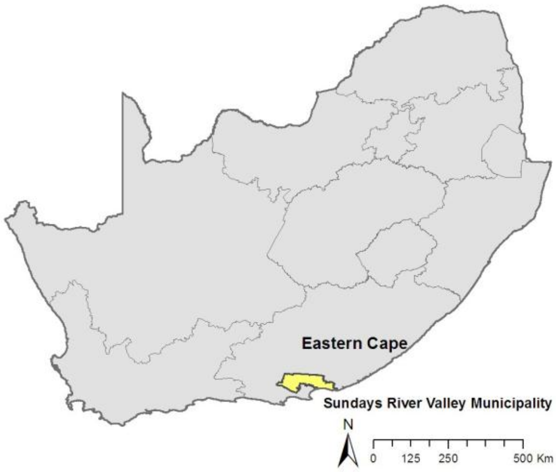

Figure 1: Location of the Sundays River Valley Municipality within South Africa

With no large urban settlement, and a combination of multiple small towns and commercial farming, the SRVM is a primarily rural or prototypical 'Category B3' municipality. As of 2009, 111 of the 278 municipalities in South Africa are classified in this category (World Bank, 2009: 10-11). As such, the SRVM does not stand alone in South Africa in its struggle with the provision of water and sanitation services to citizens living within the municipal boundaries. Nor is it alone in having to deal with contentious issues related to the historical design and operation of its water supply system.

In this paper, we follow Howick and Eden (2010) who argue that quantitative modelling can serve to support 'strategic conversations' between actors, first developing a system dynamics model of a water supply system run by the Sundays River Valley Municipality and then exploring the utility of the model in such a context. We demonstrate its use as a neutral tool to support strategic conversations in a multi-actor space, where actors are historically divided and still contending with one another.

2. Method

The recognition of the variety and conflicting interests of the stakeholders involved and the lack of clarity about the effect of operational procedures on the security of the water supply, led to the decision to adopt a system dynamics modelling approach to the seemingly intractable water supply problems of Greater Kirkwood. The system dynamics method was designed for application in socio-technical systems (Lane 2000), with the aim of clarifying and quantifying the interactions between elements of a physical system and the humans intervening in, or operating the system. Stakeholders are able to locate themselves and their actions within the "stocks" and "flows" used to characterize the system, and so experience the method as enhancing communication (Stave 2003). An added advantage of system dynamics for this particular situation is that detailed and accurate data on the water supply system (e.g. the evolution in water demand over time, variations in the water treatment pumping capacity and the storage reservoirs fluctuations over time) are not prerequisite to modelling. Instead a deep knowledge of the design capacity of the system, and experienced behaviour over time is required. Whereas detailed data were not always available, information on system behaviour was readily obtained from the following sources:

- Technical reports of the Sundays River Valley Municipality, including the Water Services Development Plans (Sundays River valley Municipality 2010a, 2010b, 2011)
- Information pamphlets outlining how the Water User Association water supply system works and the annual reports of the WUA (WUA 2007, 2011, 2012).
- Three workshops on the 'turnaround of the SRVM water services' (31 November to 1 December 2011, 10 October 2012 and 28 February 2013), attended by representatives from the national Department of Water Affairs, the SRVM and the WUA.

Accordingly, after first characterizing the situation of the Sundays River Valley Municipality and its water supply at catchment scale, we chose to focus on the complex, real world problem situation of the Greater Kirkwood water supply and represent this as a system diagram (Figure

3, section 3). Next, the system diagram is specified as a system dynamics model in VenSim PRO Version 6.0a-1. To corroborate the physical system understanding, three site visits to the Greater Kirkwood area were undertaken by one of the authors in the period January to November 2012. Presently, the model is in use as a means of supporting discussions between stakeholders about contentious issues, and about the ways they can address these issues. Research aimed at evaluating the utility of the model as a means of supporting strategic conversations between stakeholders (cf. Howick & Eden, 2010) is ongoing.

3. Lower Sundays River Valley, its water supply situation and involved actors

The SRVM has a population of 54 500 people living in 14 700 households (Statistics South Africa, 2012: 2; 27). Agriculture provides 48% of the employment in the area with tourism and community services accounting for a significant portion of the remaining 52% of the employment (SRVM WSDP, 2010, D: 4). Unemployment and dependency on social grants are, however, endemic: an average of 47% of the SRVM population has a household income of less than R800 ($85/£60) per month, with unemployment estimated to be as high as 44% (SRVM WSDP, 2010, D: 10).

A schematic for the water supply system of the Lower Sundays River Valley is given in Figure 2. The three primary actors involved in the supply of water to the Lower Sundays River Valley area are the Department of Water Affairs, the Lower Sundays River Water User Association and the Sundays River Valley Municipality.

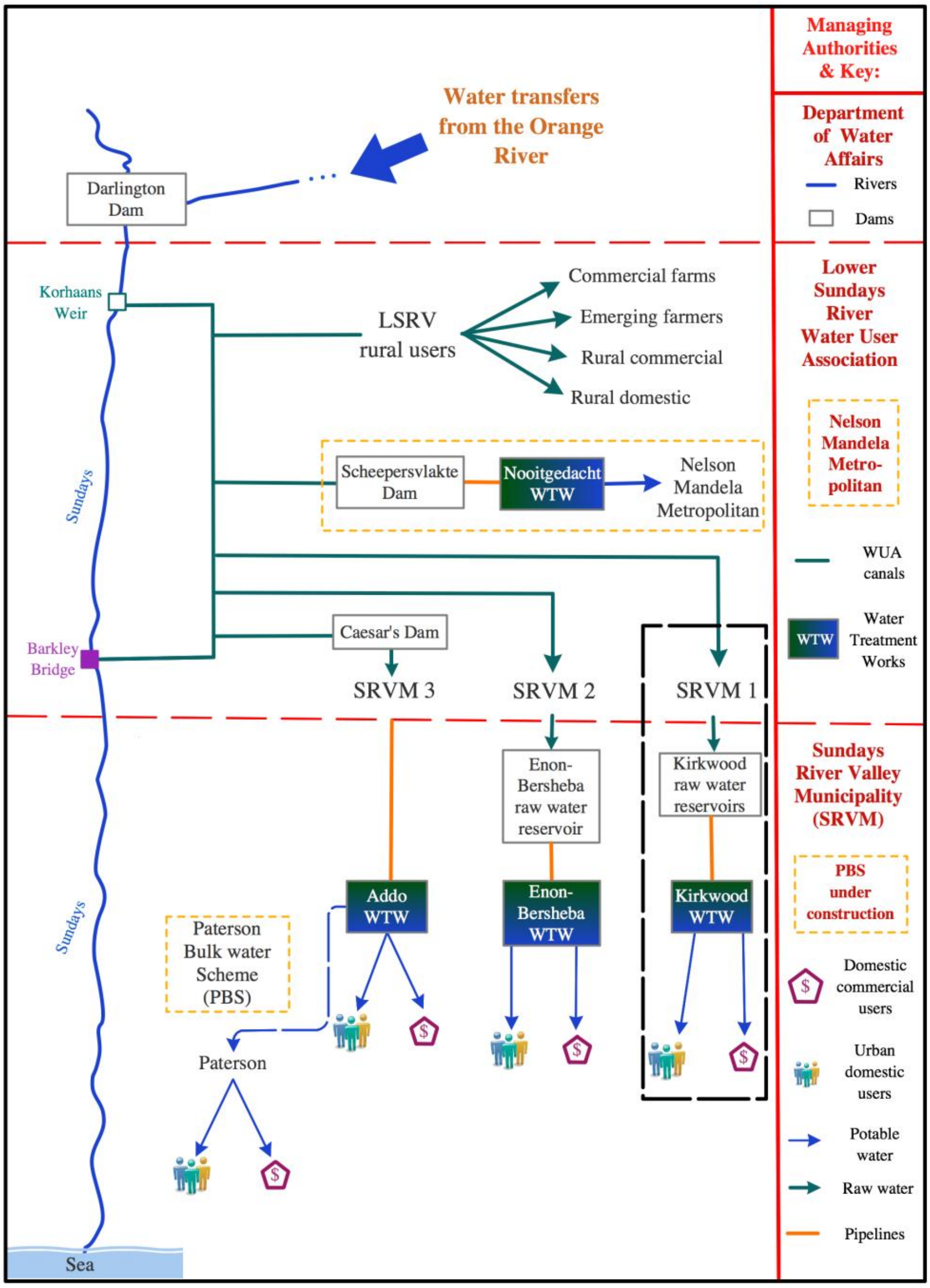

Figure 2: Schematic of the water supply system in the Lower Sundays River Valley area. The focus for the system dynamics model is demarcated by a dashed black box.
WUA = Water User Association;

The Department of Water Affairs manages the inter-basin transfer scheme, which delivers untreated water from the Orange River system some 300 kilometres away, via a series of tunnels, pipelines, canals and interconnecting rivers (*not shown*). Downstream of the Darlington Dam, the Lower Sundays River Water User Association (WUA) manages the bulk water supply system, which delivers untreated water to a range of users (summarized in the middle section of Figure 2). The canal system managed by the WUA is run in a network fashion with no major storage points within the system: water orders are calculated on a weekly basis, with releases from Darlington dam planned according to demand. Water is released from Darlington dam, flows down the Sundays River, and is abstracted into the WUA's canal system at the Korhaans Weir. The water is then diverted through a network of canals that spans the length of the irrigated farming region in the LSRV, with over 900 delivery points in the form of sluices delivering to users in the Valley (Lower Sundays River Water User Association, 2007). It is the responsibility of the users (primarily commercial farmers) to store adequate water 'off-site' (i.e. in dams) to last them for the periods when the WUA does not supply – for example, over weekends and public holidays.

The SRVM's system is depicted in the third section of Figure 2. The SRVM receives untreated water from the WUA to three supply systems (Enon-Bersheba, Addo and Greater Kirkwood). The water source for the fourth system (Paterson) has historically been groundwater, but a new pipeline will connect Paterson to the Addo water treatment works in the near future. This will make all four urban settlements in the SRVM increasingly reliant on the WUA for the supply of untreated water.

4. System description and model development

4.1. System elements and system boundaries

The choice was made to focus on the Greater Kirkwood water supply system in this modelling effort (dashed black line in Figure 2), primarily because the SRVM and the WUA indicated that they were experiencing conflicts in this regard. The real world problem situation of Greater Kirkwood's water supply is represented in the system diagram of Figure 3. Three elements interact with each other, and together form the Greater Kirkwood water supply system. The Water User Association supplies the water according to an order placement procedure. The water goes through the Sundays River Valley Municipality bulk water supply system, where it is stored, treated and distributed to five separate zones in the Sundays River Valley. Ideally, the water supply is based on the water demand of the domestic population in Sundays River Valley Municipality. The system boundaries are depicted by the inner black line, while the arrows impinging on the system represent the effects of external factors and the means of stakeholders to intervene in the system. The blue arrows leaving the system represent the 'outcomes of interest'.

The brown horizontal arrows on the left depict the effects of external factors. They affect the system behaviour and system performance, but cannot be influenced directly by the stakeholders or the factors within the system (Enserink et al., 2010). The four identified external factors are 1) seasonal variation in climate, including summer heat, droughts, varying rainfall and winters; 2) policy changes regarding water provision as a basic human need, for instance the *free basic water* policy from 2001; 3) the amount and time period of water supply from the Orange River; and 4) aggregate lifestyle expectations.

The means of stakeholders to intervene in the system are depicted by red vertical arrows. (Enserink et al., 2010). The Water User Association can adjust the water delivery schedule currently in place. The Sundays River Valley Municipality can increase the capacity of the water supply system by building extra storage or placing water pumping systems. Additionally, the operational management of the water treatment works can be intensified by the SRVM. Finally, the Department of Water Affairs and the South African National Treasury can award grants to improve the system performance.

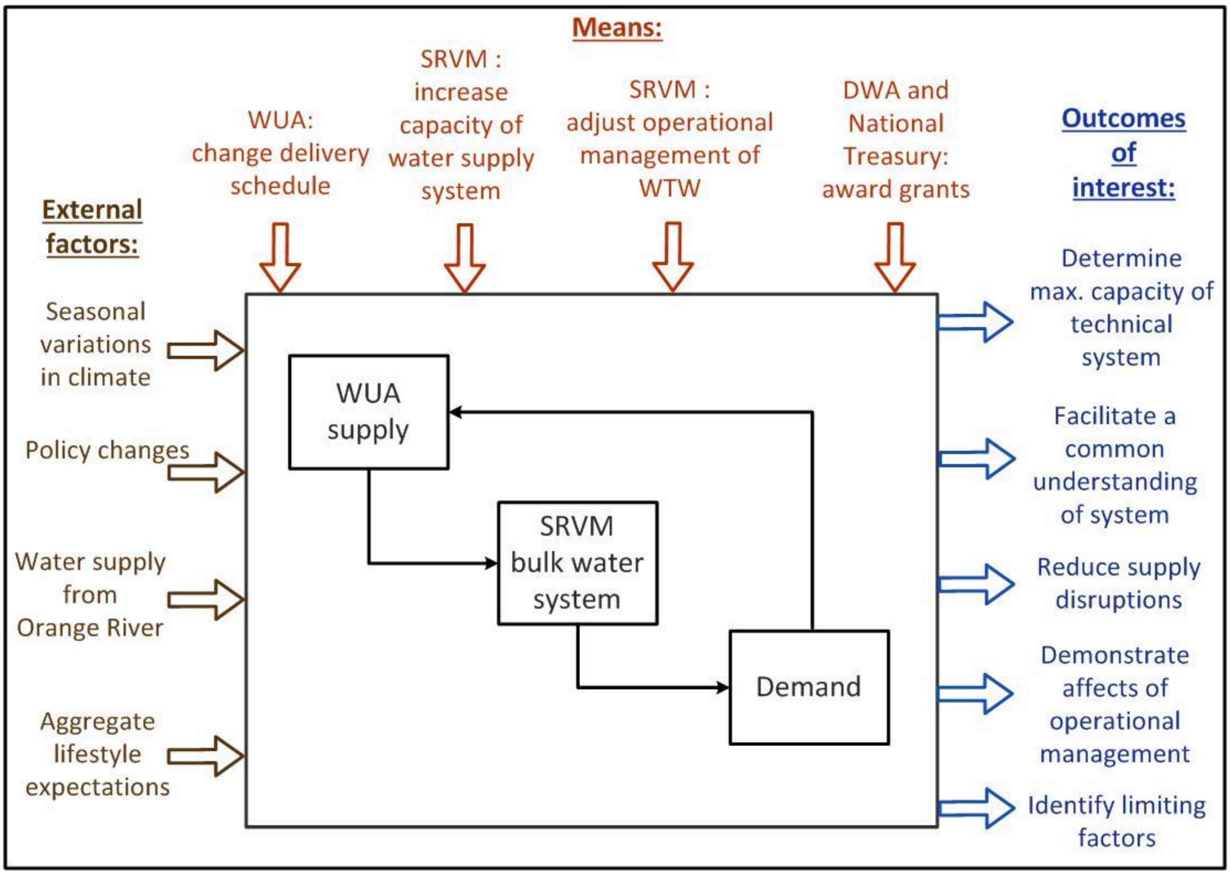

Figure 3: Systems diagram of the water supply system

The reasons to build a model in the first place, that is the purpose of the model, are described in terms of the five outcomes of interest to the stakeholders. First, the maximum capacity of the technical water supply system of Greater Kirkwood is currently unknown, needs to be determined, and is of deep interest to the SRVM. Second, a common understanding of the complex technical water supply system and its behaviour can serve as a basis for finding an operational mode that is supported by all stakeholders. A third outcome of interest is the identification of the weakest links in the water supply system serving the inhabitants of Greater Kirkwood. Identifying these limiting factors within the technical water supply system allows contingency plans to be made and enables the system operators to improve the system. Fourth, it is of interest to all concerned that supply disruptions are reduced, both in frequency and duration. Indeed, this forms the focus of an incentive driven performance evaluation approach for municipalities in South Africa, known as the Blue Drop programme. The fifth outcome of interest is deepening the understanding of the effects of operational management on the performance of the water supply system. The interrupted operation of the system owing to employee's working hours or pumps cutting at low storage levels affects the water supply service and the perception of systemic social injustice.

4.2 The model

4.2.1. The water supply system

Details of the technical water supply system of Greater Kirkwood are provided in Figure 4. The figure represents the Greater Kirkwood area enclosed by the demarcated, dashed black box of Figure 2. The Greater Kirkwood area itself comprises five zones: zone 1 is Kirkwood town, the largest urban settlement in the area; while zones 2 to 5 represent the smaller urban areas of Bergsig, Aquapark, Moses Mabida or Emsengeni. The Sundays River Valley Municipality is the owner of the technical water supply system, and responsible for maintenance and operations.

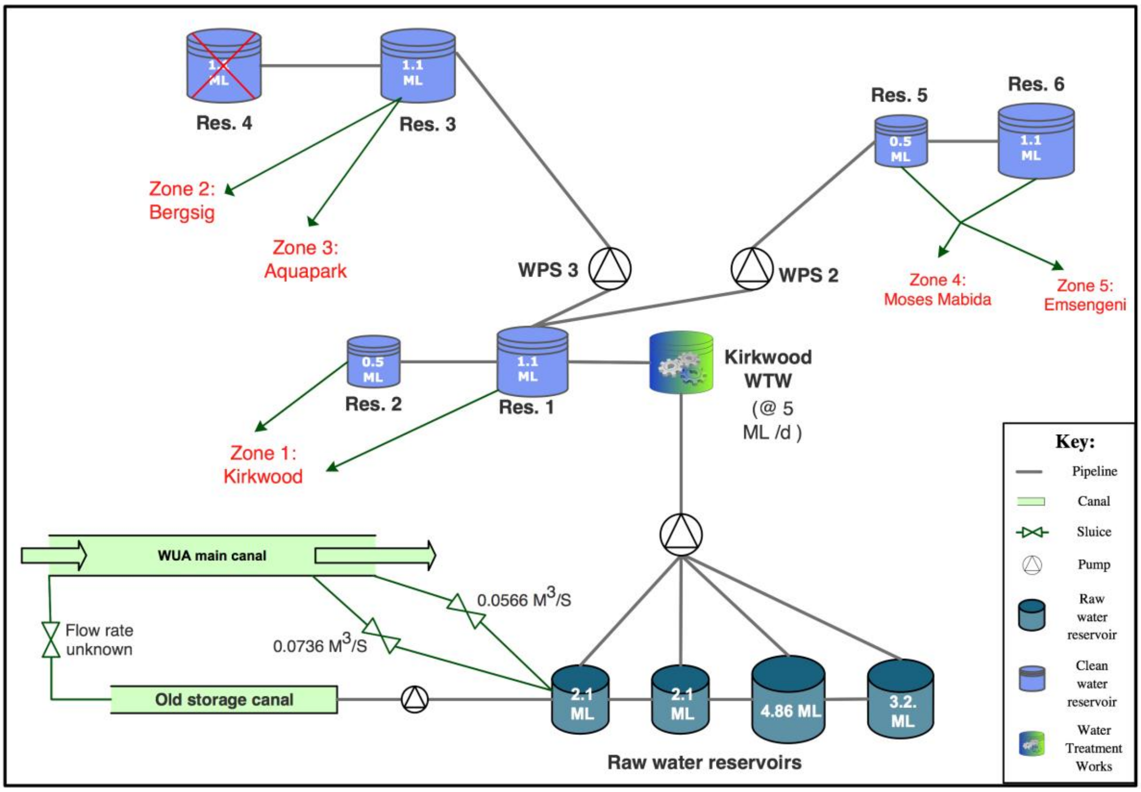

Figure 3: Simplified schematic of bulk water supply system for the Greater Kirkwood area of the Sundays River Valley Municipality (Eastern Cape of South Africa).

The intake of untreated water from the WUA main canal occurs via three sluices; one sluice to the old storage canal, and two sluices to the water reservoirs of varying sizes. The four raw water reservoirs and the old storage canal together represent the full off-site storage capacity for untreated water. The exact volume of the old storage canal is unknown, but it is estimated at 6,84 M*l*. In the model, the raw water reservoirs and the old storage canal are combined into one stock variable '*off-site storage'* with a given maximum capacity (Figure 5).

From the raw water reservoirs, the water is pumped through the water treatment works (WTW) to reservoir 1. The potable water from reservoir 1 is either pumped through to the water reservoirs storing the water for the urban areas of Bergsig, Aquapark, Moses Mabida or Emsengeni, or it stays in reservoir 1 and 2 to supply Kirkwood town. Because of its location, Kirkwood town is supplied by gravity feed. The water can only reach the other reservoirs by pumping it using water pumping systems (WPS) 2 and 3. To avoid overheating and seizure, the diesel engines of the WPSs cut out when the water volume in the reservoirs falls to 20% of the reservoir capacity or below. Once the pumps have cut out, the reservoirs need to fill to 50% capacity before the WPSs can start running again. From the time that the pumps first cut out, the people living in Zones 2 to 5 are without water, while Kirkwood town receives the remaining 20%. In short, because of its geographical location and the water supply system design, Kirkwood town is the first to receive water and the last to run out of water.

The discharge rates of the pumps and the design capacity of the water treatment works together determine the maximum feasible performance of the modelled water supply system (Figure 5). Presently, available information suggests that the pumps of the water supply system are being run over their maximum discharge rate in an attempt to meet the supply the demands for domestic water in the Lower Sundays River Valley.

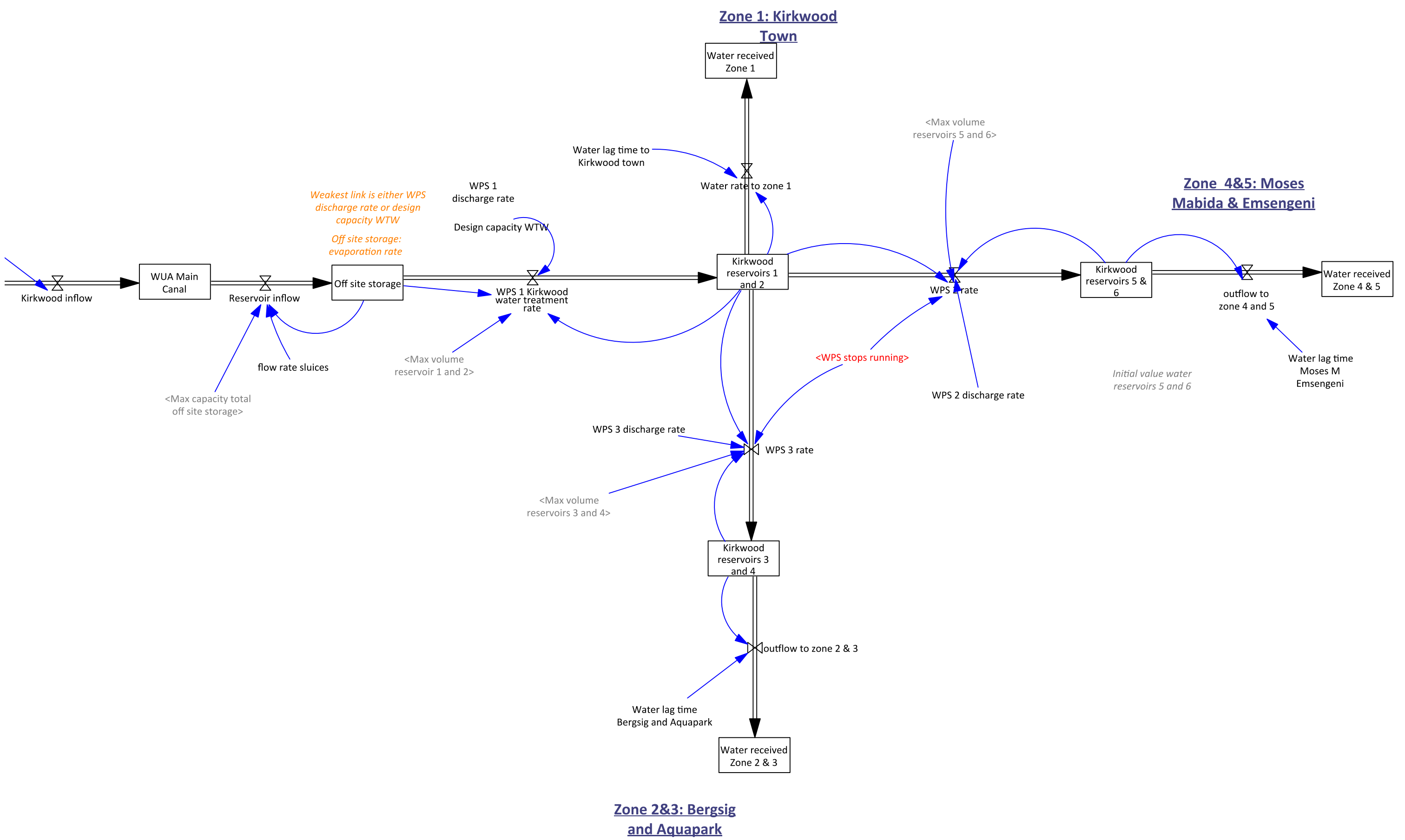

Figure 4: Water treatment, storage and supply sector of the model

4.2.2 Water supply sub-system

The SRVM orders for water are placed with the WUA on a weekly basis. The weekly order placement is designed to cope with demand fluctuations on the part of the WUA clients, who are supposed to predict the water they need. Currently, the SRVM always request the maximum possible allocation, in an attempt to prevent failure in the supply of water to the people of the Lower Sundays River Valley. This often causes wastage of water when more is supplied than can be stored. The order placement occurs on Thursday afternoon, and on Monday morning the first water for the week arrives in Kirkwood, depending on the flow level. The model of the water supply sub-system is depicted in the stock-flow diagram of Figure 6.

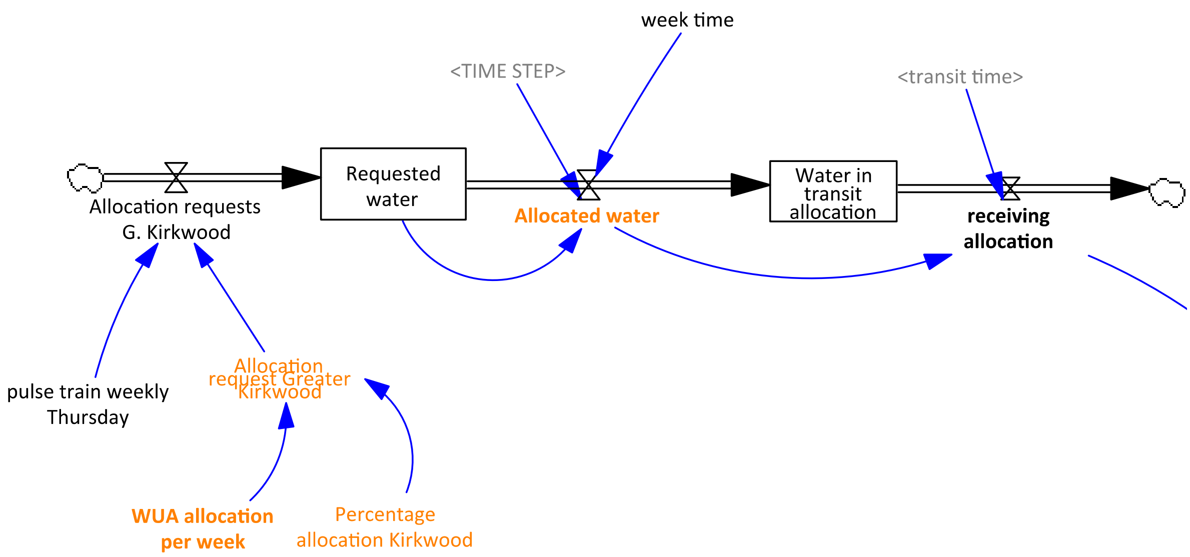

Figure 5: Water User Association Supply sector of the model

3.3.3 Water demand sub-system

As the allocation requests from SRVM are to be based on actual water demand from the towns in Greater Kirkwood in the future, the growth in water demand is an influential variable. There are little data available on this issue. Policy changes in 2001 were reflected in a dramatic increase in demand, accompanied by a responsibility to supply water to all population groups. Given the existing problems with the supply of water for domestic use to the inhabitants of Greater Kirkwood, the growth in water demand is expected to pose significant and potentially conflict-enhancing demands on the already failing water supply system. The model of the water demand sub-system is depicted in the stock-flow diagram of Figure 7.

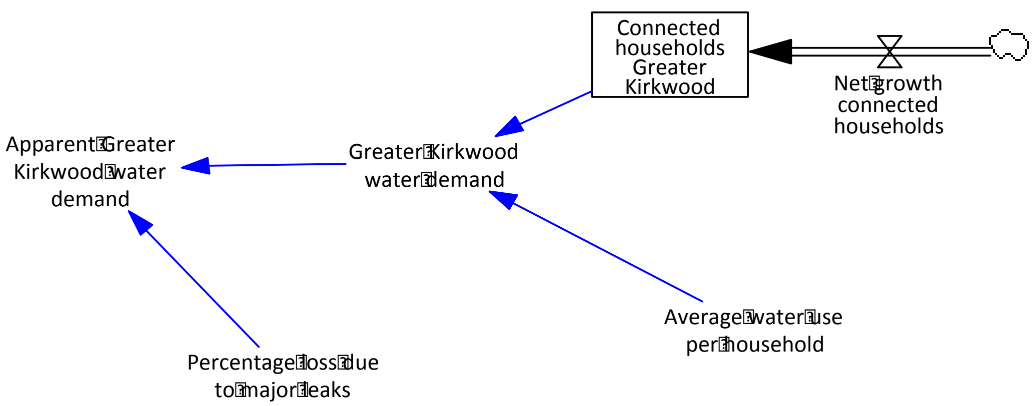

Figure 6: Water demand sub-system

5. Preliminary results and discussion

The system dynamics model was developed and is in use to support discussions between members of the Sundays River Valley Municipality, the Water User Association and other interested stakeholders. Indeed preliminary results crucial to system performance, and coherent with the lived reality of users and stakeholders in Greater Kirkwood, have already been obtained.

Presently, the municipality is running the pumps above their maximum discharge rate. This is not sustainable in the long term, but is an indication that the technical capacity of the system may in itself be insufficient to meet the demands placed upon it. Whereas the stakeholders have been blaming each other in the past, there is a growing realisation that the supply system may not be adequate. The Water User Association has long held the opinion that the municipality does not order wisely – witness water wastage through overflow, nor does it operate the system effectively – witness the failure to supply. The SRVM has long held the opinion that the WuA is to blame for not supplying on weekends, but has itself not grasped why the supply fails.

Through the system dynamics model, we have been able to establish that the off-site storage capacity of the municipality is insufficient to meet the demand for water over a weekend in the hot, dry summer. So even if the SRVM runs the water supply system extremely efficiently, the supply of water will fail. This fact had not previously been understood by the municipality, despite attempts by the WUA to communicate this from 1997 onwards.

It is not clear, however, whether the capacity of the water supply system would still be insufficient were the WuA to continuously supply water i.e. through weekends as well. This is related to the uncertainty about the volume that can be stored in the old storage canal. Clearly, then the off-site storage capacity is a limiting factor in the supply system. Similarly, we have been able to identify the pump capacity as a further limiting factor should the off-site storage capacity be increased.

An additional insight that is working to enhance social cohesion between groups is the fact that the safety mechanisms in the technical design of the pumps, together with the gravity feed to Kirkwood town, are the reason that Kirkwood is the last to be cut-off and the first to receive water. The situation is such that all areas of the municipality do not run dry at the same time. Instead some areas run dry more quickly than others, notably the lower income areas. The zone with the highest socio-economic status is Zone 1 (Kirkwood town), which runs out of water last, and receives water first; whilst the opposite applies to the zones with the lowest socio-economic status. This is perceived as systemic injustice, particularly as even twenty years after apartheid ended Zone 1 is primarily white residents, unlike the populations of the poorer zones 2 to 5. The SRVM is dealing here with an historical artefact from the apartheid era when the technical systems were designed to service "white areas". The location of the storage tank to gravity feed Kirkwood town was chosen for this in mind.

The demand for water has grown rapidly in the last decade with more houses being added to the reticulation network. As more and more houses are added to the network, there is greater expectation on the municipality to supply water to these houses. Whilst there is political pressure to supply running water and sanitation to households, there is less pressure to maintain and develop the water supply infrastructure required to continuously services to the households. The anticipation of a strong growth in the demand for water means that the SRVM now understands that the capacity of the technical system has to be improved if they are to meet the demand, and that they will have to plan for and acquire funding for such infrastructural improvement.

Further, the SRVM is now confident that their system performance can be enhanced if they were to receive a continuous supply of water. They will continue to argue for a change in the WUA operating procedures, especially given the national priority placed on basic human needs for water. It is worth noting that the WUA's delivery system was first and foremost designed for commercial agriculture, which has water demands different from domestic users. For example, the open design of the canal system paired with the hot climatic conditions requires that the canals are cleared of algae annually. The WUA's chosen method for clearing algae is to let the canals run dry. Such system maintenance is scheduled during the winter period, when the farmers' demands for water are lowest. This means that the canal system only operates for fewer days per week during the winter, despite the fact that the SRVM, as a supplier of water for domestic use, requires water all year round. However, the SRVM cannot only demand changes of the WUA. They are also obliged to rethink their policy of only running the treatment works on working days, as this is a potential further constraint on water supply that lies directly under their control.

6. Conclusions

In developing and using a systems model of the Greater Kirkwood water supply system, we have been able to identify areas of contention between stakeholders, where understanding or information is currently unavailable, fuzzy or inconsistent. These 'areas of contention' form the focus of the system dynamics modelling endeavour, which is opening up spaces for, and supporting ongoing interactions between stakeholders. The further use of the model to support changes in the operation of the water supply system of Greater Kirkwood will occur within the context of a series of larger transdisciplinary project aimed at breaching barriers to water policy implementation in South Africa.

The approach presented in this paper is a step away from group model building, which focuses primarily on the model building component of the modelling cycle. Instead, here modellers build the model with stakeholders, and then focus on *its use* by stakeholders. This unusual application of system dynamics modelling aligns with the cybernetics tradition and 'soft systems methodology' (Checkland, 2000). An analysis of this stakeholder-based use of modelling and the contribution it makes to the field of soft systems methodology is being prepared for publication at present (Clifford-Holmes & Slinger, 2013). However, even at this stage, the utility of the system dynamics method in supporting strategic conversations between dissenting actors appears promising.

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