WATER SUPPLY MANAGEMENT IN AN URBAN UTILITY: A PROTOTYPE DECISION SUPPORT FRAMEWORK

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PhD Thesis

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DEDICATION

To Liz, Jerry and Mirembe
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This thesis is based on seven papers (appended), which are referred to throughout the text by their Roman numerals:


ABSTRACT
In this study, four real-life problem situations were used to explore the challenges of developing and implementing decision support tools for planning and management within an urban water utility. The study sought to explore how the degree of adoption of formal decision support tools in practice, generally perceived to be low, could be improved. In the study, an Action Research (AR) approach was used. AR is an inquiry process that involves partnership between researchers and practitioners for the purpose of addressing a real-life problem issue, while simultaneously generating scientific knowledge. Unlike other research methods where the researcher seeks to study organizational phenomena but not to change them, the action researcher attempts to create organizational change and simultaneously to study the process.

During the study, a number of prototype data management tools were developed. GIS-based spatial analysis and visualisation tools were extensively used to inform and enhance the processes of participatory problem identification and structuring, while a number of modelling tools were applied in the generation and evaluation of alternative solutions. As an outcome of the study, a prototype framework for the application of decision support tools within an urban water supply planning and management context was proposed.

The study highlighted the challenges of embedding formal decision support processes within existing work systems in organizations, and recommendations were made on how best to achieve this. The AR approach was found to be useful in bridging the gap between academic research and technological practice, supporting the development of computerised planning and decision support tools of practical benefit to organizations.

Key words: Decision support systems; Geographic information systems; Participatory planning; Urban water supply management; Decision support framework; Action research.

INTRODUCTION
In broad terms, Decision Support Systems (DSS) may be described as tools that an organization utilizes to support and enhance its decision making activities (Bhatt & Zavery, 2002). These tools often consist of computer applications that accept input of a large amount of data; assist in categorizing and organizing the data in a manner that enables retrieval in different forms; convert the data into meaningful comparisons, graphs and trends that can enhance decision-making; and assist in monitoring and tracking performance based on the organization’s goals and objectives.

A survey of literature on the state-of-the-art of DSS development reveals five aspects that provide a background basis and justification for this study. First, although DSS offer many benefits, studies have shown that they have not been widely taken up in practice (Lu et al., 2001; Westmacott, 2001; Lawrence et al., 2002; Mysiak et al., 2005; Borowski & Hare, 2007). A number of reasons have been advanced for this. These include the lack of user involvement in the development of tools; the technocratic and/or “black-box” nature of some tools; the proprietary nature and cost of acquisition and maintenance of tools; inappropriateness and irrelevance to “real” decision contexts; a mismatch between tools and problem-solving styles; a low degree of perceived usefulness and user-friendliness; mistrust of DSS outputs due to a lack of understanding of the underlying theories and processes; and a lack of field testing during the development of tools.

Second, DSS development was in the past dominated by a techno-centric viewpoint, but there is a growing school of thought that views DSS, not simply as technological tools, but rather as any context or platform for helping decision-makers to access the necessary information for a useful debate to take place (Pereira & Quintana, 2002; Alter, 2004; Ekbia, 2004). This represents a shift in focus from computerized DSS artifacts to decision support in general; that is, the use of any plausible computerized or non-computerized means for improving decision-making in an organization.
Third, regardless of whether DSS capabilities emphasize better data availability, analysis, modelling, communication or coordination, these capabilities have little or no impact until they are adopted and incorporated into work systems within organizations (Alter, 2004). Genuinely successful applications of DSS need to reflect the workflow of users and remain compatible to the users’ working environment (Smart & Whiting, 2001). To achieve this calls for application of a “contextual design” methodology - one that involves the gathering of information about users’ needs through a process of observing and working with users in their environment, within the context of their day-to-day activities, and using this information in the DSS design process.

Fourth, the classical decision-making paradigm recognises three distinct stages of a decision-making process: problem identification (Intelligence), development of alternative solutions (Design), and selection among alternatives (Choice). A lot of research has gone into developing formal evaluation methodologies to support the choice phase, and a plethora of these exist. Likewise, many different models and modelling tools have been developed in support of the design phase. However, comparatively little research has focused on problem identification and structuring in the past (Liu & Stewart, 2004; Sharifi et al., 2004), and yet it is evident that gaining a correct understanding of a problem situation from the outset is key to its effective solution.

Finally, it has been noted (Rasmussen, 2004; Brugher & Bowen, 2005; Styhre & Sundgren, 2005) that there are shortfalls in the traditional approaches to research in the technological sciences, with respect to their failure to effectively impact on practice and to support joint learning between academicians and practitioners. Action Research (AR), which involves partnership between academicians and practitioners for the purpose of resolving real-life problem situations within the practitioners’ social context, has been advocated as a suitable way of bridging this gap. Unlike other research methods where the researcher seeks to study organizational phenomena but not to change them, the action researcher attempts to create organizational change and simultaneously to study the process. In so doing, the researcher participates in joint knowledge production with the practitioners on an experimental basis.

This thesis describes a study in which an AR approach was used to explore how the degree of adoption of DSS in practice, generally perceived to be low, could be improved. In the study emphasis was placed, not on the creation of technical DSS artifacts within an academic environment, but rather on the promotion of participatory problem-structuring and decision-making processes within a real-life organization, and the provision of support for these processes through development of appropriate computerized tools. The study sought to understand the challenges of embedding decision support tools within existing work systems in organizations, and to identify how best to provide formal decision support as an enabling framework for organizational development.

**Research Objectives**

Being an action-oriented research undertaking, the overall objective of the study was to achieve improvement in decision-making within a real-life organization through the development and application of decision support tools. The specific objectives were:

- To elicit first-hand, through practical experience in a real-life organizational setting, what the causes were for the perceived low rate of adoption of DSS in practice;
- To propose practical ways in which the identified shortfalls could be overcome, with a view to achieving the effective embedding of holistic decision support mechanisms within the organization’s work systems and promoting continuous engagement in social learning processes;
- Using the knowledge gained, to develop and prototype simple computerized tools to support decision-making within the organization, through application of a contextual design methodology;
- To identify, study and further develop specific aspects of these decision support tools targeting enhancement of the prob-
proposed a suitable framework for the development and implementation of DSS for urban water utility management, appropriate to the local context.

Organisation of the Thesis
The thesis is based on seven papers, which are appended to the text. Paper I explores the theoretical and philosophical basis for the research approach employed in the study, namely Action Research (AR). It presents a case for the benefits of using AR in Information Systems development, and highlights some challenges inherent in this approach that are of particular relevance to the overall study objective.

Paper II describes four case studies in which an AR approach was used to gain first-hand insight into the process of developing and applying computerized tools to support various aspects of decentralized management of an urban water utility in Uganda. Each of the case studies has its own unique lessons to contribute to the understanding of the DSS development process as a whole. The four case studies involved: (i) participatory problem-structuring in the face of water distribution bottlenecks; (ii) formulation of strategies for water loss management; (iii) facilitation of decentralised customer account management; and (iv) budget implementation monitoring and cost control.

Paper III focuses on the first of these four case studies. In particular, this paper discusses the use of geovisualization in facilitating problem-structuring and decision-making for problems of a spatial nature. Paper IV, which also relates to the first case study, investigates the role of simulation modelling within decision processes.

In Paper V and Paper VI, the focus shifts to the second case study. Paper V describes the application of geostatistical modelling and spatial inference to water loss management. Here, again, the emphasis is on enhancing problem identification, particularly with respect to water losses of a non-physical nature. Paper VI explores the reasons why in practice, despite the availability of tools and data necessary for decision-making and the engagement of participatory processes, decisions may not be implemented as planned.

Paper VII focuses on the third case study, involving the enhancement of decentralised customer account management through the use of decision support tools. In this paper, a set of prototype web-mapping applications are developed.

The rest of the thesis is structured as follows: First, an overview of the background theory and state of the art of decision support in general is given, providing a justification for the study as a whole. This is followed by an account of activities carried out within each of the four case studies. Thereafter, the results of the various activities are presented and discussed. Based on the findings of the study, a prototype decision support framework is proposed. The thesis concludes with a summary of lessons learnt and future perspectives derived from the study.

BACKGROUND
This section introduces the concept of decision support and how it relates to organizational decision-making. It outlines the nature and evolution of DSS, the factors determining successful DSS implementation within an organization, and the possible contribution of Action Research (AR) to this process. It also discusses the important role of visualization in enhancing the usefulness of DSS, and the application of tools such as geostatistical modelling for spatial prediction and hydraulic modelling for scenario analysis and evaluation of alternatives. A framework approach to the implementation of DSS is described. Finally, the rationale for DSS development in Uganda is outlined.

The Classical Decision-making Paradigm
Decision-making is the process of generating and evaluating alternatives and choosing a course of action in order to solve a decision problem. Not every problem is a decision problem. According to Ackoff (1981), a decision problem is said to exist where an individual or group perceives a difference between a present state and a desired state, and where:
• The individual or group has alternative courses of action available;
• The choice of action can have a significant effect, that is, not all the actions will yield the same outcome;
• The individual or group is uncertain a priori as to which alternative should be selected.

Decision problems may be categorised by the stimuli that evoke them (Mintzberg et al., 1976). At one extreme are opportunities, those initiated on a purely voluntary basis, to improve an already secure situation. At the other extreme are crises, where organisations respond to intense pressures; here, a severe situation demands immediate action. Most decision problems fall in between the two extremes, being evoked by milder pressures than crises. During the development of a solution, a given decision process can shift along this continuum. For example, an ignored opportunity can later emerge as a problem or even a crisis; a manager may convert a crisis to a problem by seeking a temporary solution; or a manager may use a crisis or problem situation as an opportunity to innovate.

Decision problems may also be classified into three types (Simon, 1960):

i) Unstructured problems: For these, none of the phases of decision-making can be formalized, and no pre-established procedures exist. These types of problems are difficult to support with models and computers.

ii) Structured problems: Here, all phases of decision-making can be formalized, and it is possible to develop standard operating procedures for addressing the problems. The decision-making process can easily be delegated or even automated.

iii) Semi-structured or Ill-structured problems: These are somewhere intermediate between the above two types. The main challenge here is to find structure in problems that seem to have no structure. Problems can be either resolved, solved or dissolved (Ackoff, 1981). Resolving a problem involves selecting a course of action that yields an outcome that is good enough, or “satisfices” (satisfies and suffices). It is a qualitatively oriented, “clinical” approach rooted in common sense and subjectivity. Most managers are problem resolvers, citing a lack of information and time to do otherwise (ibid.).

Solving a problem, on the other hand, involves selecting a course of action that is believed to yield the best possible, or most optimal, outcome. Mainly employing scientific tools, techniques and methods, this is a “research” approach that is preferred by technologically oriented managers whose organizational objective is growth rather than mere survival (ibid.).

Dissolving a problem involves changing the nature and environment of the entity in which the problem is embedded so as to remove the problem. Considered a “design” approach, it aims at changing the characteristics of the larger system into a state in which the problem cannot or does not arise. The designer makes use of the methods, techniques and tools of both the clinician and the researcher, but he uses them synthetically rather than analytically. This approach is used by managers whose principle organizational goal is development and not just growth or survival (ibid.).

Based on earlier work by Simon (1960), Sharifi et al. (2004) propose a framework for a systematic approach to decision-making (Fig.1), consisting of three phases namely Intelligence, Design (here, the word “design” is used in a slightly different context from the one earlier presented), and Choice. Intelligence involves searching the environment for conditions calling for decision. Design relates to inventing, developing and analysing possible courses of action, while choice involves selection of a course of action out of those available.

In Fig.1, “evidence” refers to the total set of data and information that the decision maker has at his disposal, including the skills necessary to handle this information. It may consist of facts, values, knowledge or experience, and is a key resource at all stages of the decision-making process. A major part of decision support is the collection, evaluation, organisation and translation of this data into forms suitable for analysis.
Decision Support Systems
Several definitions of Decision Support Systems (DSS), relating to various contexts, exist in the literature. A few that are of direct relevance to this thesis are presented here. The oldest of these is by Sprague (1980), who defines a DSS as “a class of information system that draws on transaction processing systems and interacts with other parts of the overall information system to support the decision-making activities of managers and other knowledge workers in the organization”. Bhatt & Zavery (2002) describe a DSS as computer software that facilitates and accepts inputs of a large number of facts and methods and converts them into meaningful comparisons that can enhance a decision-maker’s problem-solving abilities.

In general, it may be said that DSS provide support to “management activities”. There are three levels of management activities in organisations (Anthony, 1965): Strategic planning, Management control, and Operational control. Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are applied in managing these resources. It typically involves a small number of high-level people who operate in a non-repetitive and often very creative way.

Management control is the process by which managers ensure that resources are obtained and used effectively and efficiently in the accomplishment of organizational objectives. It involves interpersonal interaction, takes place within the context of the policies and objectives established during strategic planning, and has as its paramount goal the assurance of efficient and effective performance.

Operational control is the process of ensuring that specific tasks are carried out effectively and efficiently. The main difference between management control and operational control is that the latter focuses on tasks whereas the former is more concerned with people. There is less judgement to be exercised in operational control because the tasks, goals and resources are predefined through the management control activity.

Because management activities are different, the information requirements to support them are also different (Gorry & Scott Morton, 1971). The task orientation of operational control calls for information that is well-defined, narrow in scope, detailed and accurate. It is mainly obtained from sources within the organisation, and very frequent use is made of the information. Within strategic planning, the information required is aggre-
gate information, wide and varied in scope, and mainly obtained from sources outside the organisation. The requirements for accuracy are not stringent, and the demands for the information occur infrequently. Information requirements for management control fall between the extremes for operational control and strategic planning. It may also be noted that much of the information required for management control is obtained through the process of interpersonal interaction.

“Hard” and “Soft” DSS
Early DSS were aimed at decision makers understood as experts, who were many times assumed to be computer and systems literate (Pereira & Quintana, 2002). These were highly technocratic systems which did not explicitly take into account the social context in which decisions were taking place. Instead, they deployed mainly quantitative scientific information and required skilled users to undertake the analysis. However, as Ekbia (2004) postulates, “An overview of the development of DSS reveals the dominance of a techno-centric view that portrays technology as the panacea and silver bullet to all social and organizational problems. Challenging this view might be the key to our understanding of the shortcomings of current DSS and a first step toward an alternative framework”.

The alternative school of thought views DSS, not as technological tools, but rather as any context or platform for helping all those involved in decision-making processes to access the necessary information for a useful debate to take place. Pereira & Quintana (2002) portray this way of thinking as representing a passage from DSS to TIDDD - Tools to Inform Debates, Dialogues & Deliberations. Viewing decision support more holistically (here referred to as a “soft DSS” outlook) rather than focusing on technological tools (“hard DSS”) expands the landscape to include decision improvement interventions and strategies that may or may not involve a technical computer artifact (Alter, 2004).

The DSS concept is thus a wide-ranging one. Fig. 2 is an attempt to illustrate the spectrum of possibilities for this concept, ranging from the techno-centric view mentioned above; through formal or informal group discussions with or without computer aids; to the intriguing notion that “the cup of coffee that a decision maker drinks can be considered to be a decision support system” (Boerboom, 2006).

Challenges of Implementing DSS in Organizations
Despite the potential benefits of implementing DSS within organizations, direct transfer of DSS research results to practice in organizations faces a number of challenges. It has been argued (Carlsson & Turban, 2002) that, in implementing DSS in an organization, the key problems never appear to be technology-related, but rather are “people problems”, namely:

- People have cognitive constraints in adopting computerized systems;
- People do not understand the support that these systems offer and disregard it in favour of past experience and traditions;
- People cannot handle large amounts of information and knowledge;
- People are frustrated by theories, techniques or procedures they do not understand;
- People believe they get more support by talking to other people (even if their knowledge is limited).

The cognitive aspect of decision support has not been adequately researched, although it

![Fig. 2: An illustration of the spectrum of “decision support” possibilities.](image-url)
has long been recognized as an important consideration in DSS design (Chen & Lee, 2003). The cognitive styles of decision-makers may be considered to be predictors of DSS acceptance. Lu et al. (2001) note that DSS are preferred by “sensation-style” and “thinking-style” people, while “intuitive-style” and “feeling-style” people are usually uncomfortable with applying a DSS. This is so because “intuitive-style” people are impatient with routine, while “feeling-style” people use subjective impressions and are highly personal in their judgements. “Sensation-style” people, on the other hand, do well with established routine, while “thinking-style” people prefer a rational approach and logical objective analysis, and their judgements are highly impersonal.

Furthermore, the cognitive differences between lower and higher level management suggest that executive support should be somewhat different from lower level management support. Executives do not usually make major decisions by choosing from a set of predetermined alternatives, but rather, rely heavily on their intuition and seldom think in ways that one might normally view as “rational” (Chen & Lee, 2003). Thus, while DSS tend to be used by front-line employees and middle management, decision-making at executive level has often been done without any decision support (Mysiak, 2003). However, because more senior executives are becoming comfortable with Information Technology (IT), the roadblocks of the 1980s and 1990s for using IT in executive decision-making are being removed. In fact, IT is now viewed as a strategic tool that is central to the pursuit of competitive advantage, and DSS technologies are predicted to become more accepted throughout organizations, from front desks to executive boardrooms (Shim et al., 2002).

The classical concepts of ‘perceived usefulness’ and ‘perceived ease of use’ of Information Systems (IS), as introduced by Keil et al. (1995), are investigated by Westmacott (2001). Perceived usefulness is the degree to which a person believes that using a particular system would be free from effort. Both Westmacott (2001) and Lu et al. (2001) concur that there is a strong positive relationship between perceived usefulness and user willingness to adopt systems, while perceived ease of use is not as influential in determining user adoption. However, perception of ease of use can help in perceiving the system as useful, thereby facilitating the preference and willingness to use the DSS.

Once accepted by users, the reliability of a DSS can be measured with actual usage over time. Usage itself is an indirect measure of the users’ judgment of the value of a system (Gelderman, 2002). However, judging whether a DSS has been successful or not is difficult, and sometimes cannot even be based on whether the DSS is used by the intended users (Mysiak et al., 2005). Users may have poor introspection or (if they are not experienced in using a DSS) may not recognize good advice and may dislike being corrected by a computer system. Problems with DSS acceptance may simply be related to general problems faced by information technologies, such as a lack of sufficient data, or to the natural gap between humans’ mental information processing capabilities and the computational approach that underlies traditional DSS.

Some considerations to be made for successful DSS implementation in an organization are (Westmacott, 2001):

- Involvement of the end-users in the development of the DSS;
- Designing the DSS for the end-users’ needs rather than the needs perceived by the developer;
- A flexible, adaptable and updatable system;
- An easy-to-use interface, requiring limited time to learn how to use the system;
- Visual display of results.

Other factors to be considered are system quality, information quality and information presentation (Bharati & Chaudhury, 2004). System quality includes ease of use, convenience of access, and system reliability. Information quality covers information relevance, accuracy, completeness, and timeliness, while information presentation relates to graphics,
The Role of Action Research in DSS Development

One problem facing the adoption of decision support tools for real-world applications is that the overwhelming majority of DSS are developed in academic environments, which implies limited scope for organizations to continue customizing the systems and adapting them to changing conditions once the corresponding research project has been completed (Mysiak, 2003). Under these conditions, the risk of DSS failing to address real-world problems is high, despite undeniable benefits stemming from their usage. Instead, a contextual design strategy would be more appropriate (Smart & Whiting, 2001). In contextual design, the designer works with users in the context of their own work environment. This approach forces designers into the users’ world, and also allows users to participate in design activities.

Information Systems (IS) researchers advocate the use of Action Research (AR) as an appropriate means of undertaking work in the field of IS development (West & Stansfield, 2001; Baskerville & Myers, 2004; Melin & Axelsson, 2007). AR is an inquiry process that involves partnership between researchers and practitioners for the purpose of addressing a real life problem issue, while simultaneously generating scientific knowledge (Styhre & Sundgren, 2005). In AR, the research takes place in real-world situations, and aims to solve real problems. What separates this type of research from general professional practice, consultancy, or daily problem-solving is the emphasis on “scientific” study; the researcher studies the problem systematically and ensures that the action or intervention is informed by theoretical considerations (O’Brien, 2001). The AR approach is described in detail in Paper I.

With such a situated approach, the DSS development process plays a role in enhancing organizational learning. There are two types of learning in organizations (Bhatt & Zavery, 2002): single-loop learning (problem-solving) and double-loop learning (critical reflection leading to further learning). While the former maintains the organization, it is the latter that redefines an organization, enabling it to adapt and thrive in dynamic environments. By its nature, AR is an iterative process, with action and critical reflection taking place in turn; this makes it suitable for application in situations and processes where organizational development is the principle goal.

AR can also be compared with action learning, a process in which a group of people come together regularly to help each other learn from their experiences (Dick, 1997). This could take place within an organization or across different organizations. Both action learning and action research are intended to improve practice; action research intends to introduce some change, while action learning uses some intended change as a vehicle for learning through reflection. In each, action both informs reflection and is informed by it. The reflection produces the learning (in action learning) or research (in action research). Subsequently in both, the action is changed as a result of the learning or research, and this in turn leads to more learning or research.

DSS and Visualization

The true utility of a DSS is measured in part by the comfort level of those who use it (Westphal et al., 2003). Often, DSS user interfaces are dominated by the presentation of information via character and numerical formats, and are thus considered an area of pursuit for those who have a propensity for numbers and enjoy mathematical equations. Unfortunately, many of the individuals who stand to benefit the most from DSS, such as CEOs, politicians and administrators, lack this mathematically oriented mindset (Li et al., 2001). In general, interpretation of data is much more intuitive if the results from a DSS are translated into charts, maps and other graphical displays, because visualization exploits the natural human ability to quickly recognize and understand visual patterns. As Nyerges et al. (1997) observes, “Reducing the complexity of issues through appropriate management, analysis and visualization of information might lead to better decisions, because the task of making the decisions is
simplified”. Visual representations can serve as powerful “vehicles of thinking” that help the process of extracting useful information from complex or voluminous data sets (ibid.). In some situations, problems may be known but not adequately communicated to, or perceived by, the stakeholders who should decide on appropriate courses of action (Bacic et al., 2006). Visualization facilitates the presentation of problems and remedies in a manner that makes them easily justifiable before policy-makers and the lay public. It is commonly said that a picture speaks a thousand words; issues that may not be easy for lay persons to understand may be made plain through visualization, thus making it possible for involvement of a wide range of stakeholders in the decision-making process. However, there is need for some degree of caution here. Human beings are so visually oriented that visualization techniques sometimes have unwarranted authenticity (Bunnel & Boyland, 2003). A major problem with DSS is the tendency for users to accept rather than interpret outputs, and yet, as visualization techniques grow more sophisticated, ‘what you see is not always what you get’, to reword a common phrase.

When dealing with data of a spatial nature, a form of visualization referred to as geovisualization comes into play. Geovisualization, which has been described as “making data visible” (Kraak, 2003), involves the use of visual geospatial displays to explore data, and through that exploration to generate hypotheses, develop solutions and construct knowledge. In this respect, the visualization process is considered to be the translation or conversion of geospatial data from a database into graphics by applying appropriate cartographic methods and techniques (Ogao, 2002). Spatial data by its nature can be visualized on a map, since each observation has coordinates in geographic space. However, visualization is not limited to enabling the process of seeing patterns and relationships in geospatial data, but also includes manipulating the data to derive new useful information. There are three possible modes or strategies of map usage (ibid.):

- Presentational – the map is simply used to present facts to the user;
- Confirmative – the map is used in a goal-oriented examination of hypotheses, aimed at confirming or rejecting a given hypothesis;
- Exploratory – the map is used in an interactive, undirected search for patterns and trends, with the aim of coming up with hypotheses about the data.

While visualization techniques are useful to enable qualitative interpretation of data, analytical techniques are necessary to enable an evaluation of this data (Bryan, 2003). Thus, the concept of information visualization is not limited to the graphical display of data, but encompasses a much broader spectrum including the design of appropriate graphical interfaces used to input and access that data, the creation of standard and novel data presentation formats, and the use of models and analytical tools yielding outputs of a visual nature.

**Modelling within Decision Processes**

Most DSS analysis is performed numerically using databases and mathematical models, as a complement to people’s limited memory and computing capacity (Lu et al., 2001). In simple terms, a mathematical model may be considered to be a simplification or abstraction of reality. Faced with complexity of a system, an attempt is made to simplify and abstract the most important relations within the system. This simplification is then termed a “model”, or incomplete representation of reality.

The questions and purpose of the decision process determine the kind of abstraction and simplification that occurs during model construction. As visualization techniques grow more sophisticated, model outputs tend to further confuse the abstracted, simplified model with the complex real world. To use a DSS effectively, it is important to be mindful of the abstraction and translations that the visualization techniques obscure (Bunnel & Boyland, 2003).

Once a decision problem is understood and the ways in which performance measures are to be calculated have been agreed, data are collected and system performance under different scenarios is modelled. With knowledge of the performance of different solu-
tions, decision variables are adjusted and outcomes compared. Further evaluation that takes into consideration other stakeholder requirements leads to the selection of one option for implementation that is acceptable to all stakeholders. As with the problem definition process, this evaluation and selection process is often iterative in nature.

Thus, effective tools to assist in such decision processes must have the ability to represent critical aspects of the system, to compare the performance of different options against competing objectives through simulation of the various options, to consider scientifically verified or calibrated model outputs alongside diverse stakeholder views and interests, and to present model outputs in ways that are relevant to the decision context and are easily understood by all stakeholders, including those with non-technical backgrounds.

Modelling tools or evaluation technologies can be applied by an experienced practitioner in a “stand-alone” manner to address a particular aspect of a decision problem. However, it has been recognised (Bruen, 2002) that if these tools and technologies are to be used as part of interaction amongst both technical and non-technical players then their use and interpretation must be made simple, and this is most conveniently done by embedding them in a DSS.

In relation to Simon’s decision process mentioned earlier (Simon, 1960), models are primarily useful at the design and choice phases of the decision making process, while the intelligence phase largely depends on people’s intuition and experience. Intuition is good at identifying and defining important factors but poor at combining that information; mathematical models, on the other hand, are good at combining factors but poor at defining them.

A major problem with any DSS is a tendency to accept rather than interpret model outputs. Novice model users often hold a ‘black box’ view of DSS, believing that entering current states into the model and running the model will answer management questions. Dissatisfaction with the outcome of this approach often leads to disillusionment for these users, who still retain the black box view of the DSS but now disbelieve its results (Bunnel & Boyland, 2003). Misuse of the DSS quickly turns into disuse; and, needless to say, an unused DSS is of no benefit to decision-makers (Lu et al., 2001).

A Framework Approach to DSS Development

The terms framework, taxonomy, conceptual model and typology are often used interchangeably (Power, 2004). Taxonomies classify objects; typologies show how mutually exclusive types of things are related; frameworks provide an organizing approach; and a conceptual model shows how ideas are related. Typologies, frameworks, or conceptual models are crucial to the understanding of a new or complex subject. In the absence of convergent theory, a framework is helpful in organizing a complex subject, identifying the relationships between the parts, and revealing the areas in which further developments may be required (Sprague, 1980).

Earlier in this section, a number of definitions for DSS were presented, ranging from restrictive technological ones to broader, all-encompassing ones. In fact, the term “decision support system” renders a certain intuitive validity to the latter outlook on DSS, because it implies that any system that supports a decision in any way should be considered to be a DSS. Unfortunately, neither the restrictive nor the broad definition is much help in providing guidance in understanding the value, technical requirements, or approach for developing a DSS (Sprague, 1980). This is because people from different backgrounds and contexts – a manager and a computer scientist, for example - tend to view DSS quite differently. Thus, the field of decision support suffers, in many ways, from the broad, ambiguous use of the term DSS. The intuitive and descriptive appeal of the term coupled with its historical importance should encourage researchers to differentiate more clearly what type of DSS is being studied or built. For a given context, both researchers and managers need a meaningful framework for discussing what is being done to support decision-making using information technologies (Power, 2004). A taxonomy or typology helps reduce the confusion for managers who are investigating and discuss-
ing decision support systems. The taxonomy also helps users and developers communicate their experiences with and expectations for DSS.

Likewise, the academic or theoretical definition of DSS differs from the “connotational” definition derived from practice. The former is carefully articulated in textbooks and journal articles, while the latter evolves from what is actually developed and used in practice, and is heavily influenced by the personal experiences that the user of the term has had with the subject (Sprague, 1980). Frameworks are useful in helping IS researchers better identify meaningful, homogeneous categories for DSS research. They also help IS professionals in describing and explaining the various types of DSS. Within an organization, both managers and DSS designers need to understand the categories or types of DSS so they can communicate better about what needs to be accomplished in supporting decision-making processes.

Gorry & Scott-Morton (1971) note that a framework which allows an organisation to gain a perspective on the role of information systems can be a powerful means of providing focus and improving the effectiveness of systems development efforts. Such a framework is useful in planning for information systems development within the organisation and for distinguishing between the various model building activities, models and computer systems which are useful for supporting different kinds of decisions. Moreover, an understanding of managerial activity is a prerequisite for effective systems design and implementation.

Faced with a decision situation, not only does the decision-maker execute the steps leading to a solution, but he also plans his approach and allocates the organisational resources to get there. This may be referred to as meta-decision-making, that is, decision-making about the decision process itself (Mintzberg et al., 1976). Given an organization’s limited resources, there must be an appropriate framework within which to view management decision-making and the required systems support. Thus, a framework may be considered to be a useful decision support tool in itself - one that supports meta-decision-making, thereby providing decision support about decision support. Without a framework to guide management and systems planners, the system tends to serve the strongest manager or to react to the greatest crisis. As a result, systems development activities move from crisis to crisis, following no clear path.

Since the early 1970s, a number of frameworks describing the characteristics of DSS have been formulated. Hayen (2006) examines several of these frameworks using a published case-based research approach. Among these, he considers the Gorry & Scott-Morton framework (Gorry & Scott-Morton, 1971) to be a landmark work that continues to provide significant guidance in the study and application of DSS. Within this framework (Fig. 3), the classification of management activities based on purpose (Anthony, 1965) and that based on problem type (Simon, 1960), are combined to provide a

![Fig. 3: The Gorry & Scott-Morton Information Systems Framework, with examples](Gorry & Scott-Morton, 1971).
means of examining and categorising the purposes and applications of information systems activities.

Most of the traditional IS activity in organisations has been directed at decisions of a structured, operational control nature (the top left cell of the matrix in Fig 3, and yet for the most part, managers deal with unstructured decisions (the lower half of the matrix). One way of improving decision-making within an organisation would thus be to provide increased information support to managers for decisions falling within the latter category. Another way of improving decision-making would be to increase the understanding of a particular problem situation, which in effect would shift the problem from the unstructured toward the structured half of the matrix, where it would then be dealt with using appropriate, pre-established methods.

In contrast to the Gorry and Scott-Morton framework, Alter (1977) proposes a taxonomy based on the idea that a DSS can be categorized in terms of the generic operations it performs, independent of type of problem, functional area or decision perspective. The seven DSS types identified by Alter (Fig. 4) are:

- File drawer systems, that provide access to data items;
- Data analysis systems, that support the manipulation of data by computerized tools tailored to a specific task and setting or by more general tools and operators;
- Analysis information systems, that provide access to a series of decision-oriented databases and small models;
- Accounting and financial model-based systems, that calculate the consequences of possible actions;
- Representational model-based systems, that estimate the consequences of actions on the basis of simulation models;
- Optimization model-based systems, that provide an optimal solution consistent with a series of constraints that can guide decision making;
- Suggestion DSS, based on logic models that perform the logical processing leading to a specific suggested decision for a fairly structured or well-understood task.

On the other hand, Sprague (1980) proposes a framework that considers the levels of technology included in the “DSS” label, the roles different participants play in the building and use of a DSS, and the developmental approach for the creation of a DSS (Fig. 5).

The three levels of technology considered in the framework are: Specific DSS, referring to the actual IS application (hardware and software) that allows a specific decision maker or group of decision makers to deal with a specific set of related problems; DSS Generator, which is a package of related hardware and software that provides a set of capabilities to quickly and easily build a Specific DSS; and DSS Tools, which are hardware or software elements that facilitate the development of a Specific DSS or a DSS Generator, and include programming environments, data access software, and the like.

The roles considered within the framework are: Manager or User - the person faced with the problem or decision, and the one who must take action and be responsible for the consequences; Intermediary – the person who helps the user in applying the decision support tools; DSS Builder – the person who assembles the necessary capabilities from the DSS Generator to configure the Specific DSS with which the user and his intermediary interact (this person must have familiarity both with the problem area and the IS components and capabilities); Technical Supporter – the person who develops additional IS capabilities or components (such as databases, analysis models, and data display functionalities) when needed as part of the DSS Generator; and Toolsmith – the person who develops new technology, languages, hardware and software, and improves the linkages between sub-systems.
The developmental approach considered in the framework is one of iterative design, in which the four steps of the traditional IS development process – analysis, design, construction, implementation – are combined into a single step which is iteratively repeated until a relatively stable system evolves. Here, the manager is the iterative designer of the system, and the systems analyst is merely the implementer of required changes as identified by the manager. The iterative changeability is built into the DSS. Rather than a focus on developing a system, which is then run as a traditional IS application, this approach results in the installation of an adaptive process, in which the decision maker and a set of IS capabilities interact to confront decision problems.

Thus, within Sprague’s framework, the DSS is considered to be an adaptive system which consists of all three levels of technology in place, operated by the different participants within their roles, and adapting to changes over time. In this respect, the development of a DSS is the development and installation of this adaptive system.

Power (2004) proposes an expanded conceptual framework for classifying and describing DSS that consists of one primary dimension and three secondary dimensions (Fig. 6). The expanded DSS framework builds upon both Alter’s (1977) empirically-derived framework and Sprague’s (1980) normative framework. It integrates more recent software and technology developments and provides a more consistent naming convention for computer-based DSS.
The primary dimension is the dominant technology component or driver of decision support. In this respect, the framework combines the first three of Alter’s seven types of DSS as data-driven DSS, and the second three as model-driven DSS. It renames suggestion DSS as knowledge-driven DSS and adds two new categories, namely communications-driven and document-driven DSS. The three secondary dimensions are the targeted users, the purpose of the system and the primary deployment or enabling technology. User categories include individuals, groups, functional departments, customers or suppliers. The DSS can be created for a function-specific, task-specific, or general purpose. Finally, in the framework, the DSS deployment and enabling technology may be a mainframe computer, a client/server LAN, or web-based technology architecture.

It is also useful at this point to introduce the concept of Work-Centered Analysis (WCA) (Alter, 1999). WCA is a framework for thinking about business processes and the information systems that support them, with a focus on the work being done. It is a concept that stems from ideas derived from management theories such as Total Quality Management (TQM), business process reengineering, and systems theory.

In this context, a work system may be defined as a system in which human participants perform a business process using information, technology, and other resources to produce goods or provide services for internal or external customers. The core of a work system is a business process, defined as consisting of steps or tasks related in time and place, having a beginning and an end, and having inputs and outputs.

In turn, an information system may be considered to be a type of work system that uses information technology (computer infrastructure, hardware and software) to capture, transmit, store, retrieve, manipulate or display information, thereby supporting one or more other work systems.

Figure 7 illustrates the WCA framework and the role of information systems within this framework. The WCA framework implies that the system doing the work is much broader than the technology, but rather includes the business processes, the participants, any information used, and any technology applied. In the figure, the organization may be considered to consist of a collection of interdependent business processes, working together to generate products or services within a business environment. The latter includes the organization itself and everything else that affects its success, such as competitors, suppliers, customers, regulatory agencies, and demographic, social, and economic conditions.
In light of the above discussion, empirical research aimed at understanding the business processes within an organisation and how best to support these processes at different management levels and in the face of different problem issues, can act as a basis for the establishment of a framework to guide the development and implementation of information systems providing the required support, which in turn should lead to better decision-making within the organisation. This is the overall aim of the study.

The Rationale for DSS Development in Uganda

A study was carried out to appraise the need for development of DSS for Water Resources Management (WRM) in Uganda (Ngirane-Katashaya et al., 2006). Findings showed that, in spite of rapidly advancing computer technology and the proliferation of software for decision support globally, relatively few DSS had been developed, implemented, and evaluated in the field of WRM in Uganda. Examples of those encountered included the Lake Victoria Decision Support System (LVDSS) and the Nile Decision Support Tool (Nile DST). These were basin-scale tools that focused on management of the water resources for the respective basins (Lake Victoria and the Nile River) as a whole. The study concluded that there was room for applied research in developing additional practical tools to underpin and support sustainable development and management of the country’s water resources. By building DSS, many needs of policy-makers and resource managers in the water sector would be met, such as the provision of mapping capability for land and water resources, establishment of a digital database for information, creation of a suite of spatial analysis tools, development of predictive models, and provision of a basis for evaluation of management alternatives.

Some considerations that were identified as being important in developing DSS appropriate for the local Ugandan context were:

- Use of an open, modular architecture, allowing for ease of upgrade of component modules as well as addition of new modules in response to changing needs with time;
- Provision of user interfaces that allow easy interaction, are simple enough to be used directly and mastered by local decision makers without the constant support of computer analysts, and present outputs in formats that are easy to interpret;
- A cost-effective development and deployment process, demanding minimum hardware, software and licensing costs. This would necessitate the identification, adoption and adaptation of suitable existing tools, models and routines, with particular emphasis on the usage of non-proprietary, inexpensive or widely available industry-standard software tools.
METHODS
This section begins with a description of the functional setup of the organization within which the study was undertaken. In the study, a problem-driven approach was applied, in which four real-life cases were used to explore different aspects of the challenges inherent in the establishment of formal decision support mechanisms within the organization. A description of each problem case is given, and the activities undertaken in each case are outlined. These activities included: participatory problem-structuring; development of prototype data management tools; development and application of geovisualization tools; hydraulic modelling and scenario analysis; performance of spatial and geostatistical analyses; and development of web-mapping applications. A more detailed account of the activities carried out is found in the appended papers.

The Study Area
The National Water and Sewerage Corporation (NWSC) is a public utility owned by the Government of Uganda (GoU). NWSC is mandated to provide water supply and sewerage services in 22 urban centres in Uganda, of which Kampala, the capital city, is the largest (Fig. 8). Established in 1972, NWSC's legal position was further strengthened by the enactment of the NWSC Statute No. 7 of 1995 and the NWSC Act of 2000. Through these legal frameworks, the powers and structure of NWSC were revised to enable the corporation to operate autonomously on a commercially and financially viable basis, with its overall management founded on a performance contract between itself and the GoU (NWSC GoU, 2003).

In 2004, as a means of operationalizing the GoU contract and as one of several Performance Improvement Programmes (PIPs), NWSC introduced a novel concept called Internally Delegated Area Management Contracts (IDAMCs). The IDAMCs involve the corporation’s head office entering into two-year, performance-based management contracts with teams of key staff in each of its 22 towns of operation. Each team of key staff, referred to as the Operator for the respective town, is selected out of staff from NWSC as a whole through a competitive bidding process. The Operator is then granted autonomy and responsibility for a number of activities, including network operation and maintenance, network expansion and intensification, new connection implementation, billing of customers, revenue collection, procurement of works, supplies and services, and human

Fig. 8: Map of Uganda showing towns served by NWSC, including Kampala. (Source: KW GIS office)
resource management.

In the case of Kampala, owing to the size of the city and the scope of operations, management has been further decentralized to eleven geographical administrative units referred to as Branches (Fig. 9), through Branch Performance Contracts (BPCs) signed between the Operator (Kampala Water, or KW) and the respective Branch Managers (who are also selected through an internal competitive bidding process). The Branches, in turn, are further subdivided into smaller geographical units, called Territories. This study was undertaken within KW, and sought to develop tools to support the decentralized management setup described above.

**Introduction of Problem Cases**

In Paper I, it is emphasized that an Action Research (AR) study needs to address real-life problem situations in order for it to have an immediate impact on practice and to promote joint learning between academicians and practitioners. In this study, four real-life problem issues were:

i) Investigation of water distribution bottlenecks (Case 1);
ii) Water loss management (Case 2);
iii) Territorial management of customer accounts (Case 3);
iv) Budget implementation monitoring and control (Case 4).

Paper II presents an overview of the four problem cases and how they were addressed. Paper III and Paper IV focus on Case 1 in greater detail; while Paper V and Paper VI deal with Case 2. Paper VII focuses on Case 3.

All four cases involved a number of participatory activities, bringing together different players within the organization. In terms of geographical scope, Case 2, Case 3 and Case 4 dealt with KW as a whole, while for Case 1 and some activities within Case 2 a single Branch was selected for study, namely Branch 5 or Ntinda Branch. The reasons for selecting this Branch were threefold:

i) It was planned that this Branch act as a pilot Branch for development of decision support tools that would later be rolled out to the rest of the Branches;

ii) It was anticipated that the individual decision support tools developed would eventually be integrated into a single deci-

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**Fig. 9: Kampala Water Administrative Units, referred to as Branches. Inset is Branch 1 (City Centre), further sub-divided into five Territories. (Source: KW GIS Office)**
The four cases are summarized in the subsections that follow.

**Case 1: Investigation of Water Distribution Bottlenecks**

**The Problem**

The Kampala piped water network was experiencing structural and hydraulic problems, manifesting in chronic low pressures and supply intermittence in parts of the city, frequent occurrences of leaks and bursts, and water transmission bottlenecks. Of particular concern was the transmission and distribution network for the Naguru water storage tank, a 4,000 cubic meter tank supplying the north-eastern part of the city (Fig. 10). This part of the city required special attention because it was experiencing supply insufficiencies in several locations, prompting an outcry from customers residing in the area. For a long time, it was not clear what the underlying causes of the problem were, nor how best to go about solving it. More often than not, a reactive, “fire-fighting” approach had been employed to try and mitigate the effects of the problem through implementation of short-term actions. These actions often took the form of uncoordinated field activities carried out by a number of different technical teams, usually without prior comprehensive planning or analysis. The positive effects of these adhoc interventions were not readily apparent.

In recognition of the pressing need, the KW management set out to identify and implement more lasting measures to remedy the situation. As part of this process, it was found necessary to bring key players together to develop a common understanding of the nature and causes of the problem, and to formulate and implement appropriate courses of action.

**Participatory Processes**

For the researcher, the primary focus was on facilitating participatory problem identification and structuring. To achieve participation, the researcher established a new discussion forum within the organization. The Technical Think Tank (or T-Cube, as it came to be known) brought together engineers, technical supervisors, field staff, and other staff involved in operational activities of direct relevance to the problem at hand.

At its inception meeting, the researcher in-
introduced T-Cube 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”. The key goal was identified as the generation of practical technical solutions to identified problem issues in a manner that would render these solutions clearly justifiable to the relevant decision-makers. Accordingly, the specific objectives of T-Cube were formulated as follows:

- To collectively identify technical problem issues affecting KW;
- 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 proposed solutions.

Figure 11 shows a flyer that was distributed to members of T-Cube, explaining the motive behind the establishment of the discussion forum.

Subsequent to the launch of T-Cube, fortnightly meetings were held, and during these meetings a number of issues were identified, actions formulated, and tasks implemented. Details of the activities of T-Cube are contained in Paper III and Paper IV.

**Geovisualisation Tools**

As a way of providing further support for participatory problem-structuring, the researcher generated a set of maps, using data available for the study area. These maps were subsequently used to inform and guide the discussions that took place during the T-Cube meetings. The maps showed:

- the location and density of customer connections within the study area;
- the location, nature and frequency of customer complaints (leaks, bursts, no-water and low-pressure cases);
- the distribution of water demand in the area, based on historical consumption;
- the constraints of supplying water by gravity from different storage tanks and flow sub-systems.

Paper III describes the map generation process in detail. The maps were produced using ArcGIS, an industry-standard GIS software application from ESRI. Sources of data for the map layers included:

- Topographic basemaps in AutoCAD Drawing Interchange Format (DXF), originally obtained by KW from the Survey and Mapping department of the government Ministry of Lands;
- Customer records extracted from the customer information management and transaction processing system (CUSTIMA) and geocoded by means of unique property reference identifiers;
- Historical records of monthly metered consumption volumes for each customer, extracted from CUSTIMA and going back a period of six years;
- Customer complaints extracted from the

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**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?
Call Centre database (a custom Microsoft Access database used to log and route calls received on the company’s 24-hour helpline), going back a period of eighteen months;

- Elevation data, contained in the topographic basemaps and consisting of a layer of 3D contours at a contour interval of 10m.

The Naguru flow sub-system is predominantly gravity-driven, and therefore pressures at different locations within the system depend on the ground elevations at those locations relative to that of the Naguru storage tank. To further assist in visualizing the topography of the study area (thereby gaining a better understanding of the system hydraulics), a Digital Landscape Model (DLM) of the study area was created. The DLM was built using ESRI’s ArcGIS 3D Analyst Extension. Paper III details the process of constructing the DLM. Using ESRI’s 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.

Simulation Modelling and Scenario Analysis

During the T-Cube discussion sessions, the need to establish a hydraulic model of the study area and carry out simulation analyses for various proposed interventions was identified. Paper IV describes in detail the actions that were undertaken in this regard. They involved the establishment and calibration of a model representing the distribution network, and the subsequent analysis of the baseline situation as well as a number of alternative scenarios. Hydraulic modelling was done using WaterCAD, a graphical water distribution modelling software application supplied as part of Bentley’s Haestad Methods Water Solutions.

To obtain data to use in establishing and calibrating the hydraulic model, the entire KW distribution network was divided up into supply zones (based on water source), and historical consumption records derived from the Billing database were analysed for each supply zone to obtain representative demand figures. A skeletonized representation of the Naguru distribution network was established, consisting of links and nodes. Physical pipe characteristics for this skeletonised system were obtained from an existing pipe database. Nodal demands were computed for this simplified network representation, based on the demand analysis earlier carried out. Field flow and pressure measurements were used to calibrate the model. Subsequently, seven scenarios were simulated and their outcomes compared. The results were discussed within T-Cube and were also compiled into a PowerPoint presentation that was delivered to the NWSC Top Management.

Case 2: Water Loss Management

The Problem

In a water supply utility, Non-Revenue Water (NRW) is calculated as the difference between the volume of water produced and the volume of water sold, expressed as a percentage of the volume of water produced. The
KW contractual performance target for the period July 2006 to June 2008 was to reduce NRW levels from 37.8% to 26%. However, six months into the contract period, the NRW levels had instead taken an upward trend (Fig. 12).

In a bid to reverse this undesirable trend of events, the KW management set out to identify the root causes of the persistently high NRW levels and develop strategies to address them. The goal was to draw up and implement an Action Plan for NRW reduction, leading to a return of NRW to acceptable levels.

**Participatory Processes**

As part of efforts to address the situation, the researcher coordinated the formulation of an Action Plan for NRW reduction. For this, two brainstorming workshops were organised. These workshops involved the participation of both technical and commercial managers from all departments and Branches of KW.

Prior to the first workshop, the researcher put together a small team of staff from various departments to collect historical data related to activities with a potential impact on NRW. The tasks assigned to members of this planning team are shown in Table 1. The data was analyzed and synthesized into a PowerPoint presentation that the researcher made to participants at the start of the first workshop, as a way of informing and guiding the discussions that ensued. During this workshop, four discussion groups were formed to map out strategies for various aspects of the water loss management process, namely: reduction of physical losses; reduction of commercial losses; control of unbilled authorised consumption; and regulation of system input volumes.

<table>
<thead>
<tr>
<th>Category of Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Customer complaints (leaks, bursts, etc) – nature, frequency and distribution</td>
<td>Call Centre database, to be correlated with branch records of complaints handled</td>
</tr>
<tr>
<td>2. Data on field anomalies reported by Marketing Assistants – nature, frequency, distribution</td>
<td>Branch commercial and billing officers</td>
</tr>
<tr>
<td>3. Demand/consumption analysis</td>
<td>Billing database</td>
</tr>
<tr>
<td>4. Records from Illegal Use Reduction Unit (IURU) – location and nature of cases handled</td>
<td>IURU</td>
</tr>
<tr>
<td>5. Meter servicing records (nature, frequency and distribution of faults)</td>
<td>Large Meters, meter workshop</td>
</tr>
<tr>
<td>6. Production/Reservoir records</td>
<td>Reservoirs&amp;Boosters engineer/superintendent</td>
</tr>
<tr>
<td>7. Property refs (customer locations)</td>
<td>GIS office</td>
</tr>
<tr>
<td>8. Un-updated new connections (obtain lists, correlate with billing)</td>
<td>Branch surveyors</td>
</tr>
<tr>
<td>9. Un-updated old connections – correlate with billing</td>
<td>GIS office</td>
</tr>
<tr>
<td>10. New connection records (numbers, updating, billing analysis)</td>
<td>Branch engineers, Billing database</td>
</tr>
<tr>
<td>11. Analysis of estimated billings</td>
<td>Billing Database</td>
</tr>
<tr>
<td>12. Branch-by-branch analysis of water sales trends</td>
<td>Billing database</td>
</tr>
<tr>
<td>13. Consumption registered on suppressed accounts (as a component of unbilled metered consumption)</td>
<td>Billing database</td>
</tr>
<tr>
<td>14. Records from fire brigade on fire-fighting consumptions</td>
<td>Fire brigade</td>
</tr>
<tr>
<td>15. Mains flushing records (Preventive Maintenance, O&amp;M, New connections); reservoir cleaning</td>
<td>Network engineers, Branch Technical Supervisors</td>
</tr>
<tr>
<td>16. Records on stolen meters</td>
<td>Branches</td>
</tr>
</tbody>
</table>

**Table 1: Data collected by the planning team as a means of generating background information to guide the NRW Action Plan formulation workshops.**
Following the first workshop, the researcher and his planning team met a number of times to synthesize the identified strategies and draft an Action Plan indicating specific activities, timelines and responsibility allocations. The researcher presented this Action Plan to the KW top and middle managers at the second workshop, where it was adopted for implementation.

**Data Management Tools**

In further support of the Action Plan implementation, the researcher developed a number of computerized data management tools. The first of these tools consisted of an integrated set of modules to capture data relating to day-to-day technical and commercial operations at Branch level throughout KW, and in particular those considered to have an impact on NRW (repair of leaks and bursts; mains flushing; new connection implementation; illegal connections; stolen and vandalised fittings; handling of customer complaints; meter servicing). These were collectively grouped into a Quality of Service (QOS) module.

Also included among the tools were modules for tracking water production at the treatment plants, water storage in various reservoirs and tanks located throughout the city, water pumpage at various booster stations, and bulk water transmission to different flow sub-systems. A module was also created to maintain records on the physical network infrastructure (pipe lengths, diameters, material and age; valve and hydrant locations and diameters; bulkmeter locations and diameters). This set of modules was implemented as a Water Supply (WS) module.

In terms of deployment, the QOS module was installed on computers at the Branch offices, while the WS module was availed to the Water Production department and the GIS unit. The target users for the QOS were the Branch Engineers, while the WS module was targeted for use by the Reservoirs and Boosters supervisor. The plan was to have the data from the two sets of modules continuously collated to feed into a monthly water audit for the system as a whole.

**Geostatistical Modelling**

As a further activity, a geostatistical analysis was carried out for Branch 5. Details of this analysis are reported in Paper V. The purpose of the analysis was to find out whether any spatial correlations existed between declining water sales in the Branch and reported field anomalies such as aged and defective water meters, water supply intermittence, leaks and bursts, illegal consumption, and disconnected and estimated accounts. The geostatistical analysis was carried out using R, an open-source statistical computing and graphics software environment, and Tinn-R, a graphical user environment and code editor for R.

In the analysis, an empirical variogram was generated using water sales volumes for a random set of customers selected within the Branch, for a selected month (December 2003). The empirical variogram was subsequently fitted with a spherical theoretical variogram model. The resultant fitted model was used to generate a continuous raster map of predicted monthly water sales volumes throughout the Branch, using the optimal interpolation process of ordinary kriging. This map of predicted volumes was then compared with another map generated using the same fitted variogram model and water sales volumes for the same set of customers for December 2007. A difference map was produced, highlighting locations where significant drops in water sales had occurred between the two periods.

Subsequently, distribution plots were made of the locations of the various reported field irregularities. The distribution plots were overlaid on the difference map earlier generated, and the resultant set of layered maps was studied to identify any spatial correlations between the field anomalies and perceived drops in water sales volumes.

**Case 3: Territorial Management of Customer Accounts**

**The Problem**

“Territorial management” is a concept that was introduced by one of the utility’s executives following a benchmarking visit to an Asian water utility. Simply put, it involves sub-division of the area of operation of the
utility into geographical units small enough for a designated individual, the Territorial Manager (TM), to gain a personal knowledge of, and greater contact with, the customers within his jurisdiction. This closer focus should, in principle, enable the TM to better control aspects of water sales and revenue collection within his Territory, and at the same time make him more accountable to his superiors for its performance relative to that of the Branch as a whole. Within the BPC framework, territorial management acts both as an incentive for competition amongst Territories (leading to global performance gains) and a basis for reward of exceptional achievers.

One obvious need that arises is for the TM to be able to distinguish his customers from the rest of the customers in the Branch, both in terms of their physical locations and in terms of their accounts in the customer database. Having this clear distinction in place, the TM should have the means to continuously track the status of his designated accounts, and to plan and supervise the field activities of his subordinates based on this. He should also be able to continuously track his progress towards the achievement of local and global performance targets so as to implement remedial actions in a timely manner. Given the fact that the KW customer information management and transaction processing system (CUSTIMA, a UNIX-based billing application running on the Progress database engine) was not originally designed to directly support the territorial management concept, there arose a need to develop additional software tools to bridge the gap.

Data Management Tools
The researcher, through his own initiative and based on his perception of what was required, developed a custom application designed to support territorial management of customer accounts. Named the Account Management Module (AMM), this application was designed for use at both Branch and Territory levels. It took data from the CUSTIMA system and made it available in a Windows-based graphical user interface developed using Microsoft Access and VBA. The AMM provided a complete listing of customers in each Branch, and included drill-down functionality for filtering customers by Territory, consumer category and supply status. It also showed the amount of money owed by each customer and the date the customer had last paid his bills.

Other information provided by the AMM included customer locations (in form of unique geocoded property reference numbers), metering details, and consumption patterns (shown by means of graphical plots of historical monthly consumption volumes). The AMM also allowed users to perform searches based on customer account number, name and location, and to filter records based on the amount of payment arrears and debt age. Using the AMM, it was possible to generate a detailed statement showing all transactions for a selected customer. Finally, the AMM provided running totals of arrears and collections for individual Territories and for the Branch as a whole, compared against contractual performance targets set for the given month.

The AMM was deployed on computers at the Branch offices, as well as in the Commercial department of the KW main office. The target users were the Branch Managers, Branch Commercial Officers, and Territorial Managers.

Web-Mapping Applications
As a further activity, a geodatabase was established for a selected Branch, and a set of prototype web-mapping applications were designed and implemented. These tools provided functionality for tracking the connection status of individual customers, their consumption and payment histories, as well as complaints received from the customers. The web-mapping applications, together with the underlying base maps and geodatabase, were developed using the ESRI ArcGIS Desktop and ArcGIS Server applications. Details of the development process are contained in Paper VII.

In order to identify the required functionality for these web-mapping applications, individual consultations and group discussions were held with the prospective end-users in the selected Branch. Thereafter, data was migrated from existing CAD maps and Micro-
soft Access database files into an ArcGIS geodatabase. Using these data layers, base maps were created. A number of geoprocessing models were developed to provide functionality matching the requirements earlier identified. Subsequently, the base maps and geoprocessing models were published to a server environment and made accessible to users over the corporate intranet by means of web-mapping applications developed using ArcGIS Server.

Case 4: Budget Implementation Monitoring and Control

The Problem

A water utility with city-wide operations, managed through a tiered, decentralized structural setup, faces challenges when it comes to budgetary control. At the business unit level, departmental and unit heads need to be aware of budgetary allocations made for different activities and expenditure items relating to their units, both of a capital and operational nature. They also need to be able to keep track of the status of these various allocations, as this should guide their decision-making on whether to enter into commitments with suppliers and service providers regarding these items. Furthermore, they should be able to plan and synchronise their expenditures with the overall procurement plan of the company, to ensure adequate cash flows and smooth implementation of planned activities. Strict compliance to statutory requirements such as those set out by the Uganda Public Procurement and Disposal of Assets (PPDA) Act (PPDA, 2003) means that the procurement cycle can be quite an elaborate one, making the proper coordination of procurement activities even more crucial.

Poised at the start of a new financial year, the Operator (KW) was handed an approved budget by the NWSC head office that had been significantly reduced from KW’s original proposal. In recognition of the need to put sufficient measures in place to ensure strict budgetary control, the KW Top Management appointed a Budget Implementation Monitoring (BIM) committee, consisting of departmental heads responsible for the Finance, Accounts, Procurement, Development, Monitoring and Evaluation functions within the organization. This committee identified the need for a computerized tool to help in tracking of expenditure and to provide information to guide decision-making at various stages of the procurement cycle.

Participatory Processes

The researcher was co-opted to the BIM committee and was tasked with the responsibility of developing a computerized tool to track procurements and expenditure within the company. At its first sitting, the committee spent close to a whole day reviewing the entire procurement process for expenditure items of both capital (CAPEX) and operational (OPEX) nature, and identifying in great detail the actors, activity centres, actions and information needs at each point. During this discussion, some necessary modifications to existing practices and procedures were identified and agreed upon. The result was a comprehensive needs assessment and high-level specification for the proposed computerized budget tracking tool, which formed the blueprint for the application that was later developed.

Data Management Tools

Based on the comprehensive systems requirement analysis carried out by the BIM committee, the researcher developed a Budget Tracker (BT) application. This application consisted of a database containing all items within the company’s approved CAPEX and OPEX budgets for the entire financial year, coded by end-user department or business unit. Its primary purpose was to track cumulative commitments made against each budget item, and to prevent over-commitment or “bursting” of budget votes. Designed to model the procurement process, it contained modules for capturing purchase requisitions made by user departments, purchase orders issued to suppliers, deliveries and invoices from suppliers, and payments made to suppliers. It also captured and kept track of direct cash expenditure, cash advances and accountabilities. Status reports on the total commitments and expenditure per budget item and for each business unit could also be generated.
The BT application was installed on a server at the KW main office and was made available to various departmental heads and to line staff in the Finance and Procurement departments.

RESULTS

In this section, the results of the various activities carried out during the study are presented. They include the outputs of the participatory problem identification and brainstorming sessions; the prototype data management tools that were developed; the maps and geovisualization tools that were produced; and the results of the hydraulic and geostatistical modelling analyses.

Outputs of Participatory Processes

One output of the first T-Cube discussion session in Case 1 was the identification and clustering of technical problems facing KW as a whole (Table 2). Subsequent T-Cube sessions identified and carried out several investigative actions to try and understand the problems that were being experienced in the Naguru sub-system and propose appropriate remedies. These actions are detailed in Paper III.

In Case 2, a detailed and comprehensive

<table>
<thead>
<tr>
<th>Cluster 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lack of motivation of technical staff.</td>
</tr>
<tr>
<td>• Emphasis on commercial activities at the expense of technical ones.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Water supply imbalance (failure to supply water).</td>
</tr>
<tr>
<td>• Transmission and distribution bottlenecks (dry zones, booster requirements, wrongly sized pipes, aged pipes etc).</td>
</tr>
<tr>
<td>• Uncoordinated “troop” movements.</td>
</tr>
<tr>
<td>• Inadequate documentation of the network.</td>
</tr>
<tr>
<td>• Insufficient storage.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lack of a formal meter management framework.</td>
</tr>
<tr>
<td>• Insufficient network fixtures.</td>
</tr>
<tr>
<td>• Faulty network fittings (inaccuracy of bulkmeters, inaccessible valves and washouts, etc).</td>
</tr>
<tr>
<td>• Competence and training of technical staff (map reading etc).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Poor planning of network infrastructure.</td>
</tr>
<tr>
<td>• Lack of feasibility analyses prior to implementing new connections.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lack of coordination between KW and road contractors &amp; other utilities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bureaucratic bottlenecks in accessing materials requisitioned for.</td>
</tr>
<tr>
<td>• Limited availability of transport for emergency work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Insufficient sewerage infrastructure.</td>
</tr>
</tbody>
</table>

Table 2: Clustering of technical problem issues facing the KW network, as identified by members of T-Cube.
Table 3: Extract from NRW Reduction Action Plan.
(BE = Branch Engineer; DMEM = Development, Monitoring and Evaluation Manager; OMM = Operation and Maintenance Manager; NE = Network Engineer)

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>ISSUE</th>
<th>STRATEGY</th>
<th>ACTION</th>
<th>BY WHO</th>
<th>BY WHEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>PHYSICAL LOSSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aged pipes in the network</td>
<td>Replace affected sections of the network.</td>
<td>Extract detailed list of affected sections (pipe size, material, length, age) from branch business plans</td>
<td>BEs</td>
<td>Immediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compile lists of additional problematic pipes/sections</td>
<td>BEs</td>
<td>Immediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prioritise based on age, frequency of leaks and bursts, size of pipe</td>
<td>BEs</td>
<td>Immediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prepare BOQ’s for replacement works</td>
<td>BEs</td>
<td>Immediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Identify and reallocate funds from network rationalisation, network intensification or extension votes</td>
<td>DMEM</td>
<td>Short term</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Procurement of materials and fittings</td>
<td>DMEM</td>
<td>Short term</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Implementation of replacement works</td>
<td>DMEM</td>
<td>Short term</td>
</tr>
<tr>
<td>Poor quality materials.</td>
<td>Replace sections in the network with identified poor quality pipes and fittings.</td>
<td>Combi the network and replace poor quality fittings causing problems to the network.</td>
<td>DMEM</td>
<td>Short term</td>
<td></td>
</tr>
<tr>
<td>Pipes cut during civil works e.g. road works, drainage construction.</td>
<td>Ensure proper coordination with other service providers.</td>
<td>Set up a system for routine reporting and follow-up of problematic pipes</td>
<td>OMM, BEs</td>
<td>Long term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compile list of poor quality materials and fittings to be submitted to Procurement Dept.</td>
<td>DMEM, NEs</td>
<td>Short term</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Set up a system for routine reporting and follow-up of suspicious activities that could result in pipe damage.</td>
<td>DMEM, NEs</td>
<td>Immediate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liaise with stakeholders like KCC, MOW etc, to obtain information on planned works.</td>
<td>OMM</td>
<td>Continuous</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Identify valves, fire hydrants, washouts, and air valves without marker posts and plates.</td>
<td>NEs</td>
<td>Immediate</td>
<td></td>
</tr>
</tbody>
</table>

Action Plan for NRW reduction was drawn up, consisting of issues to be addressed, strategies for addressing these issues, specific actions to be implemented under each strategy, actors, and timelines. Table 3 contains an extract from the Action Plan that was formu-
An implementation schedule was also drawn up (Fig. 13). In Case 3, discussions were held with prospective end-users of the web-mapping tools to be developed, and a matrix of requirements for these tools was produced as an output of these discussions (Table 4). Likewise in Case 4, extensive discussions held by members of the BIM committee led to the formulation of a comprehensive needs as-

<table>
<thead>
<tr>
<th>Action Plan Item</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
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</thead>
<tbody>
<tr>
<td><strong>(A) REDUCTION OF PHYSICAL LOSSES</strong></td>
<td></td>
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<tr>
<td>Rehabilitation of problematic sections of the network infrastructure</td>
<td></td>
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<tr>
<td>Identification and replacement of aged pipes and fittings</td>
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<tr>
<td>Relocation of exposed pipes and pipes prone to damage by traffic</td>
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<tr>
<td><strong>Reduction of pipe damage due to civil works activities by other utilities and service providers</strong></td>
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<tr>
<td>Improvement of coordination of works and information flow with other utilities</td>
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<tr>
<td>Improved marking of locations of pipes and fittings (concrete markers for pipes, marker posts and plates for fittings)</td>
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<tr>
<td><strong>Improvement of workmanship in pipe laying, new connection implementation and O&amp;M activities</strong></td>
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<tr>
<td>Provide periodic refresher training for field staff</td>
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<tr>
<td>Institute stringent mechanisms for works certification and job implementation quality control</td>
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<tr>
<td><strong>Reduction of vandalism of network fixtures</strong></td>
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<tr>
<td>Engraving of fixtures</td>
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<tr>
<td>Construction of protective lockable chambers</td>
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<td></td>
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<tr>
<td>Public awareness and sensitisation campaigns</td>
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<td></td>
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<tr>
<td><strong>Pressure Management</strong></td>
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<tr>
<td>Procure services for a pressure management study</td>
<td></td>
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<tr>
<td>Implement pressure management controls in affected areas</td>
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<tr>
<td><strong>Proactive leak detection</strong></td>
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<tr>
<td>Carry out a proactive leak detection campaign covering all branches</td>
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<tr>
<td>Institute leak search reconnaissance teams in branches</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>(B) REDUCTION OF COMMERCIAL LOSSES</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Meter Management</strong></td>
<td></td>
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<tr>
<td>Procure services for a meter management study and establish an effective meter management framework</td>
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<tr>
<td>Replace aged meters</td>
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<tr>
<td>Conduct a meter resizing campaign</td>
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<tr>
<td><strong>Illegal consumption</strong></td>
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<tr>
<td>Institute mechanism for routine verification of supply status of suppressed accounts</td>
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<tr>
<td>Institute mechanism for regular audit of meter readings</td>
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<tr>
<td>Strengthen and streamline activities of Illegal Use Reduction Unit, particularly with respect to proactive illegal use detection</td>
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<tr>
<td>Minimise fire hydrant abuse, through construction of lockable chambers and metering of fire hydrants</td>
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<tr>
<td><strong>(C) REDUCTION OF UNBILLED AUTHORISED CONSUMPTION</strong></td>
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<tr>
<td><strong>Mains Flushing</strong></td>
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<tr>
<td>Introduce and enforce rationalised schedules for planned periodic mains flushing and reservoir cleaning</td>
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<tr>
<td>Introduce sufficient isolation/sectional valves in network to prevent emptying of large portions of it during repairs</td>
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<tr>
<td><strong>Fire Hydrant Drawoffs</strong></td>
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<tr>
<td>Identify critical hydrants for Police access and monitor their usage</td>
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<tr>
<td>Meter all flush guns of field teams and monitor/control excessive flushing</td>
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<td></td>
</tr>
<tr>
<td><strong>(D) IMPROVED DETERMINATION/CONTROL OF SYSTEM INPUT VOLUMES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bulkmetering</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Effectively meter all transmission mains and reservoir outlets</td>
<td></td>
<td></td>
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<tr>
<td>Repair/replace faulty bulkmeters within the distribution network</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform district water audits, starting with small pilot districts based on existing bulkmeters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Production management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair/replace all faulty level indicators at reservoirs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establish/harmonise pumpage schedules both at the treatment works and at booster stations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procure services for a Demand Management study, and use the results as a basis for control of production levels</td>
<td></td>
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</tr>
</tbody>
</table>

Fig. 13: Implementation Schedule for NRW Reduction Action Plan
Table 4: Some of the required functionality identified for the web-mapping tools to be developed to support territorial management of customer accounts.

<table>
<thead>
<tr>
<th>Question to be addressed</th>
<th>Type of Analysis</th>
<th>Required Datasets</th>
<th>Functionality required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Who will be affected if this pipe is damaged?</td>
<td>Query By Attributes (QBA)/Spatial</td>
<td>• Pipe network</td>
<td>Select pipe, and show/list affected customers</td>
</tr>
<tr>
<td>2. What are the locations of customers in this branch who owe NWSC over 200,000/=?</td>
<td>QBA</td>
<td>• Accounts</td>
<td>Type in figure, and show customers, color-coded and labeled by amount</td>
</tr>
<tr>
<td>3. Which network pipes are undersized given the number of customers connected to them and volume of water consumed?</td>
<td>Thematic</td>
<td>• Pipe Network</td>
<td>Run tool to display pipes symbolized by aggregated demand and/or no. of customers</td>
</tr>
<tr>
<td>4. What are the location, nature and status of customer complaints received today?</td>
<td>QBA/Thematic</td>
<td>• Complaints register</td>
<td>Run tool to display complaints logged in the Call Centre database, categorized by complaint</td>
</tr>
<tr>
<td>5. Where does Mr. X stay?</td>
<td>QBA</td>
<td>• Accounts</td>
<td>Type in name of customer, and run tool to return a list of matches and show the corresponding customer locations</td>
</tr>
<tr>
<td>6. Where is the bulk of the water in this branch consumed?</td>
<td>Spatial</td>
<td>• Accounts</td>
<td>Run tool to display distribution of customer accounts, symbolized by consumption volumes</td>
</tr>
<tr>
<td>7. Which customers are located within the sewer buffer zone but are not connected to sewer?</td>
<td>Spatial</td>
<td>• Accounts</td>
<td>Run tool to display sewer buffer and highlight affected customers</td>
</tr>
<tr>
<td>8. Where are meters older than 10 years located in our branch?</td>
<td>QBA</td>
<td>• Accounts</td>
<td>Run tool to identify and highlight affected water meters</td>
</tr>
<tr>
<td>9. Which parts of the network are prone to bursts/leaks?</td>
<td>Spatial</td>
<td>• Pipe network</td>
<td>Run tool to classify and display pipe sections based on frequency of failures</td>
</tr>
<tr>
<td>10. If I have a burst, which valves do I need to close to isolate that part of the network?</td>
<td>Spatial</td>
<td>• Pipe network</td>
<td>Run tool to identify and highlight control valves for a selected pipe or portion of the network</td>
</tr>
<tr>
<td>11. Which properties would benefit or be affected by planned mains extensions?</td>
<td>Spatial</td>
<td>• Pipe network</td>
<td>Run tool to identify properties falling within specified pipeline buffer zones</td>
</tr>
<tr>
<td>12. In the event of a fire outbreak at a given location, which fire hydrants would be readily accessible for use by the Fire Brigade?</td>
<td>Spatial</td>
<td>• Pipe network</td>
<td>Run tool to identify hydrants within proximity of a selected property or location, and categorise/prioritise them based on hydrant field condition</td>
</tr>
</tbody>
</table>

Geovisualization Tools
The four maps that were produced in Case 1 are presented in Paper III. They included:
- A dot map showing location and spread of service connections;
- A proportional symbol and graduated colour map of average water consumption;

Geovisualization Tools
The four maps that were produced in Case 1 are presented in Paper III. They included:
- 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.

The Digital Landscape Model (DLM) of the study area that was produced is shown in Fig. 18.

In addition, as part of the process of development of web-mapping applications, ArcGIS base maps were created for the selected Branch (Fig. 19).

Table 5: Requirements for the Budget Tracker tool, as identified by the BIM committee

<table>
<thead>
<tr>
<th>ITEM</th>
<th>DESCRIPTION</th>
<th>STEPS/PROCESSES</th>
<th>DATA TO BE CAPTURED</th>
<th>SOURCE/CAPTURED BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custodian</td>
<td>Finance Department</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tool to be accessed by</td>
<td>All Managers; Line staff in Accounts and Procurement Sections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary items to be tracked</td>
<td>Budget codes; Approved budget amounts; Amounts already committed; Uncommitted balances</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Expenditure Items (CAPEX)</td>
<td>Stage 1- Purchase Requisition (PR) level</td>
<td>Budget Code; PR No.; Subject; Estimated Amount</td>
<td>Procurement Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 2- Purchase Order (PO) level</td>
<td>PR No.; PO No.; Planned Delivery Date; PO Amount</td>
<td>Procurement Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 3- Invoice level</td>
<td>PO No.; Invoice No.; Supplier’s Name; Amount; Date of Receipt of Invoice</td>
<td>Procurement Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 4- Payment level</td>
<td>PO No.; Invoice No.; Payee; Amount Paid; Date of Payment; Payment Voucher No</td>
<td>Accounts Section</td>
<td></td>
</tr>
<tr>
<td>Operational Expenditure (OPEX): (a) Conventional - affecting those items that go through the PR/PO/Invoice/Payment cycle</td>
<td>To follow the same procedure as for the CAPEX items</td>
<td>As for CAPEX above</td>
<td>As for CAPEX above</td>
<td></td>
</tr>
<tr>
<td>Operational Expenditure (OPEX) (b) Non-conventional - affecting those items that do not go through the PR/PO/Invoice/Payment cycle (e.g. Medical Expenses)</td>
<td>Stage 1: Invoice received in Accounts Section and Payment Voucher raised</td>
<td>Date of Receipt of Invoice; Amount; Payee; Voucher Routing No</td>
<td>Accounts Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 2: Payment effected</td>
<td>Date of Receipt of Invoice; Amount; Payee; Voucher Routing No.; Payment Voucher No</td>
<td>Accounts Section</td>
<td></td>
</tr>
<tr>
<td>Non-Conventional Procurements (e.g. Direct cash expenditures; Cash Advance requests etc)</td>
<td>Stage 1: Entry point</td>
<td>Budget Code; Amount; Voucher Routing No.; Subject</td>
<td>Accounts Section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 2: At point of payment</td>
<td>Voucher Routing No.; Payment Voucher Date; Amount Paid; Date of Payment; Budget Code</td>
<td>Accounts Section</td>
<td></td>
</tr>
<tr>
<td>Required Reports</td>
<td>Outstanding invoices not yet paid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Budget under- and/or over-performance, globally for KW as well as for individual business units.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Undelivered orders</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unconverted PPRs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uninitiated procurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Budget reallocations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Considerations</td>
<td>New connection materials - As these are centrally procured, commitments on them will be tracked centrally. A dummy code will be created and the total budgeted amounts for all the branches will be aggregated here.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procurement plan - The Start date will be part of the tracking tool will be specific to the budget line items. Dummies will be made for selected aggregated items.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Branch Capex Purchase requisitions - Anything of capital nature must commence at the centre. A PR can be raised at the branch but must be signed for approval at the centre to enable tracking of the commitment.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>POs signed at the branch - On a weekly basis branches must submit LPOs signed at their end to enable completion of entries in the tracking tool.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Labour for New Connection trenching at the branches -DMEM to provide information on what has been trenched every month from every branch. Accounts Section to update the payments made to trenchers per branch.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Commitments from previous financial year - All POs or commitments from 06-07 are carryovers and should not affect our budget this financial year. They will be placed on a dummy code for the purposes of the tracking tool.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requisitions raised during previous financial year - All items initiated last FY but not yet committed by 30th June 07 must be coded according to the current budget to enable their tracking.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reallocations – The tool must have the flexibility to permit approved budgetary reallocations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supplementary Budgeting - Two cases: a) where there is an increase in the original amount, this will be treated as a reallocation; b) where a new activity is to be added to the already existing activities, in which case a new budget code would be created and the new amount reflected thereon.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Integration with existing systems - Tool to be designed as a standalone application. After 6 months a review can be made to determine whether to integrate the tool with other systems.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Necessary changes to PR form</td>
<td>“Budget Code” to replace “Vote Head”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Amount Approved” to replace “Programme”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Amount Committed” to replace “Subprogramme”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Uncommitted Balance” to replace “Balance Remaining”</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 14: The Water Supply (WS) module, showing data analysis screen for system input volumes.

Fig. 15: The Quality of Service (QOS) module, showing job card for tracking physical water losses.
Fig. 16: One of several user interface screens implemented in the Account Management Module (AMM); this particular screen is used to track the status of arrears on active customer accounts.

Fig. 17: The Budget Tracker (BT) module, showing data input screen for payments to suppliers.
These maps were subsequently published and incorporated into the web-mapping applications that were established (Fig. 20). A number of geoprocessing models were built, as detailed in Paper VII. An example of the output from one of these geoprocessing models is illustrated in Fig. 21.
Fig. 20: Web-mapping application developed using ArcGIS Server.

Fig. 21: Sample of geoprocessing model for planning of new pipelines. In this example, the model is used to identify which properties would benefit from the company’s policy of providing free connection materials and labor for customers located within 60m of a planned sewer pipeline, and which customers would have to pay extra charges to cover connection costs within the mandatory 100m buffer zone.
Outcomes of Hydraulic Modeling and Scenario Analysis

Paper IV details the hydraulic modelling activities carried out in Case 1. For purposes of demand analysis, five supply zones were demarcated. These were subsequently subdivided to yield a total of ten supply sub-zones (Fig. 22). Historical metered consumption records derived from the Billing database were analysed to obtain demand estimates pertaining to each supply zone (Table 6). The skeletonised Naguru distribution network was used to establish and calibrate a hydraulic model, which was subsequently used to simulate and compare a set of alternative interventions. Examples of the scenarios that were simulated are illustrated in Fig. 23.
Table 6: (a) No. of accounts per supply zone, grouped by consumer category; and (b) Average monthly consumption volumes for each consumer category.

<table>
<thead>
<tr>
<th>Supply Zone</th>
<th>No of Blocks with water accounts</th>
<th>Domestic</th>
<th>Commercial</th>
<th>Govt/Inst</th>
<th>Standpipes</th>
<th>Foreign Dom</th>
<th>Foreign C/I</th>
<th>Foreign G/I</th>
<th>Urban Poor</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gunhill</td>
<td>79</td>
<td>4,229</td>
<td>2,305</td>
<td>328</td>
<td>322</td>
<td>73</td>
<td>14</td>
<td>11</td>
<td>151</td>
<td>7,481</td>
</tr>
<tr>
<td>Makenko</td>
<td>120</td>
<td>1,915</td>
<td>229</td>
<td>31</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,177</td>
</tr>
<tr>
<td>Muyenga South</td>
<td>364</td>
<td>9,046</td>
<td>766</td>
<td>239</td>
<td>219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10,463</td>
</tr>
<tr>
<td>Muyenga North</td>
<td>193</td>
<td>1,046</td>
<td>766</td>
<td>239</td>
<td>219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10,463</td>
</tr>
<tr>
<td>Muyenga South</td>
<td>601</td>
<td>5,151</td>
<td>980</td>
<td>123</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,428</td>
</tr>
<tr>
<td>Naguru</td>
<td>237</td>
<td>16,726</td>
<td>2,779</td>
<td>252</td>
<td>275</td>
<td>18</td>
<td>2</td>
<td>2</td>
<td>248</td>
<td>20,302</td>
</tr>
<tr>
<td>Naguru (Gazana No)</td>
<td>118</td>
<td>1,993</td>
<td>458</td>
<td>60</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,592</td>
</tr>
<tr>
<td>Rubaga</td>
<td>252</td>
<td>10,949</td>
<td>1,777</td>
<td>222</td>
<td>317</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12,854</td>
</tr>
<tr>
<td>TOTALS</td>
<td>1,608</td>
<td>66,172</td>
<td>13,515</td>
<td>2,151</td>
<td>2,164</td>
<td>229</td>
<td>22</td>
<td>24</td>
<td>1,968</td>
<td>106,303</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of Accounts</th>
<th>Average Monthly Consumption Volume per Category (m³)</th>
<th>Maximum of Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic</td>
<td>101,208</td>
<td>16 15 14 14 13 13 13 13</td>
<td>16</td>
</tr>
<tr>
<td>Commercial</td>
<td>16,794</td>
<td>42 42 42 42 43 43 43 45</td>
<td>45</td>
</tr>
<tr>
<td>Government</td>
<td>2,608</td>
<td>13 13 13 13 13 13 13 13</td>
<td>13</td>
</tr>
<tr>
<td>Standpipe</td>
<td>3,220</td>
<td>45 45 45 45 35 35 35 34</td>
<td>46</td>
</tr>
<tr>
<td>Foreign Missions Domestic</td>
<td>252</td>
<td>59 59 59 59 50 50 50 48</td>
<td>48</td>
</tr>
<tr>
<td>Foreign Missions Govt</td>
<td>28</td>
<td>95 95 95 95 95 95 95 95</td>
<td>95</td>
</tr>
<tr>
<td>Foreign Missions C/I</td>
<td>27</td>
<td>153 154 159 148 147 147 147 147</td>
<td>147</td>
</tr>
<tr>
<td>Urban Poor</td>
<td>2,007</td>
<td>29 29 29 29 26 26 26 26</td>
<td>26</td>
</tr>
<tr>
<td>Global Weighted Average for all categories</td>
<td>23 22 21 20 20 20</td>
<td>20 23</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 23: One of the proposed interventions to be investigated through simulation modelling, involving the laying of a new 300mm outlet main (dashed line) from (a) Naguru Tank, all the way to (b) Ntinda Trading Centre.
Results of Geostatistical Analyses
In Case 2, an empirical variogram was generated from historical water sales volumes, and subsequently fitted with a spherical theoretical model. The fitted model was used to generate raster maps of predicted water sales volumes for December 2003 and December 2007. These raster maps of predicted water sales volumes were used to generate a difference map. Distribution plots of reported field irregularities were subsequently overlaid on the difference map. The results are presented in Paper V.

DISCUSSION AND CONCLUSIONS
This section discusses the results presented above with respect to the level of achievement of participation in problem-structuring; the challenges of getting the prototype data management tools adopted by the prospective end-users; the role played by the geovisualization tools; and the potential benefits of the hydraulic and geostatistical analyses carried out. Thereafter, a summary of the reflections from the study as a whole is presented. Based on the various actions and reflections, a prototype decision support framework is proposed. The section concludes with recommendations of possible future work stemming from this study.

Participation in Problem Structuring and Requirements Assessment
Paper III reports that the establishment of T-Cube resulted in the promotion of a culture of participatory problem analysis, especially among the middle-management staff of KW. However, it is also noted in Paper II and Paper III that T-Cube did not attract the participation of the top decision-makers within the organization, who continued to apply a more intuitive and spontaneous decision-making approach, pressed by the urgency with which the specific problem situation needed to be addressed. The brainstorming workshops for NRW control, however, enjoyed the participation of a wider spectrum of managers and decision-makers, leading to the formulation of a comprehensive Action Plan. In this particular case, though, as discussed in Paper VI, the greatest challenge turned out to be in implementing the formulated strategies and actions; that is, in moving from planning to action.

Challenges of User Adoption of Data Management Tools
As described in previous sections, during the course of the study the researcher developed a number of custom data management applications. The majority of these applications were developed using Microsoft Access and Visual Basic for Applications (VBA). The choice of developer tools was based on the ready availability of these tools, being part of the Microsoft Office suite of products in common usage in KW. There were thus no additional software and licensing costs involved in the development and deployment of the applications. The second consideration was that the developer tools were easy to work with and provided a ready means of creating simple, user-friendly point-and-click graphical interfaces for the applications that were developed.

Apart from the AMM, all the data management applications were developed in consultation with the prospective end-users at various stages. The consultations were in form of discussions with individual users and periodic presentation of work-in-progress to groups of users, from which feedback was obtained and incorporated into the system designs. The researcher also relied on first-hand observation of the way in which different tasks were carried out by the prospective end-users in executing their day-to-day activities. For the AMM, though, the researcher mostly used his own judgment to decide which modules and functionality to build into the application.

However, despite the potential benefits that these tools offered, it was not easy to get the
intended users to adopt and integrate them into their everyday work practices. Paper III discusses the reasons for this. They ranged from a natural aversion to computer technology, to perceptions of increased data capture workloads and excessive managerial control resulting from adoption of these tools. In the case of the AMM, a lack of end-user participation in the system development process resulted in a case of “iceberg subjects” (a term described in Paper I as a situation where the real possibilities for improvement are not understood by the intended beneficiaries).

**Roles and Benefits of Geovisualization Tools**

In Case 1 (Paper III), four maps were produced. The first of these maps served to provide a spatial overview of the extent and density of water supply coverage in the area. The second map provided a picture of how water consumption (and implicitly, water demand) varied throughout the area. The third map highlighted which specific types of problems were being experienced in different parts of the network, and enabled the pinpointing of locations of physical weaknesses in the pipe infrastructure. The fourth map helped in identifying which areas could or could not be supplied by gravity flow alone.

In addition to the four maps, the Digital Landscape Model (DLM) provided an interactive tool for navigating through a virtual model of the study area in three dimensions, acting as a further means of visualizing and understanding the interplay between the terrain in the study area and the hydraulic behavior of the piped water network.

The four maps and the DLM proved to be useful tools in enhancing the debates that occurred during the T-Cube sessions, and enabled a better understanding of the underlying causes of the problem situation faced in the area.

In Case 3, with the establishment of a set of web-mapping applications, real-time customer related information derived from the billing database was made available to the Territorial Managers at the Branch offices in a form suitable for spatial analysis. This greatly facilitated processes such as attribute-based spatial data search and retrieval at Branch and territorial level. The ArcGIS base maps were more intuitive to interpret than the CAD ones previously in use, and the access to dynamic data linked to the map features was a great improvement from the previous static situation.

**The Role and Benefits of Hydraulic Modelling**

In Case 1, a hydraulic model of the study area was established and calibrated. This model was subsequently used to simulate a set of alternative scenarios representing identified options for improving both the upstream and downstream performance of the Naguru piped water infrastructure. Based on the analyses carried out, conclusions were drawn regarding the capacity of the existing transmission mains to handle present and projected water demands within the area, both with and without implementation of proposed changes within the downstream distribution network. Similarly, the effects of implementing alternative interventions on the hydraulic regime within the area as a whole were assessed. Hydraulic modelling was thus demonstrated to be a very useful tool for planning and design of interventions in piped water systems. Presentation of model results to stakeholders using simplified sketches was found to improve on the understanding and awareness of the non-technical decision-makers concerning the outcomes of hydraulic modelling activities, which often constitute highly technical analyses requiring specialist domain and tools knowledge.

**Benefits and Shortcomings of Geostatistical Analyses**

In Case 2 (Paper IV), a geostatistical modelling analysis was carried out. Here, a novel approach was used, which involved generating a continuous spatial map of water losses, and overlaying this map with various field evidences of irregularities. The combination of feature space and geographic space analyses served to highlight the relative contributions of these field irregularities to the perceived declines in water sales, and to highlight spatial trends within these factors. In addition to the maps that were generated, graphs of historical consumption and new
connection data for the area also visually highlighted the problems faced in the area. Furthermore, a geostatistical analysis tool was established for the study area, in form of scripts of R code, making it potentially possible to adapt and reuse the tool in similar analyses for other Branches within KW. However, it was acknowledged that the geostatistical analyses carried out in the study were not exhaustive, and there was room for further work in this area. It was noted that there were few empirical studies of this kind reported in the literature, and so this study would create awareness and prompt interest in the conducting of similar studies in the future.

A Prototype Decision Support Framework

Throughout this thesis, emphasis has been placed on two aspects of DSS development: the need to support and enhance the identification and problem-structuring phase of the decision-making process; and the need to promote the adoption of DSS usage as a culture within every-day organizational decision-making - that is, how best to put DSS to work in practice. Based on the theory, actions and reflections documented in previous sections of this thesis, a prototype decision support framework has been proposed. The framework is both empirically derived and normative, as it is based on practical experiences drawn from the case-based activities carried out during the course of the study, but is also informed and influenced by the classical frameworks (Gorry & Scott-Morton, 1971; Alter, 1977; Sprague, 1980; Power, 2004) as well as the classical decision-making paradigm described in the literature.

From the background theory earlier presented, a summary of the typologies and characteristics of DSS has been compiled (Table 7). Based on this and on the study outcomes, a procedure for provision of decision support for problem-solving has been formulated. A process flow chart for this procedure is shown in Fig. 24. This process flow chart constitutes the prototype decision support framework that is proposed as an outcome of this study.

The following may be noted concerning the proposed framework:

- The framework is structured in form of a business process flow-chart, modelled along the lines of the process flow-charts that constitute part of KW’s documented Quality Management System (QMS) (KW Quality Manual, 2007). This is to further emphasise the need to embed structured decision-making within established organisational work systems, and the need to focus on improving business processes rather than on developing and deploying computerised information systems. The framework acts as a basis for incorporating formal decision-making processes as part of the organisation’s documented procedures and work instructions, which themselves are subject to periodic review as part of a continuous learning and organisational improvement process.

- The purpose of the framework is to act as a basis for identification of the nature and mode of delivery of formal decision support tools and processes to be availed to various levels of decision-makers at various stages of a decision-making process, in the face of a given problem situation affecting a specific business process. In this respect, the framework seeks to support meta-decision-making; that is, it provides decision support about the required decision support.

- As a decision support tool itself, the proposed framework is dynamic, contextual and adaptive in the sense that its contents (the specific repertoire of decision support tools, participants and processes) will depend on the specific problem situation being addressed. A starting point in the decision process for a given problem situation would therefore be to populate the framework itself, through a process of identifying which business process (or processes) is affected, understanding (and if necessary, modifying) this business process, and then identifying the decision support tools and activities required at each stage. The action learning that may occur as this process unfolds should feed back into refinement and improvement of the affected busi
Table 7: Summary of DSS Typologies and Characteristics, derived from the literature.

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>PROBLEM DEFINITION</th>
<th>DECISION PROCESSES</th>
<th>PARTICIPANTS</th>
<th>DSS TOOLS SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stimulus</td>
<td>Nature of Problem</td>
<td>Type of Problem</td>
<td>Level of Mtg Activity</td>
</tr>
<tr>
<td>CATEGORIES</td>
<td>Opportunity</td>
<td>Decision Problem</td>
<td>Non-Decision Problem</td>
<td>Structured Semi-structured</td>
</tr>
<tr>
<td></td>
<td>Crisis</td>
<td>Problem</td>
<td>Non-Decision Problem</td>
<td>Unstructured Operational Control</td>
</tr>
</tbody>
</table>
Fig. 24: The prototype decision support framework.
ness process, or perhaps even result in the creation of new business processes where necessary. This was exemplified in Case 4 of this study.

- Another important aspect to be considered in applying the proposed framework relates to the level of management activities for which decision support is being sought. In retrospect, it is clear that most of the tools developed and applied within this study provided support at the operational control (and to some extent, the management control) levels. This may be as a result of the fact that the organisation within which the study was carried out (Kampala Water) was, in essence, an Operator (under the IDAMC framework) whose primary mandate was that of implementing water management activities of an operational rather than strategic planning nature. It may therefore be true to some extent to consider the proposed framework to be more applicable to the operational control and management control levels of management activities, rather than the strategic planning level.

- The proposed framework also emphasises the inclusion of participatory processes at all stages of the decision-making process, including the initial step of establishing a decision support framework pertinent to a given problem situation and context. The actual participants may vary depending on which stage of the process is being implemented, as well as on the level of managerial activity involved; however, a fundamental aspect of the participation should be the need for continuous learning and reflection on the part of the participants. Problem-solving should act as an opportunity for enactment of a mutual learning process. Thus, participation should also involve aspects of training, benchmarking, peer review and knowledge transfer, and proper documentation of activities and outputs at each stage should be done, acting as an audit trail and enriching the knowledge base of the organisation. These attributes were emphasised during, and were a major characteristic of, the T-Cube discussion sessions.

- As a direct outcome of practical activities carried out within the case studies described in this thesis, three categories of decision support tools emerge: Geovisualisation tools, in support of problem identification and structuring; Data Management tools, for continuous collection, analysis and presentation of data (evidence) required to inform various stages of the decision-making process; and Modelling tools, useful in the generation and evaluation of alternative solutions to problems (the design stage of the decision-making process), as well as in informing the problem-structuring stage.

- A fourth category of decision support tools has been included within the framework, namely Choice models. Within the scope of this study, this category of tools was not empirically investigated, due to the fact that the researcher’s focus and emphasis was on the Intelligence (and to some extent, Design) phases of the decision-making process. During the early stages of the research, however, a desk study was carried out by a Masters student attached to the project as a research assistant (Karungi, 2006). The study sought to assess and compare various Multi-Criteria Decision Analysis (MCDA) tools and make recommendations of possible tools to be applied within the broader research project. However, as earlier mentioned, these tools were not explicitly used within the scope of the four case studies. It is recognised, though, that these and similar tools (such as financial and economic models) would be required to provide more formal decision support at the choice stage.

- The fifth category of decision support tools, namely Task Management tools, has been prompted by the identified difficulties in making the transition from planning and decision-making to effective implementation of selected courses of action. Closing the gap between the end of a decision-making process and its implementation by preserving and communicating the context within which the decision has been taken, and linking decision implementation activities to the corre-
sponding decision process, is considered essential to making the decision cycle fully successful. During the study, a start was made on the development of a customised “Task Manager” tool. However, due to time constraints, this tool was not tested within the scope of the activities reported in this thesis.

- Finally, it should be emphasised that the proposed framework is still emergent in nature. It is the outcome of reflection on the actions carried out during the study, together with attempts to relate the results of these actions to the theory that informed and prompted them. Within the constraints of this research project, it has not been possible to enter the next iteration of the classical theory-action-reflection Action Research cycle to test the proposed framework on new case studies, with a view to refining it. This will be an area for future work.

Summary and Future Perspectives
This thesis has been based on seven papers. Paper I highlighted the shortfalls of traditional approaches to research in the technological sciences, with respect to their failure to effectively impact on practice and to support joint learning between academicians and practitioners. In the paper, Action Research (AR) was proposed as a suitable way of bridging this gap. The AR approach was deemed necessary for the development of appropriate and sustainable technologies and technological practices in the developing world, particularly in the field of Information Systems development.

In Paper II, an AR approach was used to explore the challenges inherent in decision support systems development in an urban water utility in Uganda. Using case studies, three aspects of interest were highlighted: the need for proper problem identification prior to formulation of actions; the challenges of moving from planning to action; and the importance of embedding formal decision support processes within existing work systems in organisations. The necessity of a holistic outlook, going beyond a focus on technological tools, was underscored.

In Paper III, the role of geovisualization in enhancing problem identification was explored. Geovisualization was demonstrated to be useful in “making data visible” and supporting decision-making in an urban water supply management context. Furthermore, the establishment of a discussion forum for participatory problem analysis was found to be beneficial in promoting structured decision-making within the company. Paper IV involved the use of hydraulic modelling and simulation analysis to support the generation and evaluation of alternative courses of action. The simulation modelling results acted as a basis for understanding the implications of implementing proposed interventions, thereby aiding the choice process.

Paper V explored some useful geospatial and geostatistical analysis tools for problem identification and statistical inference. It was noted that reported empirical studies involving the application of geostatistics to water loss management within urban water supply systems were few, and therefore it was anticipated that this study would prompt further research into this specific application area in the future.

Paper VI explored the reasons why a gap existed between the outcomes of planning and decision-making processes and the effective implementation of proposed actions. Among other things, it emphasised the need for strengthened supervision, monitoring and evaluation activities, as well as a commitment on the part of all players to support and systematically see planned actions through to their logical conclusion.

In Paper VII, web-technology was demonstrated to be a useful platform for the development of tools facilitating decentralised management of customer accounts. Through the case studies, a number of insights have been gained into how best to ensure successful DSS implementation in an organization. As an outcome of the study, a prototype decision support framework has been proposed. The framework is emergent, based as it is on reflections on the empirical actions carried out within this study. It is hoped that in future this framework will be subjected to further research, development
and refinement, as subsequent iterations of action research within the organisation unfold.

Looking beyond the technology, it is hoped that this thesis work has created awareness on the need to apply a more structured and rigorous approach to decision-making within the organization, going beyond “fire-fighting” or problem-resolving to systematic identification of the best possible solutions to problems encountered, and even to the adjustment of basic systems and business processes as a way of preventing problems from arising in the first place. This shift from a clinical to a research and design orientation will be key to ensuring that the organization not only survives, but continues to grow and develop.

This study has been carried out within the framework of a broader research collaboration programme, whose overarching theme is “Sustainable Technological Development in the Lake Victoria Basin”. The study has been performed as part of an academic PhD research undertaking. This fact notwithstanding, both the aim and context of the study have justified the usage of a hands-on, action-oriented research approach. This kind of approach holds the promise of delivering tangible results that are of practical benefit to a developing nation like Uganda, as she strives “to take all practical measures to promote a good water management system at all levels” (Constitution of the Republic of Uganda, 1995).

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