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Using geovisualisation to support participatory problem structuring and decision making for an urban water utility in Uganda

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Abstract: This paper describes the application of geovisualisation to facilitate participatory identification and structuring of problems in an urban water supply system in Uganda. The city of Kampala has experienced rapid expansion over the years, with a corresponding increase in the demand for piped water supply. However, this demand was not well matched with expansion of the water supply system, and as a result parts of the city have been facing chronic supply anomalies and insufficiencies. Faced with the task of identifying remedies to the problems in the system, the city water company undertook a formal participatory problem structuring and decision analysis process, to try and understand the underlying causes of system failures as well as the geospatial patterns of these failures. As part of this process, analysis, mapping and geovisualisation of data derived from historical records of water consumption, as well as records of pipe breakages, supply intermittences, and other recorded customer complaints, was done. The maps so produced were key in bringing the various stakeholders and decision makers to a common understanding of the problem issues, and helped in the formulation of alternative courses of action. Furthermore, with the establishment of a formal discussion forum for problem analysis and decision making, structured participatory decision making was entrenched within the company's work ethos. It is hoped that in future, the coupling of the geovisualisation tools with the existing operational databases in the company will result in the development of a functional spatial decision support system and a dynamic framework for system performance monitoring and reliability assessment.

Keywords: Decision support; Geovisualisation; Participatory problem structuring.

1.0 Introduction

Given the multiple complexities inherent in an urban water supply system, a rational and systematic approach can help in the formulation and evaluation of alternative management strategies and interventions. Of primary importance in this regard is the provision of tools to help bring the decision makers to a good level of understanding of problem situations that arise, in terms of their root causes, symptoms, impacts and geographical extents.

Sharifi et al (2004) present a framework for a systematic approach to decision making, based on the classical work of Simon (1960). In this framework (Figure 1), the decision making process consists of three phases, namely intelligence, design and choice. Sharifi et al (ibid) point out that whereas to date much research has been focused on the choice phase, resulting in a wide variety of well researched evaluation techniques and methodologies, in practice identifying and defining a problem is much more important. If the intelligence phase is not given enough attention the wrong problem may be identified and solved; likewise, if design is given insufficient attention, a choice may be made from a set of alternatives that are too limited or may not even correspond to the problem at hand.

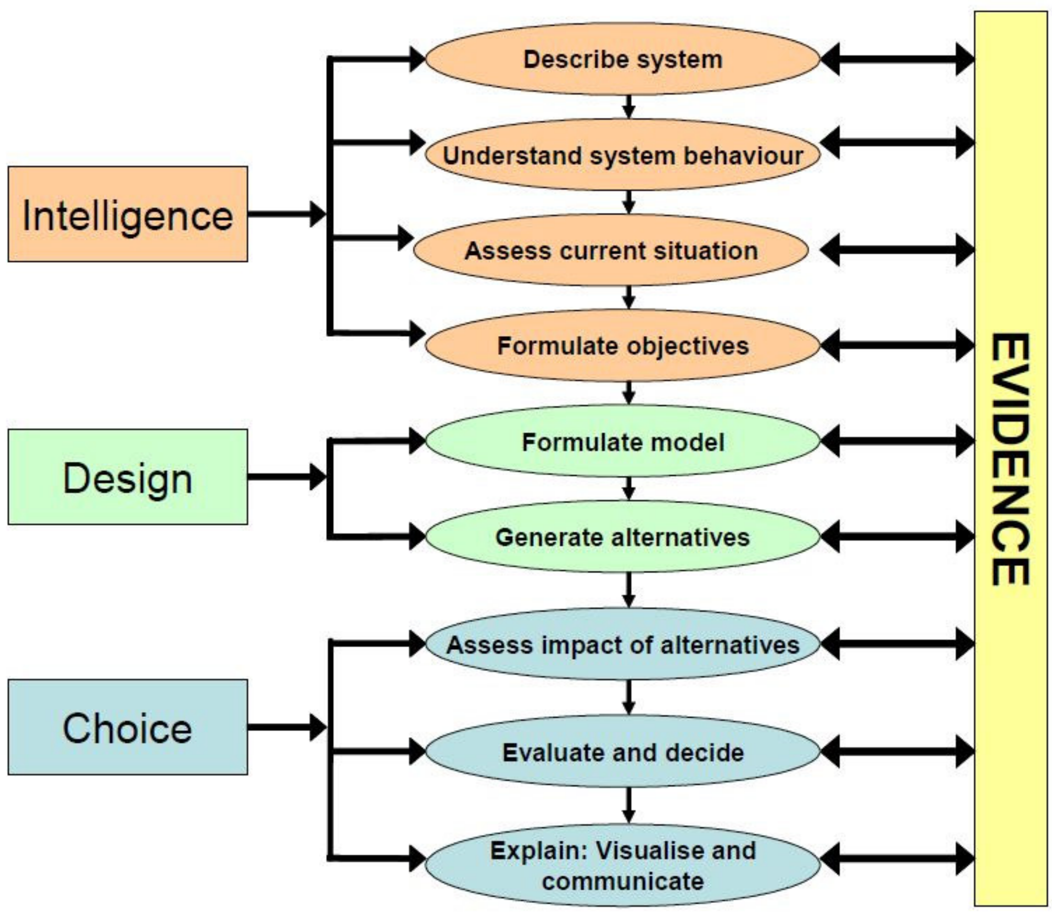


Figure 1 - Framework for a systematic approach to decision making (Sharifi et al 2004, based on Simon 1960)

This paper describes the application of geovisualisation techniques to facilitate participatory identification and structuring of problems in an urban water supply system in Uganda. Geovisualisation, which has been described as "making data visible", involves the use of visual geospatial displays to explore data, and through that exploration to generate hypotheses, develop problem solutions and construct knowledge (Kraak 2003). Within a decision-making context, geovisualisation offers the possibility for decision makers to analyse both the spatial and non-spatial aspects of a decision problem and how they interact, and use the insight so gained to formulate the right remedies.

Applied in the context of a water supply system, geovisualisation can serve as a tool to help unearth trends in data collected as part of daily technical and commercial operations, for use as a basis for planning and management decisions. Furthermore, it can assist in bringing to light the points of structural weakness in the physical system infrastructure, thereby enabling the pinpointing of "hotspots" requiring urgent attention. Bacic (2006) points out that in some situations, such information may be known but not adequately communicated to, or perceived by, the stakeholders who should decide on corrective action. Geovisualisation thus facilitates the development of appropriate remedial actions which are both well focused and easily justifiable before policy and decision makers. Moreover, it is said that a picture speaks a thousand words; issues that may not be easy for lay, non-technical persons to understand and appreciate may be made plain through geovisualisation, thus making it possible for involvement of a wide range of stakeholders in the decision making process.

According to Ekbia (2004), a key tenet of the problem-solving paradigm is its emphasis on mental representations (or symbols or models) of external situations. According to this view, people deal with the outside situations by building models thereof in their heads. All thinking (decision making) thus consists mainly of the manipulation of these internal models and symbols; problems are in the decision-makers' heads, as are solutions to these problems. An obvious disadvantage of this is the limitations, physiological and psychological, of the human brain. Authors as early as Miller (1956) have pointed out that the span of absolute judgment and the span of immediate memory impose severe limitations on the amount of information that we are able to receive, process, and remember. It would be unwise therefore, as an example relating to the context of this study, to uphold the prevalent practice of reliance on the "head knowledge" of a few veteran staff as the sole basis for decision making concerning operation of a complex water supply system.

Ekbia (ibid) proposes a shift of focus from the traditional view of problem solving in the head to the notion of dealing with problematic situations and of taking actions that would reduce the indeterminacy of those situations. Among other reasons, he suggests that starting from the external situation makes it more likely and easier for multiple decision makers to arrive at a common representation of the problem (as opposed to each having their own mental perception of the situation), which is a major step toward consensus. One practical implication of this is that any decision making process should involve a problem scoping phase. People often start with different understandings of a situation, and arriving at a common problem statement might indeed be a major step towards its solution. As Bacic (2006) observes, the use of spatial information can help integrate different views of different individuals and groups into common understanding of feasible solutions.

To ensure equity in decision making, it is widely recognized (Mostert, 2003; Giordano et al, 2004; Valkering et al, 2004) that there is a need to take different interests and views explicitly into account by allowing a diversity of stakeholders to participate in the planning process. This calls for the application of decision support tools that enhance the participation of both technocrats and non-technocrats in the decision process. However, Alter 2004 argues that decision support is not about tools per se, but rather, about making better decisions within work systems in organizations; in this respect, the common emphasis on features and benefits of Decision Support Systems (DSS) as technical artifacts rather than on how to improve decisional aspects of work systems in organizations may contribute to the frequently cited failure rates of technology-based DSS innovations. As such, decision support may best be provided through creation of a decision environment - a means of facilitating debate, dialogue and the search for solutions - which may or may not include a technical artifact called a DSS. Likewise, Pereira and Quintana (2002) point out that DSS are no longer viewed as the means to backup decisions but rather to initiate debates - representing a passage from DSS to TIDDD: Tools to Inform Debates, Dialogues & Deliberations.

According to Bryan (2003), human beings are adept at visualizing and interpreting low dimensional information, particularly when presented as maps; moreover, "…the integrated visualization and interpretation of the continuous spatial distribution of multivariate … parameters can be synergistic and provide information beyond that gained from single-parameter visualization". Li et al (2001) state that, in general, interpretation of data is much more intuitive if results from a DSS are translated into charts, maps and other graphical displays, because visualization exploits our natural ability to quickly recognise and understand visual patterns. In this respect, visual representations serve as powerful "vehicles of thinking" that help us extract useful information from complex, voluminous datasets. Lotov et al (2005) explain that the effectiveness of visualization is based on the fact that about one half of a human brain's neurons are associated with vision; thus, one can consider computer visualization of information as a direct method to increase understanding.

A Geographic Information System (GIS) may be described as a general purpose technology for handling spatial geographic data in digital format, with the ability to pre-process data into a form suitable for analysis, to support direct modelling and analysis, and to post-process results into a form suitable for graphical display. As Gonzalez (2002) points out, spatial analysis and visualization capabilities make GIS a suitable extension of learning about, and therefore, understanding our environment better. Different conceptions of the same space which are difficult to verbalize or externalize can be visualized using GIS; such insights may guide appropriate and concerted action. Gonzalez (ibid) states: "… the well-documented capabilities of GIS in integrating data from disparate sources, in spatial analysis, and visualization are very promising in reinforcing a joint-learning approach".

The project described in this paper sought to apply computer-aided geovisualisation techniques to the Kampala water supply system, with a view to elucidating the problem issues and concerns in the area. The aim of the project was to develop a set of maps and other geovisual aids for the area and use them to inform and guide a participatory process of formulating alternative courses of action. Participation was achieved through the establishment of a formal discussion forum within the company, bringing together both operations and support staff of the company in regular brainstorming and decision analysis sessions, thereby embedding structured decision making in the existing work processes of the organisation.

This paper is arranged as follows: Section 2 introduces the study area, describes the participatory problem scoping process, and outlines the steps followed in processing data that was used in the map production effort; Section 3 presents the maps that were produced and discusses the information depicted on the maps with regard to its usefulness in guiding the search for appropriate solutions. The paper concludes in Section 4 with some future perspectives on the role of geovisualisation as a tool for participatory spatial decision support within the Kampala water supply system, and the adoption of formal structured decision analysis within the company's work ethos.

2.0 Materials and Methods

2.1 The Study Area

The Kampala Water Supply Service Area (KWSSA) is one of nineteen geographical units (towns) managed by the National Water and Sewerage Corporation (NWSC) in Uganda (Figure

2). The KWSSA water supply network serves an area of approximately 450 square kilometres, and consists of three water treatment plants, five primary reservoirs, eight secondary reservoirs, and about 1,500km of distribution mains (excluding service connections). It is the sole source of piped water supply for Kampala, the capital city of Uganda.

Figure 2 - Map of Uganda showing towns served by NWSC, including Kampala

The city of Kampala has experienced rapid growth over the last twenty years. Numerous hitherto sparsely populated areas have developed into dense suburban residential neighbourhoods, and industries, commercial structures and institutional facilities like schools have also proliferated. Not surprisingly, as population has increased - Uganda currently has the second highest population growth rate in the world (UNFPA 2007) - and income levels improved, the demand for water has multiplied.

To meet this demand, the city's piped water network has been extended beyond the administrative boundary of Kampala district, to cover significant portions of the adjoining districts of Wakiso and Mukono (Figure 3). Because of the capital-intensive nature of water supply infrastructure development, most parts of the network have been constructed under diverse projects, funded by grants from different sources (World Bank, EU, KfW, the Austrian Government, etc) and executed by several different agencies. Also, community and local government initiatives have resulted in several disparate network expansions and intensifications at the community scale. Most of these have been haphazard and uncoordinated, their implementation driven by political rather than engineering considerations. In more recent years, funds generated locally from water sales profits by the company have also been used to expand the network. Finally, significant extensions to the network by private individuals and institutions have also been made over the years.

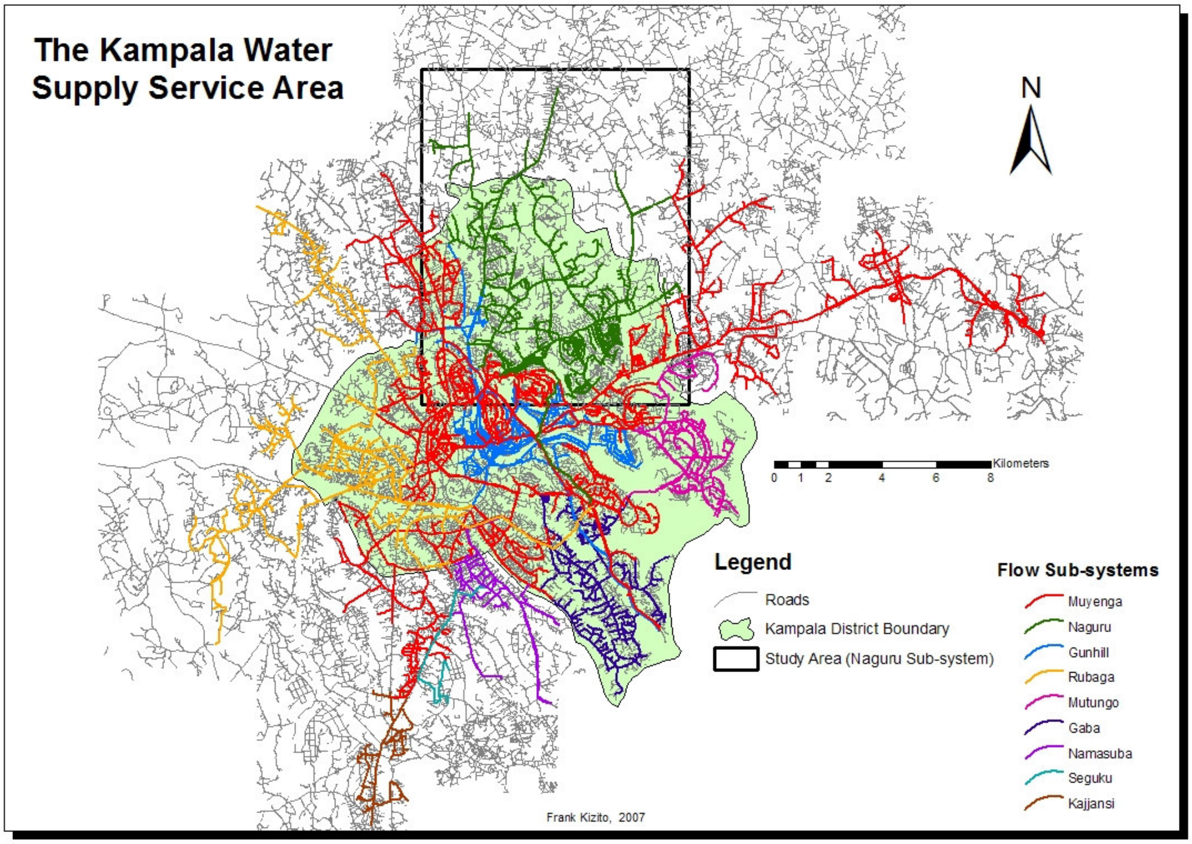


Figure 3 - The Kampala water distribution network, which now extends well beyond the district administrative boundary. Also shown is the area selected for this study.

The result is a network that is not optimised from a hydraulic and engineering point of view. It has increasingly become evident to the water company that there is an urgent need to implement measures to cope with the increased demand on the physical system infrastructure. Of particular concern is the undesirable occurrence of supply intermittence ("dry zones") in some areas and the effect of this on revenue and on customer satisfaction, the latter manifesting in increased outcry by sections of the affected public expressed through phone calls to the company Call Centre and letters published in the print media.

2.2 Understanding System Behaviour

The functional and structural relationships among system elements may be described as follows. In order to match the ever-growing demand for water supply and serve hitherto unsupplied areas, it becomes necessary to expand the water supply infrastructure. However, a piped water network is an interconnected hydraulic system for which changes in one part affect performance in other parts of the system. Likewise, the sizing of individual components of the system depends both on the local demand and the requirement to provide sufficient carrying capacity to serve locations further "downstream". All this calls for careful, holistic planning and design of network extensions.

Furthermore, being the sole provider of piped water in the city, the company is under a social obligation to provide water to all sections of the society. This obligation is often leveraged by local politicians, who rightly see water as a driver for development of the areas they represent, and who therefore successfully lobby for funds for the extension of services to these areas, irrespective of the hydraulic limitations. And, as the saying goes, “He who pays the piper calls the tune”.

An attempt is made here to apply the “DPSIR” framework (EEA 1999; Figure 4) to establish the cause-effect relationships at play in the system:

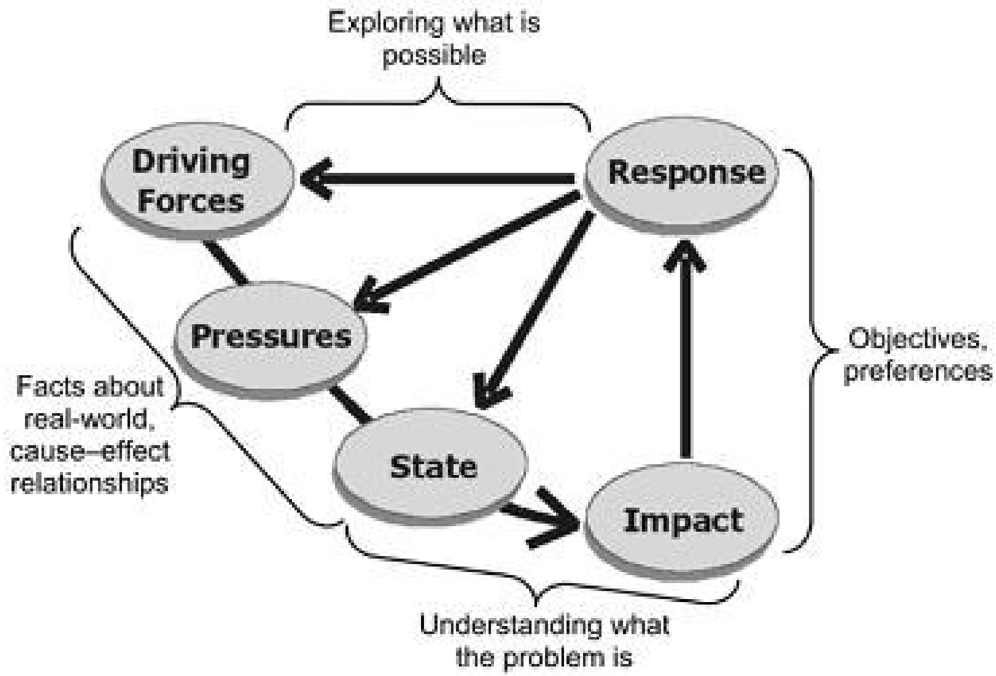


Figure 4 - Components of the DPSIR framework (Mysiak et al, 2005; based on EEA 1999)

Driving Forces: Ever-increasing water demand over the years, due to high population growth rate, a boom in the construction industry, rapid city-suburban sprawl, and improved income levels; Demands for service provision by politicians representing un-served areas.

Pressures: Unplanned, uncoordinated and haphazard expansion of the water supply network, by many players, both professional and unprofessional.

State: A network that is hydraulically unable to satisfy the increased demand placed upon it.

Impact: Decline in service levels, from 24 hour supply to supply intermittence in some areas; Frequent pipe breakages due to poor workmanship of unprofessional construction workers; Inability to extend water supply to parts of the city that are currently un-served.

Response: Identification and generation of alternative courses of action to mitigate the pressures and/or change the state described above, thereby enabling the company to cope better with the driving forces.

2.3 Participatory Problem Structuring

In recognition of the pressing need to tackle the problems facing the network, it was found necessary to bring key players together in brainstorming sessions to develop a common understanding of the nature and causes of the problem and formulate alternative courses of action. To do this, a novel approach was taken. This involved the creation, within the company, of a Technical Think Tank – or T-Cube, as it became known – consisting of engineers, technical supervisors, field staff and other staff involved in various aspects of direct and indirect relevance to the issues at hand. Box 1 illustrates the motive behind the establishment of T-Cube.

> Welcome to TECHNICAL THINK TANK (T-Cube), Kampala Water's forum for participatory problem structuring and decision analysis of technical issues!
>
> As engineers and technicians in Kampala Water, we have a big problem. While NWSC in general and KW in particular have made major achievements on the commercial and customer care front, there is a question that is rather annoyingly becoming more frequently asked by the public out there:
>
> **"Are there engineers in NWSC?!?"**
>
> Of course, the reasons for this are plain: We are plagued with a network that seems to worsen every day, with dry zones spreading like a cancer. And as long as people out there have no water, we really have no business being here.
>
> T-Cube is a new forum for us to put our heads together and ask ourselves some hard questions. What is the real problem? What can be done to resolve it/them, in the short and intermediate term? What alternative courses of action exist? How can we evaluate our alternatives and identify the most effective solution? Most importantly, how can we justify the "best" solution to the decision and policy makers in Kampala Water?

Box 1 - Contents of flyer distributed to T-Cube members at its maiden session

At its inception, T-Cube was introduced as "a new forum for supporting the formal structuring and analysis of technical problems, by making use of all available data, tools and techniques, and promoting decision making characterised by participation and dialogue". Members agreed that most of the problems being experienced were technical in nature, and thus the key goal of the Think Tank would be to generate practical technical solutions to these problems, in a manner that would render the solutions clearly justifiable to the decision makers. Accordingly, the specific objectives of T-Cube were formulated as follows:

- To collectively identify technical problem issues affecting the KWSSA network.
- To collectively define the scope of the identified problems.
- To formulate solutions to these issues in a structured manner.
- To actively spearhead the implementation of the solutions.

As a first activity during its maiden session, T-Cube members undertook a preliminary scoping analysis, during which issues were identified, clustered and prioritised for discussion. Box 2 presents the issues and clusters that were identified.

Cluster 1 • Lack of motivation of technical staff. • Emphasis on commercial activities at the expense of technical ones.	**Cluster 4** • Poor planning of network infrastructure. • Lack of feasibility analyses prior to implementing new connections.
Cluster 2 • Water supply imbalance (failure to supply water). • Transmission and distribution bottlenecks (dry zones, booster requirements, wrongly sized pipes, aged pipes etc). • Uncoordinated "troop" movements. • Inadequate documentation of the network. • Insufficient storage.	**Cluster 5** • Lack of coordination between KW and road contractors & other utilities. **Cluster 6** • Bureaucratic bottlenecks in accessing materials requisitioned for. • Limited availability of transport for emergency work.
Cluster 3 • Lack of a formal meter management framework. • Insufficient network fixtures. • Faulty network fittings (inaccuracy of bulkmeters, inaccessible valves and washouts, etc). • Competence and training of technical staff (map reading etc).	**Cluster 7** • Insufficient sewerage infrastructure.

Box 2 - Clustering of problem issues facing the Kampala Water network, as done by T-Cube members during its maiden session

Notwithstanding the order of prioritisation reflected in the cluster numbering in Box 2, it was agreed that a start be made with Cluster 2 problems. In particular, the T-Cube members zeroed in on a portion of the KWSSA system hereafter referred to as the Naguru sub-system, consisting of the extents of the piped network forming the transmission, storage and distribution sub-system for the Naguru storage tank, a 4,000 cubic meter tank supplying the north-eastern part of the city (Figure 3; see also Appendix 1). This area was selected for special attention because it presented the most pressing challenges at the time regarding both transmission and distribution of water, and had registered a significant share of complaints relating to water supply anomalies in the recent past (Appendix 2).

Subsequent sessions of T-Cube systematically appraised the water supply situation for the Naguru sub-system and identified a number of tasks required in order to understand it fully. Some of the tasks are listed in Table 1, in the order in which they were identified and tackled. As shown, it was soon realised that a number of maps would help in problem elucidation and the search for solutions, and so a set of maps were developed as described in Section 2.4.

Issue	Task Identified	Initial Findings /Action Taken	Recommendations	Follow-up Actions /Findings
Insufficient volumes of water transferred from Muyenga tanks to Naguru tank	Analysis of outlet bulk meter readings for a period of 3 years for Muyenga and Naguru tanks	Members noted that the outflow leaving Naguru seemed to be more than what was supplied by Muyenga, which seemed to defy the laws of conservation of mass (flow conservation).	Calibrate the two bulk meters at the outflows of both Naguru and Muyenga.	Bulkmeters were inspected and serviced; however, they were not calibrated due to lack of equipment at the time.
	Field inspection of existing transmission line, guided by the network records (maps)	Reported that all air valves except one newly installed air valve were non-functional. Several valves were suspect. Muyenga interconnections were found to have no effect on the outflow to Naguru. It had been thought that the interconnections provided extra water to boost supply to Naguru. However, when the valves were closed to isolate Tank E, no significant change in outflow was noted. Muyenga attendants reported that there was always enough water in the Muyenga tanks.	Expedite the process of procurement and installation of air valves and the level marker for Naguru. Valve at Muyenga outflow to Naguru (V–438) to be tested (valve with 300 turns). Also study the layout at Muyenga to generate a situation analysis. Understand the merits and demerits of the existing configuration and propose alternative configuration.	Procurement process initiated. A report was given on the valve testing. It was found in good working order, closing and opening fully after about 245 turns. It was recommended that this be subjected to a detailed Consultancy study to propose a more appropriate pipe configuration.
	Assessment of new transmission mains solution proposed by Consultants	Hydraulic models were generated for the existing and proposed transmission options. From the simulations, a supply of 200 l/s would suffice for the demands of Naguru. Simulation of proposal 1 gave a supply of about 170l/s to Naguru.	Modeller requested to find out whether all proposals could be adjusted to supply 200 l/s. Modeller requested to simulate a scenario where 200 l/s was supplied from Muyenga to Naguru. Would the existing mains withstand the flows?	4 proposals were tested; only two were found feasible, that is, the inter-connection of 600 to 450 to 400, and the proposal to place an online pump near Naguru. The head-losses in the system do not allow for 200l/s to be transmitted from Muyenga to Naguru. According to the model, only 114l/s can be transmitted from Naguru

Issue	Task Identified	Initial Findings /Action Taken	Recommendations	Follow-up Actions /Findings
		The existing situation was also simulated and it indicated that the Naguru tank would be empty by midday.		to Muyenga from the existing infrastructure (DN400).
Hydraulic zoning of distribution network	T-Cube members resolved to undertake the generation of hydraulic supply zones for each of the KWSSA storage tanks, starting with the Naguru tank.	Criteria identified for the proposed supply zoning were: • Topography of the area • Hydraulic feasibility • Presence and comparison of alternative supply sources • Distribution of customers (demand distribution)	Topography: ***Generate contour maps that are colour-coded to indicate the areas that can and cannot be supplied.*** Hydraulic Feasibility: Establish a calibrated hydraulic model for the entire KWSSA network, and use it to study the distribution of pressure and flows Alternative supply sources: Identify areas traversed by pipes from different supply systems, and establish the comparative advantage of supply from each system. Distribution of Demand: ***Generate demand geo-visualisation maps, to clarify which areas place a greater demand on the system.***	Maps were generated based on elevations of areas that can be supplied by Muyenga, Gunhill and Naguru tanks. Using these maps, members identified that Kulambiro, Kanyanya, and Kalinabiri hilltops needed separate boosters and tanks. It was reported that model setup was progressing and the reconnaissance for calibration points was almost complete. Currently, a 200 ST from Muyenga is being used as an alternative supply route to Kyebando. No alternative sources were identified for the Kalinabiri and Kulambiro hill areas, save for Naguru. Supply from Gunhill was also to be considered for Gayaza road. Maps were created based on historical consumption records for the area. They highlighted pockets of concentrated high demand; however, these were few.
Historical network performance bottlenecks	Prepare information on problematic areas.	A number of locations were identified as having been problematic in the past.	Historical network failures: ***Generate maps of nature and distribution of customer complaints registered by the Call Centre.***	From these maps, it was evident which parts of the system were most affected by water shortages, and which parts were more prone to pipe breakages.

Table 1 - Some of the tasks identified and carried out by T-Cube members during the first three problem structuring sessions

2.4 Map Production

2.4.1 Creation of a Digital Landscape Model

The Kampala water supply system is largely a gravity flow system, and so terrain is an important factor to be considered in investigating performance of the system as a whole or a selected part of it. To gain a better appreciation of the local terrain conditions in the study area, it was considered useful to create an interactive, navigable Digital Landscape Model (DLM).

To do this, a layer of contour lines consisting of 3D polylines was extracted from 1:1000 scale AutoCAD topographic base maps that had been supplied to the water company by the Survey and Mapping Department of the government Ministry of Lands. The extracted layer of 3D polylines was subjected to interpolation using the ESRI ArcGIS 3DAnalyst Topo-to-Raster tool, resulting in creation of a raster Digital Elevation Model (DEM) at a grid spacing of 50m by 50m covering the entire study area. This raster layer was added to ESRI ArcScene and its base height and vertical exaggeration settings appropriately adjusted to enhance visualisation. Layers representing roads, houses, water mains, house connections and features such as trees, fences, fields and farms were added to the scene, their base height settings were adjusted in order to drape them over the DEM earlier created, and appropriate colours and symbology were applied.

The result was the DLM illustrated in Figure 5. Using ArcScene, it was then possible for the T-Cube members to view and interactively explore the terrain from different angles and at different zoom magnifications.

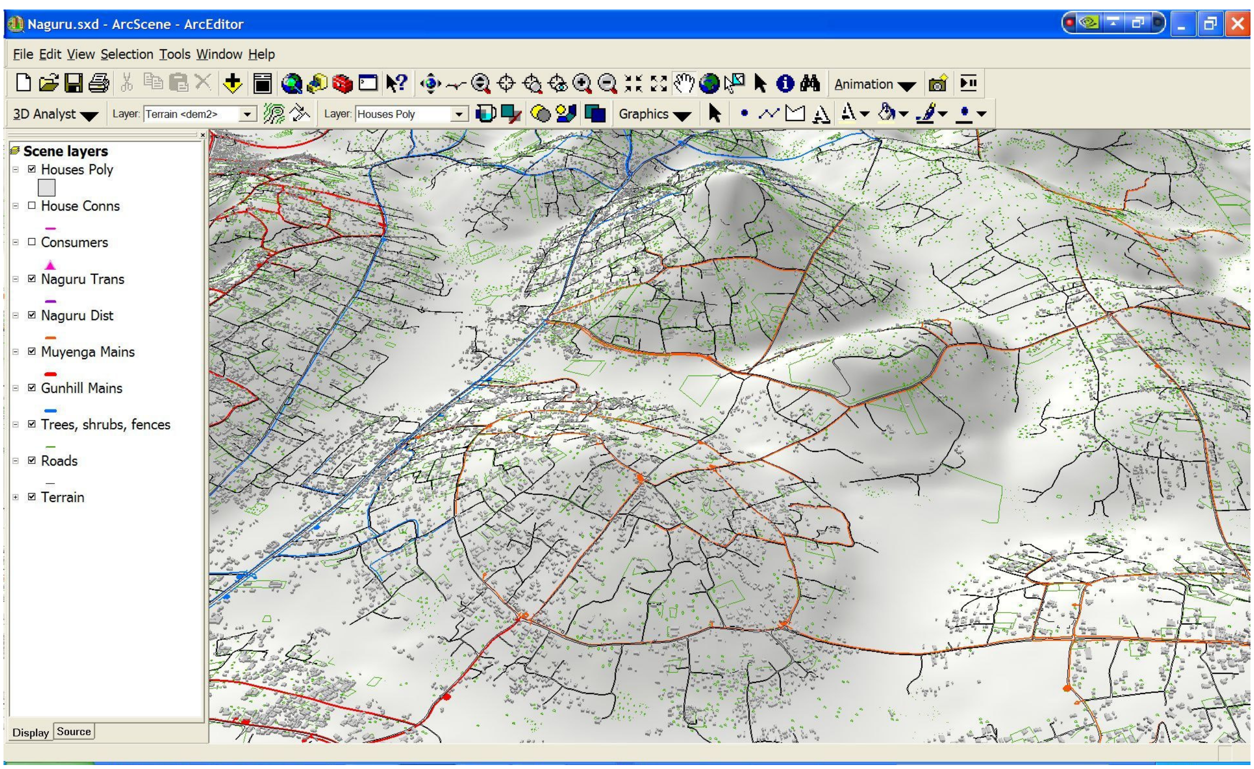


Figure 5 - A portion of the Digital Landscape Model of the study area

2.4.2 Other Derived Maps

It was considered useful to plot the distribution of water connections in the study area, as a means of visualising the extent and density of service coverage. Furthermore, from historical consumption records it would be possible to understand how consumption (and implicitly, demand) varied at different locations in the area. Data on customer complaints would help pinpoint the locations of physical weaknesses in the system infrastructure, while the DEM and the elevation data contained therein would facilitate correlation of hydraulic system performance with the terrain conditions.

Accordingly, in addition to the DLM, a number of maps were produced:

- A dot map showing location and spread of service connections;
- A proportional symbol and graduated colour map of average water consumption;
- A nominal point map showing nature and distribution of customer complaints;
- A graduated hue elevation difference map depicting areas that could be supplied by gravity from the various storage tanks.

2.4.2.1 Base Maps

For all the maps, layers representing houses, roads, water mains and blockmap frames were extracted from AutoCAD drawings maintained by the company, and added to ArcGIS's ArcMAP as base layers. (A blockmap is a mapping unit used by the water company, and corresponds to a square geographical area of 500m by 500m; there are about 2,500 blockmaps that cover the entire water supply system).

2.4.2.2 Connection Location and Density Map

To create a dot map of connection locations, property references from the AutoCAD drawings were added to the base map. Property references consist of block insertions containing a "propref" attribute which is a string of the form "#/??/#" (e.g. 11/22/42). The first two parts of the string ("11/22") identifies the specific blockmap (1122) where the customer is located, while the third part ("42") is the specific number assigned to the customer's house on that particular blockmap (Figure 6).

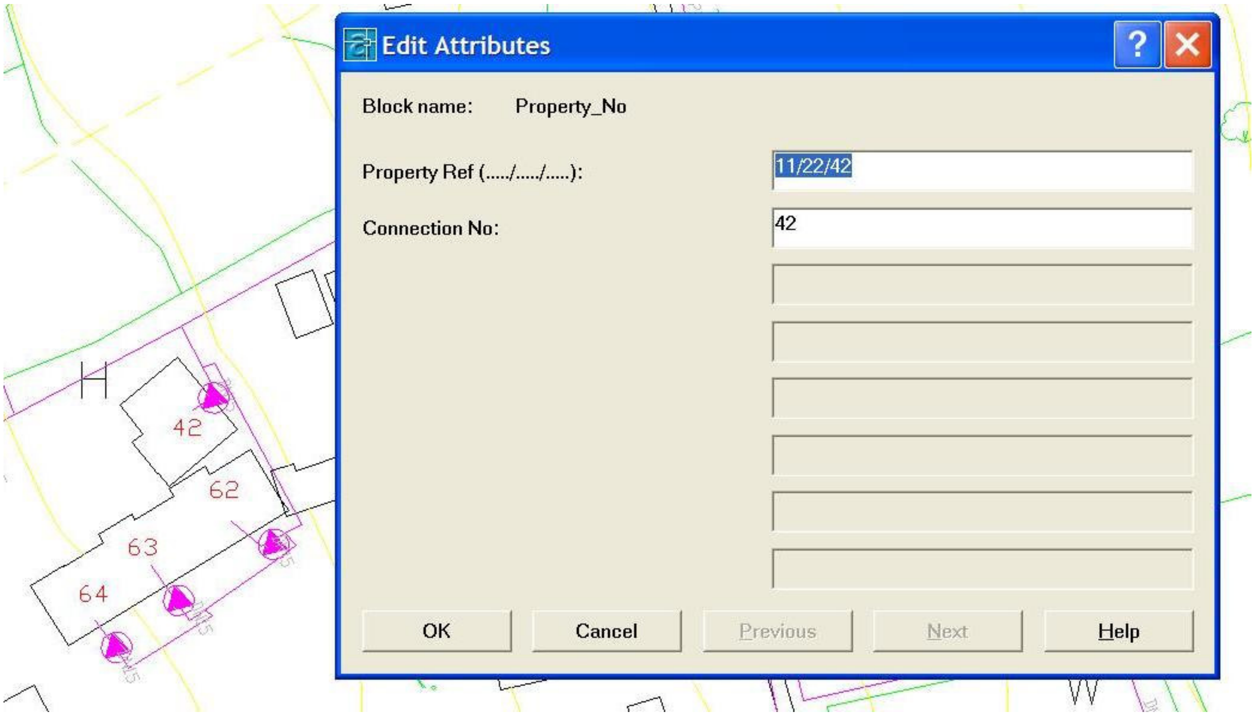


Figure 6 - Block insertions ("proprefs") used to geo-reference customer locations in the AutoCAD dwg files.

The property reference serves as a unique spatial identifier for each customer in the system, and within the AutoCAD drawings these block inserts are made in the actual geo-referenced locations of the customer premises. Thus, this layer was simply added to the base map in ArcMAP as a point overlay, and the points were assigned a single uniformly sized symbol. The resultant map is shown below in Figure 13 (Section 3).

Additionally, the propref attributes, together with their x,y location coordinates, were extracted from AutoCAD into an ASCII comma delimited table using the AutoCAD EATTEXT command. These extracted propref attributes were later processed in Microsoft ACCESS (Figure 7) and used in the production of the other maps as described below.

Branch 5 Propref coordinates : Table

Block Name	PROPREF	CONNNO	X-Coord	Y-Coord
Property_No	15/25/112	112	456350	38968
Property_No	15/25/97	97	456263	38944
Property_No	15/25/129	129	456234	38953
Property_No	15/25/128	128	456229	38956
Property_No	15/25/98	98	456252	38972
Property_No	15/25/127	127	456226	38951
Property_No	15/25/126	126	456219	38951
Property_No	15/25/122	122	456211	38953
Property_No	15/25/125	125	456208	38957
Property_No	15/25/26	26	456181	38969
Property_No	15/25/58	58	456167	38954
Property_No	15/25/18	18	456202	38920
Property_No	15/25/83	83	456304	38873
Property_No	15/25/67	67	456326	38827
Property_No	15/25/88	88	456339	38786
Property_No	15/25/114	114	456290	38783
Property_No	15/25/117	117	456285	38816
Property_No	15/25/119	119	456305	38741
Property_No	15/25/3	3	456250	38745
Property_No	15/25/65	65	456235	38780
Property_No	15/25/80	80	456193	38775
Property_No	15/25/76	76	456180	38802
Property_No	15/25/75	75	456194	38845
Property_No	15/25/66	66	456335	38731
Property_No	15/25/57	57	456311	38691

Record: 1 of 17409

Figure 7 - Property References, together with their spatial coordinates, extracted from AutoCAD

2.4.2.3 Demand Analysis Maps

The water company uses a core transaction processing and billing software system called CUSTIMA to maintain records on water billing and sales. This software is built on the PROGRESS database engine and runs on a Unixware platform. However, a subset of data from CUSTIMA is extracted daily into Microsoft ACCESS by means of an overnight process employing FTP, ODBC and SQL data transfer and query protocols; this dataset is then made available to users in the various technical and commercial units to guide their daily operations.

Records contained in the derived ACCESS database and going back a period of six years were analysed. These consisted of monthly volumes of water billed for each customer connection, in cubic meters. Using the ACCESS Query by Example (QBE) interface, a crosstab query was applied to summarise the six-year monthly consumptions for customers located in the study area into average monthly consumption values. It was possible to do this for the specific area under study because the billing database includes a field containing the property references (geocodes) that link customers to their actual geographical locations. Figure 8 illustrates the resultant dataset, with some fields (customer names and addresses) removed for reasons of privacy.

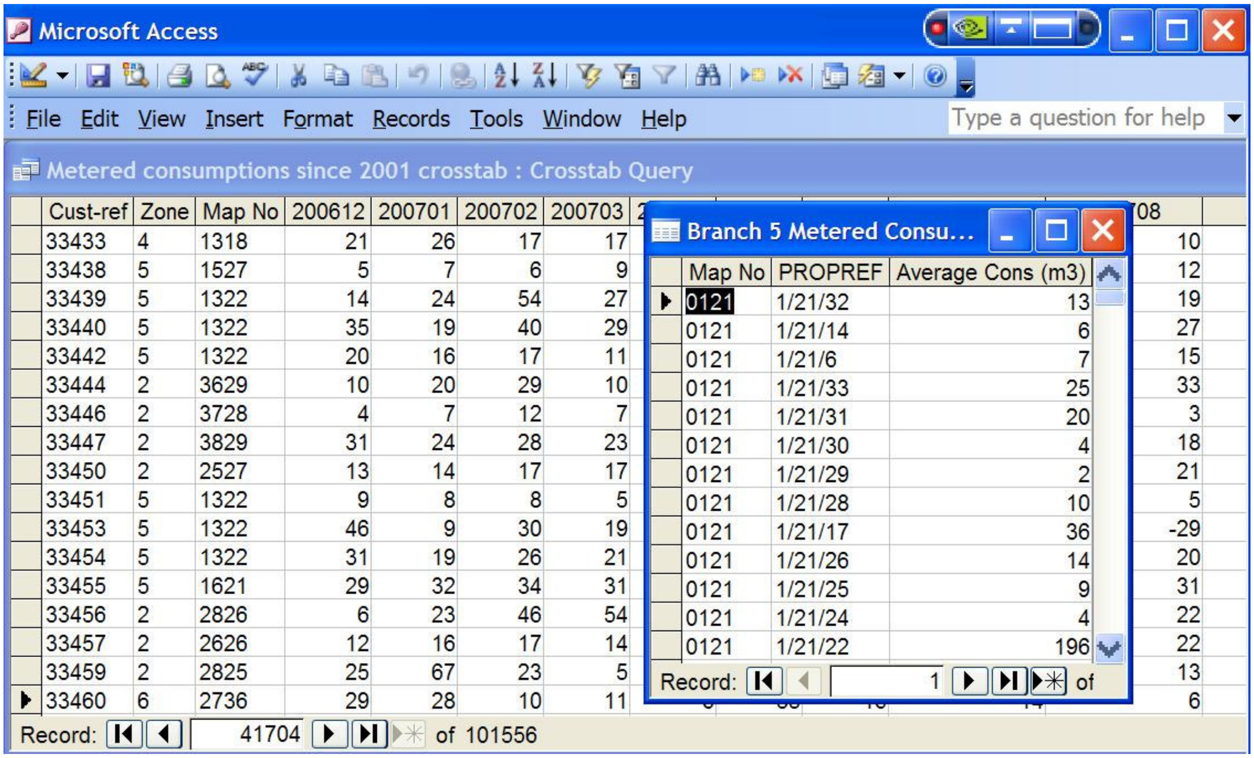
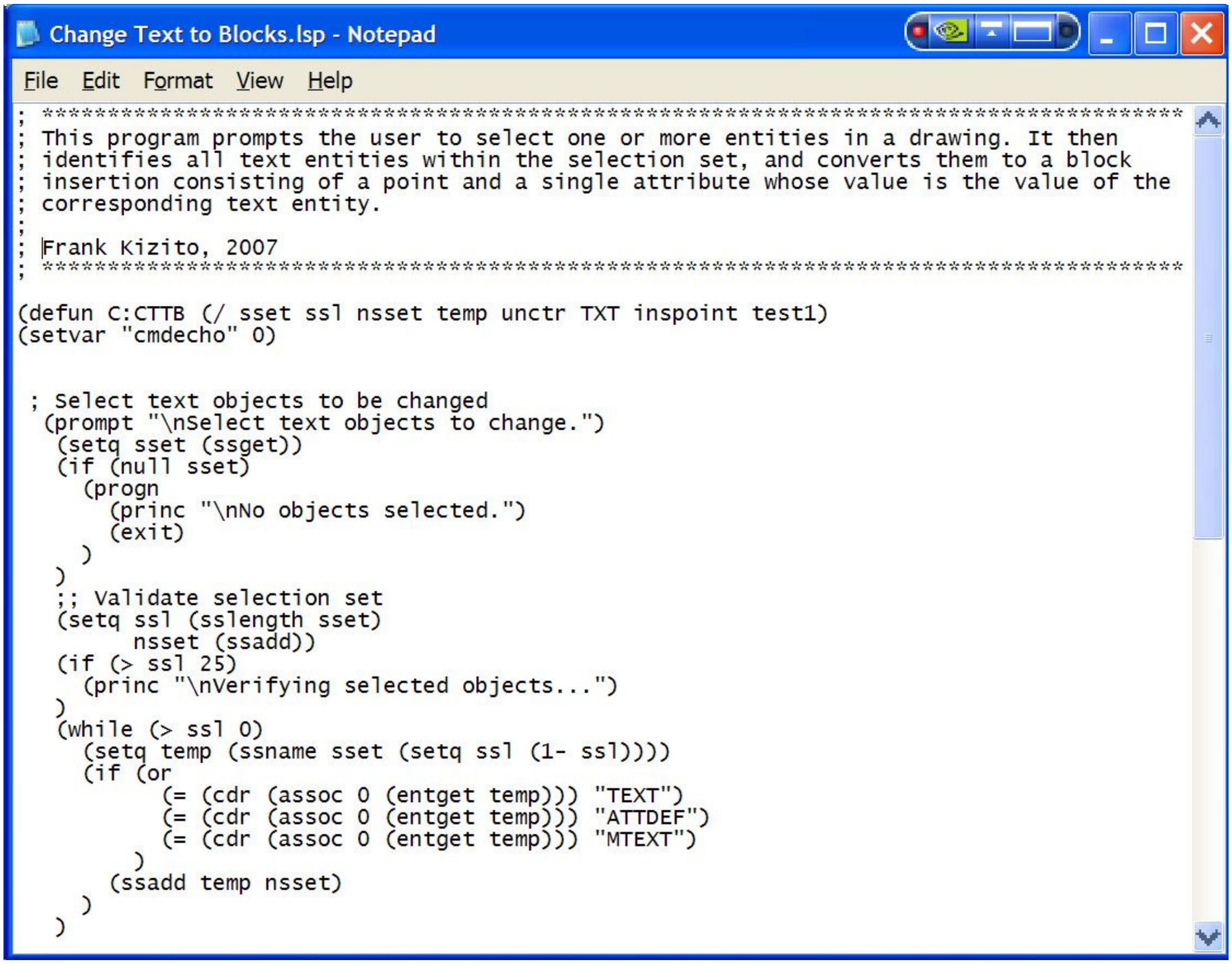


Figure 8 - Cross-tabulation of historical monthly metered consumption records using Microsoft ACCESS Query-by-Example. Inset: Data averaged for each customer in the study area.

This data was linked with the table of propref coordinates extracted earlier and used to generate a raster dataset of average monthly consumption, using the 3DAnalyst Topo-to-Raster tool. The resultant raster dataset was added to ArcMap as a layer and symbolised using a classified hue scale, with manually specified class boundaries.

To create a proportional symbol layer showing the distribution of average water consumption values, it was first necessary to create a new point layer with a single point for each blockmap in the study area. This was done in AutoCAD by generating, for each blockmap frame, a block insertion with a single attribute containing the blockmap number as a value. To do this, suitable code was written in AutoLISP (AutoCAD's programming language). Excerpts of the code are illustrated in Figure 9. The full code is appended to this paper (Appendix 3).




```
; ****************************************************************************************
; This program prompts the user to select one or more entities in a drawing. It then
; identifies all text entities within the selection set, and converts them to a block
; insertion consisting of a point and a single attribute whose value is the value of the
; corresponding text entity.
;
; Frank Kizito, 2007
; ****************************************************************************************

(defun C:CTTB (/ sset ssl nsset temp unctr TXT inspoint test1)
(setvar "cmdecho" 0)


 ; Select text objects to be changed
  (prompt "\nSelect text objects to change.")
   (setq sset (ssget))
   (if (null sset)
     (progn
       (princ "\nNo objects selected.")
       (exit)
     )
   )
   ;; Validate selection set
   (setq ssl (sslength sset)
         nsset (ssadd))
   (if (> ssl 25)
     (princ "\nVerifying selected objects...")
   )
   (while (> ssl 0)
     (setq temp (ssname sset (setq ssl (1- ssl))))
     (if (or
           (= (cdr (assoc 0 (entget temp))) "TEXT")
           (= (cdr (assoc 0 (entget temp))) "ATTDEF")
           (= (cdr (assoc 0 (entget temp))) "MTEXT")
         )
       (ssadd temp nsset)
     )
   )
```

Figure 9 - Part of the AutoLISP code written to perform text-to-block conversions

The newly created point layer of Blockmap numbers was then added to the ArcMap basemap. A link was created between this layer and a dBASE 5 table created by exporting from ACCESS the table containing average consumption values, aggregated by blockmap. The point layer was then symbolised using graduated symbols (filled circles), with sizes determined by the aggregated values stored in the Average Consumption column of the linked dBASE 5 table. The resultant map is shown below in Figure 14.

2.4.2.4 Mapping of Customer Complaints

For about six years now, the company has operated a 24-hour Call Centre that receives calls from customers and other members of the public, logs them in a central database designed for the purpose (Figure 10), routes tasks to the concerned operational units, and provides feedback to the callers as appropriate. Both technical issues (leaks and bursts, sewer blockages and overflows, faulty meters, low pressures) and commercial issues (incorrect billing, stolen meters, disconnections and reconnections) are reported, logged and handled.

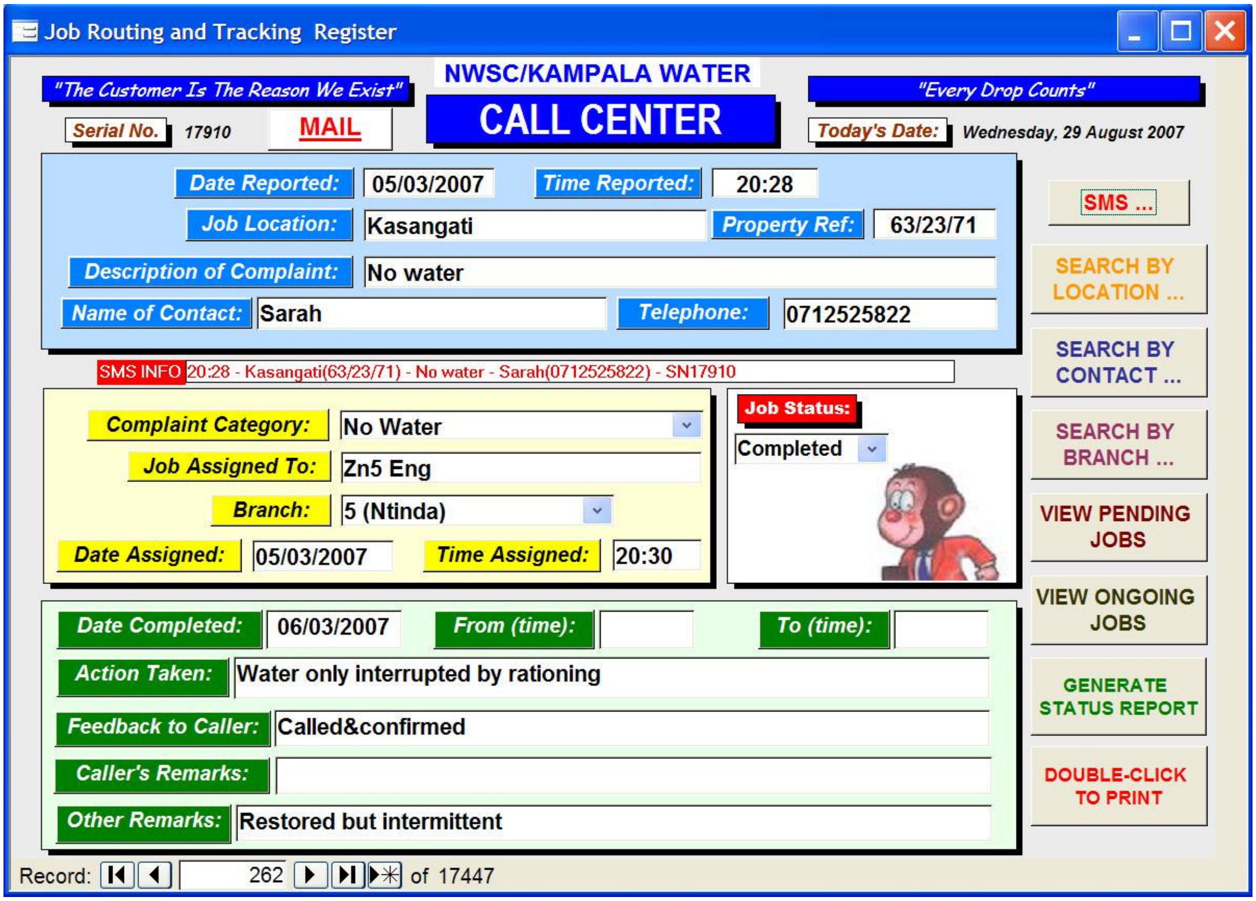


Figure 10 - Data entry interface for Microsoft ACCESS database designed to log and route customer complaints

For this study, telephone calls relating to the study area were extracted from the Call Centre database for the period July 2005 to December 2006, and were classified according to complaint category. The property references captured in these calls were then used to link the individual records to the relevant blockmap. The derived records are illustrated in Figure 11. Figure 12 shows the classification by complaint category for the entire city and for Namugongo, one of the problematic locations within the selected study area.

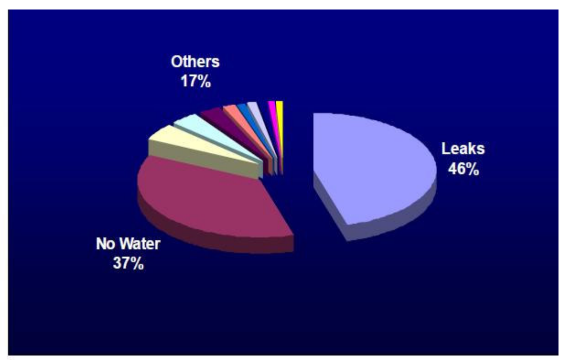
Microsoft Access - [Call Center Records (Leaks, No Water, Low Pressure) : Table]

File Edit View Insert Format Records Tools Window Help

Date Reported	Propref	Description of Complaint	Action Taken	Other Remarks
03/01/2007		Leak	Repaired	
03/01/2007	3/33/7	No water	Repaired	Intermittent water supply in the area,Lette
03/01/2007		No water	Restored	
03/01/2007	7/28/12	No water	Dry area	Advised Customer
03/01/2007		Leak	Repaired	
03/01/2007	30/23/52	No water	Restored	General low pressure in the area
03/01/2007		Leak	Controlled	Repair work by Friday 12/1/7
03/01/2007	3014/34	Leak	Repaired	
03/01/2007		Leak	Repaired	
03/01/2007	28/25/315	No water	Restored	General low pressure in the area
03/01/2007	9/25/112	No Water	General problem on ku	General problem ; effort being made
03/01/2007	10/6/88	No water	Restored	
03/01/2007	37/29/87	No water for 3 days	Restored	General problem
03/01/2007		Leak	Repaired	
03/01/2007	1237/39	No water	Restored	
03/01/2007	21/27/82	Leak at meter	Repaired	
03/01/2007		Broken pipe	Repaired	
03/01/2007		Pipe cut	Plugged the line	
03/01/2007	33/27/133	No water	Restored	
03/01/2007		Leak	Already registered	
02/01/2007		Leak	Repaired	
02/01/2007		Leak	Repaired	
02/01/2007		Leaks	Repaired 3 leaks	

Figure 11 - Records derived from the Call Centre database

CATEGORY	NO. OF CALLS	PERCENTAGE
Leaks on Service Connections	6044	45.5%
No Water	4860	36.6%
Sewage Overflow/Sewer Blockage	654	4.9%
Reconnection	452	3.4%
Bursts on Mains	388	2.9%
Low Pressure	230	1.7%
High Billing	147	1.1%
Stolen Meter	143	1.1%
New Connection Delay	137	1.0%
Faulty Meter	122	0.9%
Others	98	0.7%
TOTAL	13275	100.0%



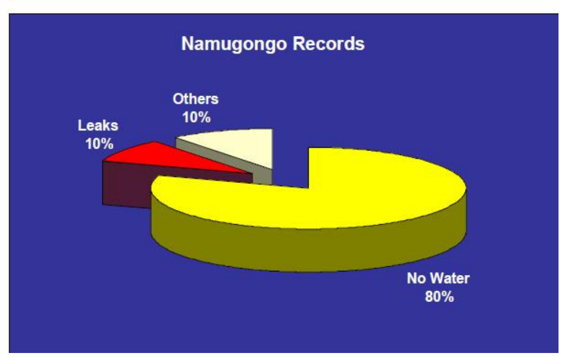


Figure 12 - Analysis of customer complaints relating to the entire city and to part of the study area.

To create a nominal point symbol map showing the location and nature of customer complaints, the point layer of property references was added to the ArcMAP basemap, and joined with a dBASE 5 table created by exporting the relevant table of Call Centre records from ACCESS. The point layer was then symbolised using nominal point symbols (different shape and colour) based on unique values from the Complaint Category column of the linked dBASE 5 table of Call Centre records. Figure 15 shows the resultant map.

2.4.2.5 Analysis of Elevation Constraints

The study area is traversed by pipes from three supply systems, namely Naguru, Muyenga and Gunhill. During the brainstorming sessions, it was considered useful to establish which of the other systems could act as alternative supply sources for the problematic spots currently supplied by the Naguru storage tank. All three being gravity systems, it was evident that a major determinant would be the relative elevations of the problem spots with respect to the ground elevations and top water levels of the three storage tanks.

To this end, a set of maps of elevation differences were created. For each supply system, a layer consisting of the DEM for the study area earlier derived was added to ArcMAP and symbolised using a graduated hue scale. Within this scale, the classification of elevations was subjected to an exclusion query, limiting display to those areas with elevations higher than a specified cut-off elevation. The cut-off elevation for each supply system was computed as the ground elevation for the corresponding storage tank, less 50m allowance for head losses within the system.

The three layers corresponding to each supply system were subsequently superimposed on each other in an appropriate order and overlaid on the base map of roads/water mains. From the resultant maps (Figures 16a to 16d), it was evident which areas could or could not be supplied by which storage tanks, based on elevation differences.

3.0 Results and Discussion

The four maps that were created are illustrated in Figures 13 to 16. Some of the information derived and conclusions drawn from discussing these maps during the T-Cube brainstorming sessions are included in the comments in Table 1, and are discussed below.

3.1 Topography

Using the map of elevation differences, T-Cube members identified areas such as Kulambiro, Kanyanya, and Kalinabiri hilltops that would require separate boosters and tanks to be installed in order to ensure adequate supply. Visually, this information was also made apparent by the DLM of the area.

3.2 Alternative Supply Sources

An existing 200mm steel pipe from Muyenga was identified as an alternative supply route for Kyebando area. No alternative sources were identified for the Kalinabiri and Kulambiro hill areas, save for Naguru tank (supply from the latter would require boosting however, as mentioned above). Supply from Gunhill storage tank was considered to be a viable alternative for parts of Gayaza Road.

3.3 Distribution of Demand

While not entirely valid, in this study historical consumption was considered appropriate for use as a surrogate for demand in the area. The derived map highlighted pockets of concentrated high demand; however, these were few. Overall, demand was found to be uniformly distributed over the study area.

3.4 Historical Network Failures

From the map showing the nature and distribution of customer complaints registered by the Call Centre, it was evident which parts of the system were most affected by water shortages, thus requiring directly targeted interventions, and which parts were prone to pipe breakages (hence being candidate for pipe replacement programmes).

3.5 Hydraulic Feasibility

In parallel to the map-production activities, a preliminary hydraulic model of the study area was established using WaterCAD modelling software. With this model, a number of existing and proposed network scenarios were tested, including alternative strategies for improving the transmission of water to Naguru tank.

3.6 Reflections on the Participatory Problem Structuring Process

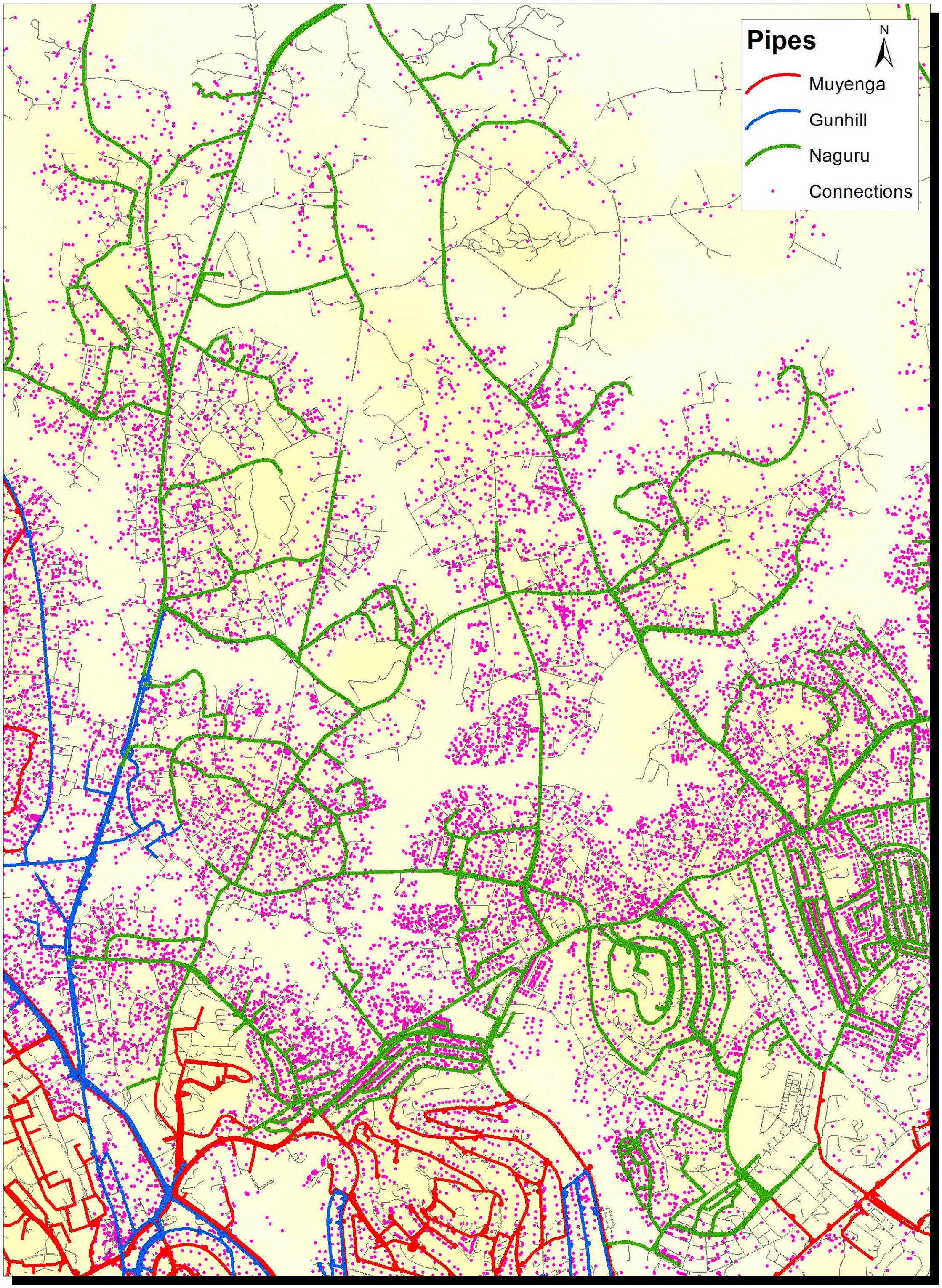
At the start of the study, a formal discussion forum was established, bringing together both operations and support staff of the company. It was hoped that this approach, involving the establishment of a participatory problem scoping and decision analysis environment backed up by appropriate decision support tools, would result in a more structured decision making process and represent a departure from the adhoc, “fire-fighting” approach that had hitherto characterised decision making for water network management in the company.

As it turned out, participation in T-Cube was limited to mostly technical first line and middle-management staff within the organization. The involvement of technical staff was because T-Cube was primarily established to tackle the technical operational problems that were apparent in the company, which stood in contrast to significant achievements the company had made on the commercial side of its operations. While a significant number of senior decision makers in the company (from the General Manager to various departmental heads) were engineers by training, they did not directly participate in T-Cube activities. This was due to the urgency with which decisions and actions were required of them in this particular situation, which did not lend itself well to the elaborate and time-consuming T-Cube analysis process.

As a result, a parallel decision making effort was undertaken by the senior decision makers together with other players (largely staff from the NWSC Head Office, who stepped in to intervene in the crisis situation). This led to the implementation of a number of hastily formulated interventions. These interventions did not immediately yield the desired effects, and had to be later followed by other remedial measures.

This further highlighted the need for a formal, rational, structured and comprehensive problem scoping process, yielding a good collective understanding of the problem situation and facilitating identification and evaluation of alternative courses of action prior to the implementation of appropriate remedial actions. It also emphasized the need to develop decision support tools within the organization to such a level that they would be able to provide ready answers for both routine and adhoc (often urgent) requirements. Whereas appropriate systems for data collection had been in place for some time, what was missing were tools to analyse this data and present the results in a form readily useful for decision making, and this was what the geovisualisation process sought to achieve.

LOCATION AND SPREAD OF HOUSE CONNECTIONS



Frank Kizito, 2007

Figure 13 - Dot map of house connections.

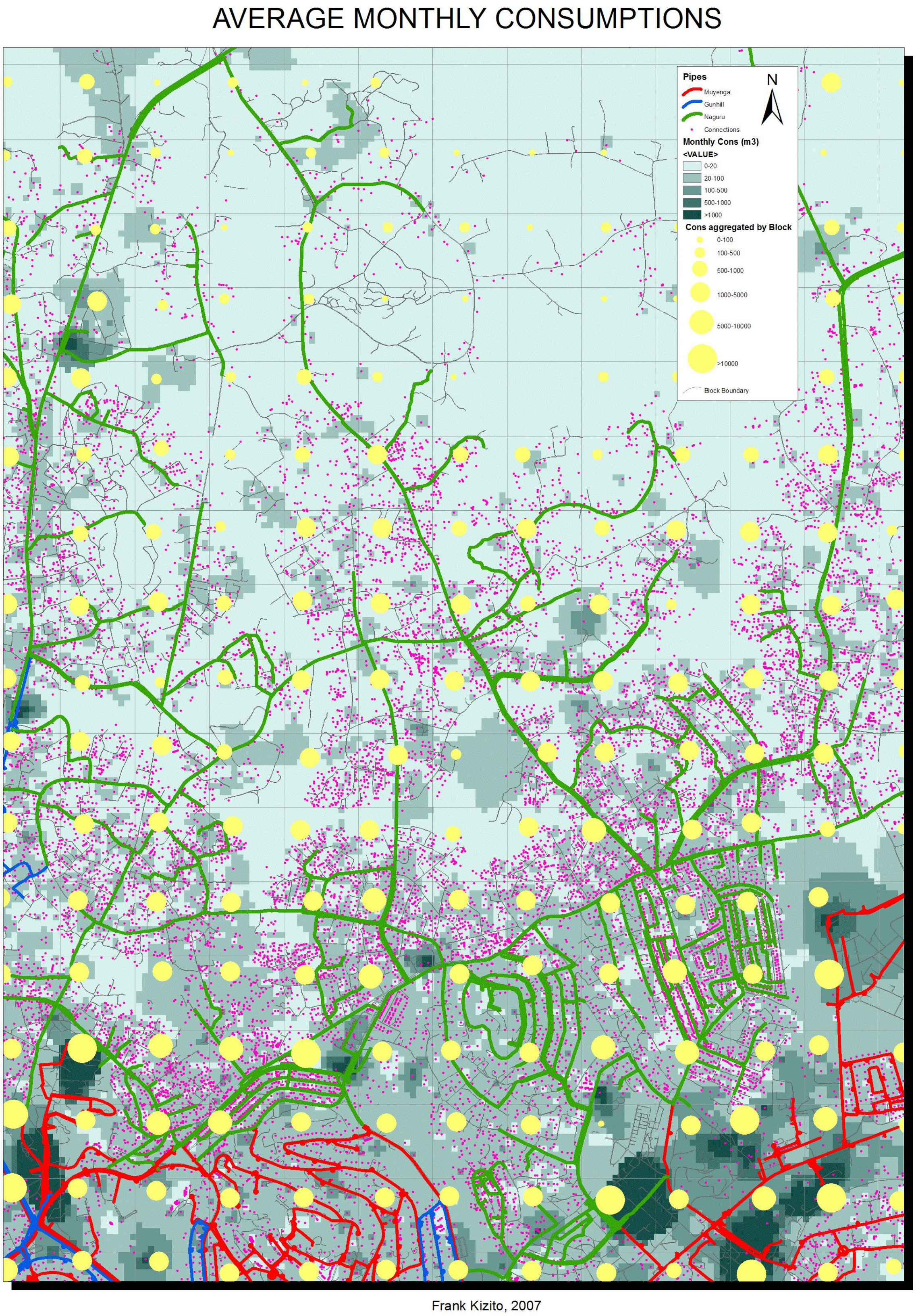


Figure 14 - Proportional symbol and graduated colour map of average monthly consumption.

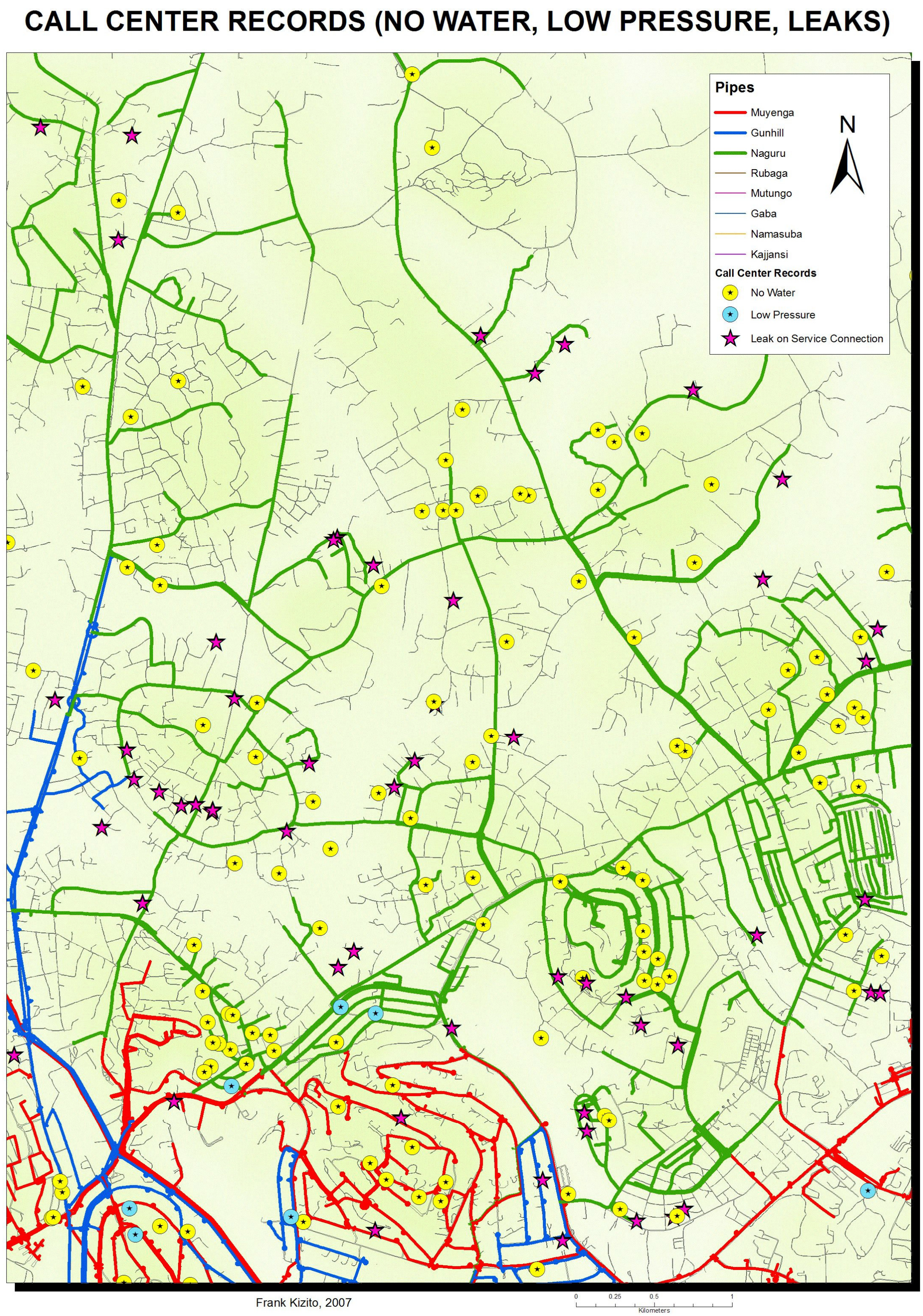


Figure 15 - Nominal point map of customer complaints (no water, low pressure, leaks).

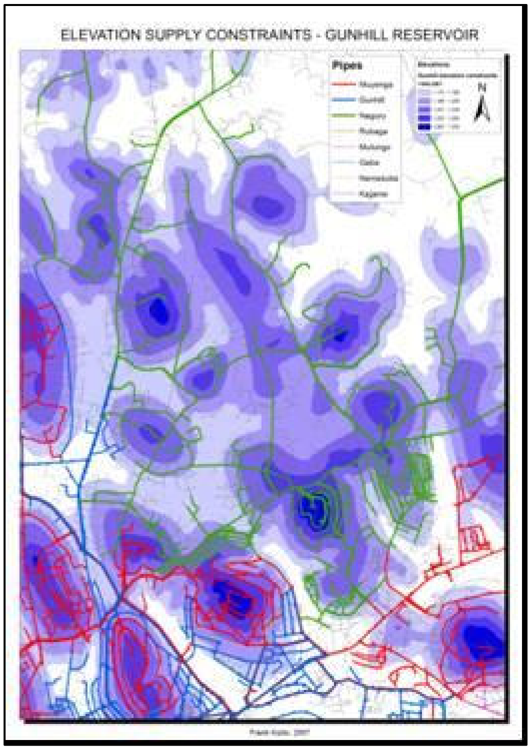


Figure 16a - Areas difficult to supply from Gunhill

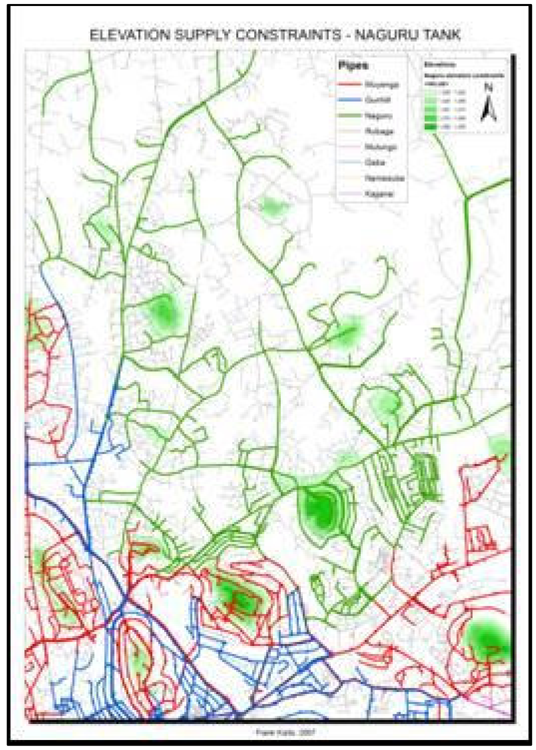


Figure 16b - Areas difficult to supply from Naguru

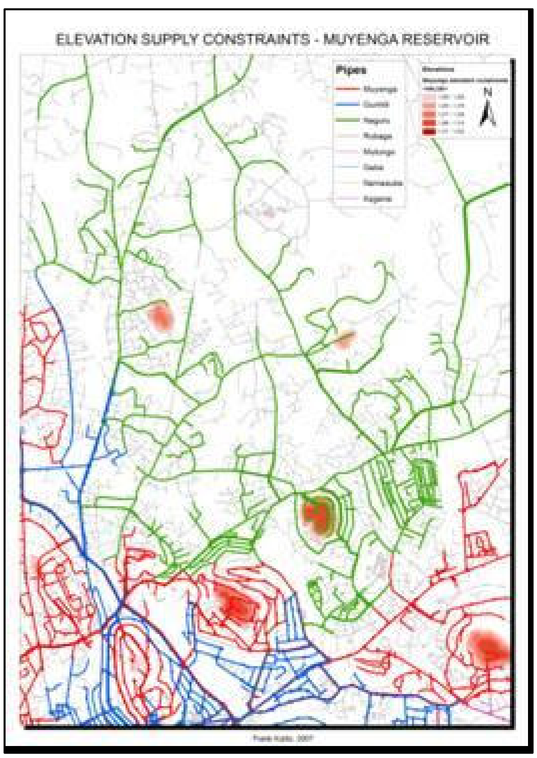


Figure 16c - Areas difficult to supply from Muyenga

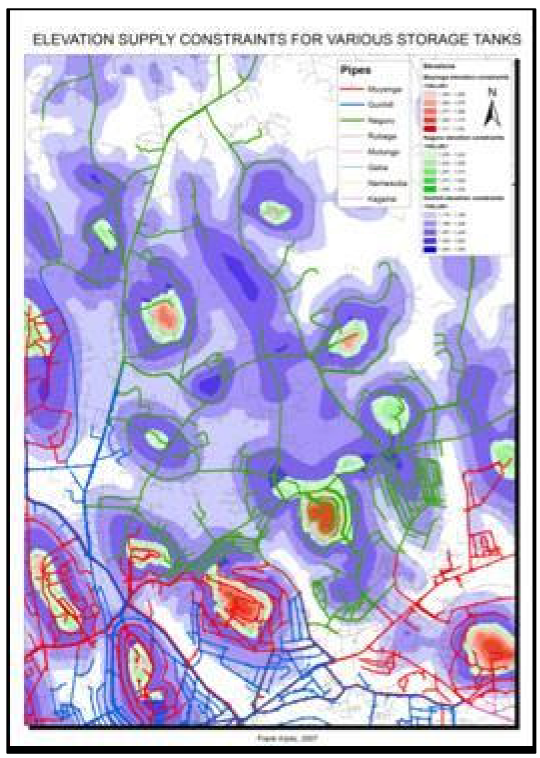


Figure 16d - Combined elevation constraint map

4.0 Conclusions

In this paper, a study involving the use of geovisualisation to support participatory problem structuring and decision making in an urban water utility in Uganda has been described. During the study, a number of maps were created. Information derivable from the maps highlighted such factors as which areas placed greater demand on the system from a water quantity point of view; which areas were yet un-served by the piped network; which specific portions of the network were prone to pipe breakages and water supply insufficiencies; which areas were candidate for transfer to different hydraulic supply zones, owing to limitations in elevation differences; which parts of the network were undersized, given the density of connections to them, and so on. Geovisualisation was thus demonstrated to be a useful tool in “making data visible” and supporting decision making in an urban water supply management context.

It is hoped that in future, the coupling of the geovisualisation tools with the existing operational databases in the company will result in the development of a functional spatial decision support system and a dynamic framework for system performance monitoring and reliability assessment. Getting managers to adopt the use of decision support systems, however, has been known to be problematic in the past. In this study, the author sought to develop the geovisualisation tools in participation with staff in the organization, and to apply these tools in solving a real-life problem, as one way of promoting the adoption of such tools and techniques within the company’s culture and practice. To some extent, this was achieved among the first line and middle management staff that were involved in T-Cube, the discussion forum that was established. Future activities will focus on seeing how the participation and commitment of senior managers and executive decision makers to the use of these tools may be improved.

darius muwanguzi/Kw/Nwsc/UG
06/06/2007 16:07

To	Ronald Kankya/Kw/Nwsc/UG@NWSC
cc	NwscUsers
bcc	
Subject	We are about there (Naguru)

History: This message has been replied to.

Good afternoon Sir,

It has taken me 2 days to realise that i'm not dreaming but actually facing facts. Yesterday, in my "sleep", i visited a number of **previously** disadvantaged areas of Bukoto, Naguru, Kiwatule, najjera, Kungu, Kyanja, and Kulambiro. These areas **previously** never saw water during the day. As i visited sampled accounts one by one in my dream, the tap owners didnot know that they had water until i opened their taps to assure them that they were receiving water during the day. As they rushed to pick their jerrycans, they insisted that it was a trick by us (NWSC) and that as soon as we leave the water will also disappear. Most customers insisted that we stay around until they fill atleast 2 jerrycans as they still thought we would disappear with the water. Account after account, it was all celebrations. Still in my dream, i found myself at Naguru at around 16:00 hrs and found that the level marker was in 2.2m-an impossibility for those of us used to the hitherto normal (Zero level) situation. Then ideas of the level marker not being standard begin coming from members. I go ahead in my dream to analyse the outflow figures from the reservoir and come up with an average of 14,000 units as compared to the usual 8,000 units. Still in my dream this morning i see the level at 4.6m and there is fear the reservoir may overflow. then people report more leakages than usual. As we set out to repair, i shake my head to confirm if i'm really asleep.........!

Guess what?

I realise i'm very awake and actually not dreaming but seeing reality.

Congs to the the team that has managed to make me dream even when i was awake.

Figure 17 - An email from the Branch Engineer responsible for the study area.

As a sort of epilogue to the paper, the reader may be interested to note that, through the combined efforts of both T-Cube members and other decision makers in the company, a lasting solution *was* found to the chronic supply problems facing the study area. Figure 17 illustrates this fact in form of a rather poetic email written by the Branch Engineer responsible for the area, himself an active member of T-Cube. A more formal report from the Branch Manager for the area is shown in Appendix 3.

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Appendix 1 - The study area in pictures

(Photos (a) - (d) by Roger Thunvik; Photos (e) and (f) taken from the NWSC KW archive)

(a) Naguru Storage Tank (4,000 cubic meters)

(b) Part of the Naguru supply area, viewed from the tank location.

(c) One of the sprawling city suburbs. In the background is Lake Victoria, the source of piped water for the city.

(d) Muyenga Tanks, the primary storage tanks from where water is transferred by gravity to Naguru Tank.

(e) Leaks and bursts, a frequent occurrence.

(f) Haphazard pipe laying has occurred in some places.

Appendix 2 - Excerpts from newspaper articles and letters from disgruntled customers within the study area

(Source: The New Vision Newspaper archives, http://newvision.co.ug/A/archive.php)

We have had no water for six months!

Tuesday, 30th May, 2006 — E-mail article — Print article

SIR — We residents of Namugongo (after the church) have had no water at all for the last six months.

The national Water and Sewarage Corporation (NWSC) keeps promising us that the problem will be solved but nothing happens! It is simply too much.

Why are we made to suffer like that yet we pay like other customers? If NWSC has no intentions of ever giving us water, we should be told the truth. But what makes us different from other customers, we wonder!

Name withheld

NWSC, help

Tuesday, 12th September, 2006 — E-mail article — Print article

SIR — The people of Kireka, Kamuli and Namugongo road up to Kyaliwajjala have been plagued with the problem of water shortage for almost half a year now.

We have used all means to try and store water but this is no longer helping us especially now that the problem is worsening.

The shortage which used to take two days now goes on for a precious four days! Please National water, help us out of this problem because we no longer have containers big enough to store water for up to four days.

Joseph Baalwa, Kireka

Three months, no water!

Sunday, 15th October, 2006 — E-mail article — Print article

SIR — I am frustrated by the National Water and Sewerage Corporation (NWSC). I have been reading regular reports on how well the company is now doing. However, such praises are not credible to the residents of Kasana Zone in kulambiro, Kisaasi. We have had dry taps for three months and we are still counting! Regular trips to NWSC at Ntinda have yielded nothing as we are told something about air valves and that the problem is being worked on! I request top NWSC managers to immediately look into this matter.

Toby Mutambo
Kulambiro

Appendix 3 - *AutoLISP* routine for text-to-block conversions

```
; ******************************************************************************************************************************
; This program prompts the user to select one or more entities in a drawing. It then identifies all text entities within the ;
;  selection set, and converts them to a block insertion consisting of a point and a single attribute whose value is the ;
;  value of the corresponding text entity.
; Frank Kizito, 2007
; ******************************************************************************************************************************
(defun C:CTTB (/ sset ssl nsset temp unctr TXT inspoint test1)
(setvar "cmdecho" 0)
 ; ****************************** Select text objects to be changed
  (prompt "\nSelect text objects to change.")
   (setq sset (ssget))
   (if (null sset)
     (progn
       (princ "\nNo objects selected.")
       (exit)
     )
   )
   ; ****************************** Validate selection set
   (setq ssl (sslength sset)
         nsset (ssadd))
   (if (> ssl 25)
     (princ "\nVerifying selected objects...")
   )
   (while (> ssl 0)
     (setq temp (ssname sset (setq ssl (1- ssl))))
     (if (or
           (= (cdr (assoc 0 (entget temp))) "TEXT")
           (= (cdr (assoc 0 (entget temp))) "ATTDEF")
           (= (cdr (assoc 0 (entget temp))) "MTEXT")
          )
       (ssadd temp nsset)
     )
    )
    (setq ssl (sslength nsset)
         sset nsset
         unctr 0
    )
    (print ssl)
    (princ "annotation objects found.")
 ; ******************************  Change current layer to TextBlock
    (setq test1 (tblsearch "layer" "TextBlock"))
      (if (= test1 nil)
        (command "layer" "n" "TextBlock" "c" "4" "TextBlock" "s" "TextBlock" "")
        (command "layer" "s" "TextBlock" "")
      );end if
 ; ******************************  Change text values to blocks
   (setvar "regenmode" 0)
   (setvar "attmode" 1)
   (setvar "attdia" 0)
   (setvar "pdmode" 1)
    (while (> ssl 0)
        (setq TXT (cdr(assoc 1(entget (ssname sset (setq ssl (1- ssl)))))))
        (setq inspoint (cdr(assoc 10(entget (ssname sset ssl)))))
       ;; Insert symbol
        (command "insert" "TxtBlock.dwg" inspoint  "" "" "" TXT)
    );end while
      (setq ss1 nil); Release variable from memory
   (setvar "regenmode" 1)
   (Princ)
) ;End CTTB
```

Appendix 4 - Report from branch manager, Branch 5 (the study area), following successful implementation of remedial actions to improve water supply in the area

(also included are illustrations of reservoir levels in the city before and after the interventions)

Naguru Reservoir Performance Analysis (5th June 2007)

General observations:

There has been a tremendous improvement in the water supply situation within the Branch. Recorded outflows from the reservoir per day are beginning to average 14,000m^3/day - a great improvement.

A visit to areas in Kungu, Najjera, Buwate, Kyanja, Kulambiro, Kiwatule and Kitetika revealed that customers who were previously not receiving water regularly were now receiving it.

It was found that customers who used to get water at awkward hours of the night once or twice a week were not even aware that water was actually flowing at their taps during the day. Customers in Kungu and lower Kulambiro were surprised when the Branch team opened their taps and water started flowing. (The main branch office is now receiving supply 24 hrs a day - a big surprise to many staff members.)

The Kiwatule-Kazinga area (1129) that previously got water after rationing (cutting off Naalya and Najjera) is receiving water with the whole network fully open.

Lower parts of Kalinabiri were also receiving water throughout the day. (The higher areas - due to hydraulic limitations and great demand - receive water on a rationing basis.)

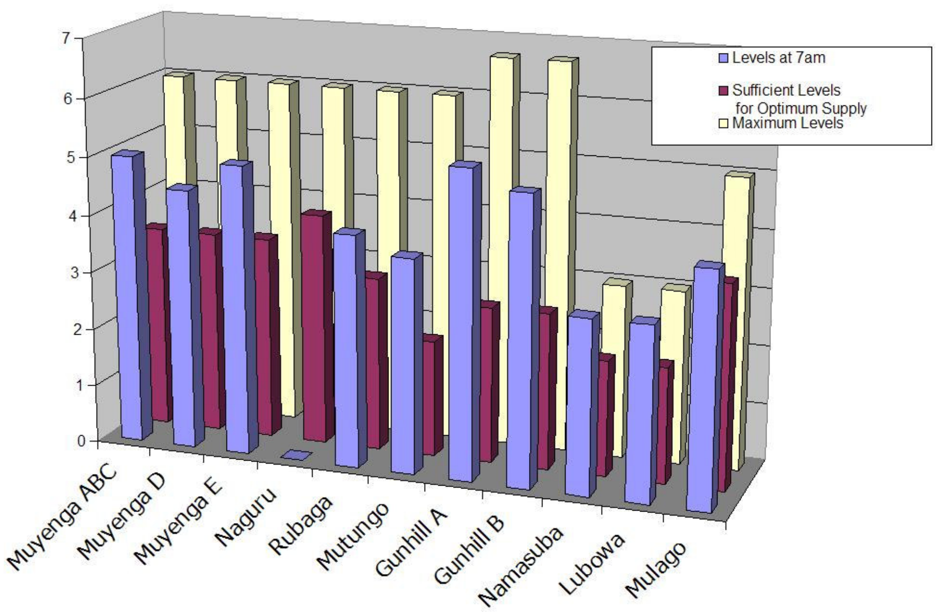
The top of Kulambiro hill (which is higher than the Naguru reservoir) still does not receive water. Intensifications will have to be done to reduce the area of the dry zone around the hill, and to also serve the surrounding growth area that stretches to Kyanja hill.

Challenges:

1. We need to maintain this 'momentum'; ensure the Naguru reservoir does not drain even with the outlet always open.
2. We need to address the issue of power outages at Gaba
3. Let us endeavour to deliver at least 18,000m^3/day to Naguru...we are going in the right direction.
4. We need to prepare Naguru to supply Namugongo and Kira...projected demand, heads achieved, etc...all need to be considered

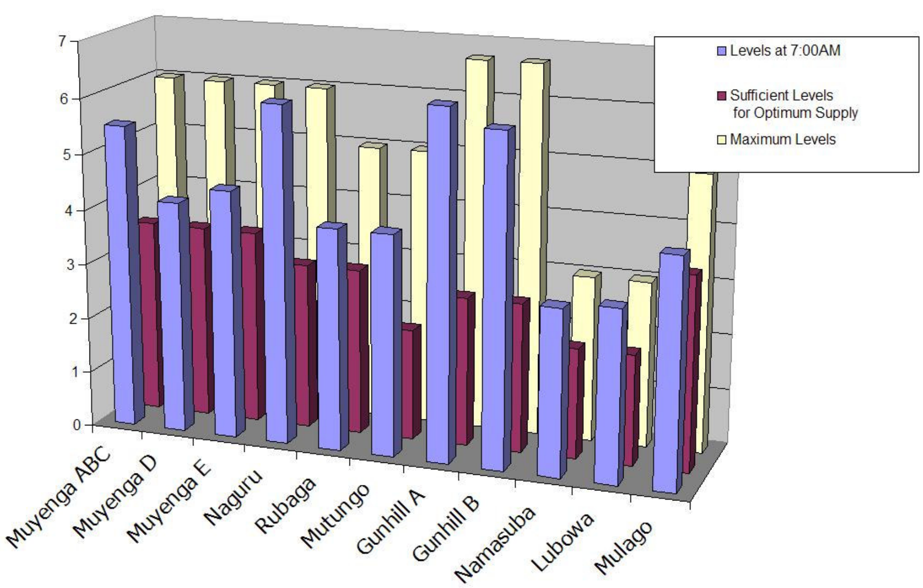
RESERVOIR LEVELS FOR 2-05-2007

(Conversion factor of 1m=3.3ft used for Gunhill Levels)



RESERVOIR LEVELS FOR 07-06-2007

(Conversion factor of 1m=3.3ft used for Gunhill Levels)



(note the bar representing the Naguru Tank)
