An Open Source GIS Solution for Managing Water Supply, Distribution and Billing

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ABSTRACT

In this work a comprehensive geocomputing solution for the Gatanga Water Trust (GWT) has been developed to assist it in managing its water supply and distribution. The solution comprises two subcomponents: a mapping component and a billing component which are tightly coupled together. The proposed system uses stable open source products for the mapping component and the database. At present the GWT uses outdated maps and sketches for design and installation of a new water supply infrastructure. A billing system is in place which is used to manage client accounts, record meter readings, prepare bills and record payments made. This presents a somewhat disjointed approach to management of the water supply and its attendant infrastructure. The database that stores the account information is very different (softcopy) from that storing the spatial information (hardcopy/paper based).

In the proposed solution, a single database is used, centralized or distributed. The mapping component provides an interface through which preliminary design of new and planned infrastructure can be done. After installation of such infrastructure and their subsequent mapping, these are reflected in the database and the information becomes available as soon as it is stored. The billing component uses the same database to manage account information. Since the information is managed in one system, there is a streamlined and orderly flow from data collection to the final products from the system.

The proposed solution leverages advancement in technology by providing two approaches A desktop application for users within the Trust's intranet and a web mapping application for users utilizing the wider internet.

1 Introduction

Improvements in information technology have provided unimaginable opportunities to support data analyses and communications in the last two decades. Geographic Information Systems (GIS) have provided new and exciting ways of acquiring natural resource data and are also providing efficient means of processing, managing and integrating this data, such as in watershed management (Opadeyi, 2007). While varying definitions exist for what a GIS, (see Aronoff (1989) and Tomlinson, (2003) for some of the definitions), there is a general consensus that a GIS is an organized collection of computer hardware, software, geographic data, procedures and rules and personnel, designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information.

A Geographic Information System allows one to create and manage spatially referenced data which is useful for any field or situation that utilizes spatial information. In the recent past GIS has been mainstreamed, since every conceivable field can potentially be enriched by using GIS technology to manage the location based information. On this front, there are a number of GIS products that can be used – proprietary (closed source) and open source. Commercial products while possessing powerful analysis features are expensive and for most clients, such solutions may not be fully utilized when procured. On the other hand, while open source products may not have the same level of complexity, they have features that can be used to answer some simple analyses. In some cases though, they are excellent alternatives since some have advanced analysis features (Sherman, 2004).

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For planning and design, the Gatanga Water Trust (GWT) uses outdated topographical maps and sketches drawn when the pipes were laid out. At present it does not have any softcopy spatial management system in place. This approach implies that it is very difficult to visualize this information in real-time incorporating proposed designs and new infrastructure installations. There is an electronic billing system in place which the management says is fraught with inconsistencies. Since this system is not connected with the spatial management system, it is not easy for employees to visually connect between client accounts and their locations in space. This current approach is thus very limited and the Trust is not able to leverage technological advances to improve the management of the water trust.

This work sought to develop an open source geocomputing solution to assist GWT manage its water supply infrastructure and distribution network. This solution comprises a desktop mapping and billing solution targeted for the intranet user and a web mapping and billing solution for both internet and intranet users. To realize this, the following specific objectives were formulated: (i) determine current and future system needs for the Trust, (ii) formulate a desktop GIS strategy to solve the needs, (iii) formulate a web based GIS strategy for internet users, (iv) combine the two solutions (strategies) into one overall solution for the Trust.

2 The study area

The study area (Figure 1) was the region covered by the GWT which covers the whole of the Gatanga District as an administrative region which incidentally has the same boundaries as the Gatanga Constituency as a political region. It comprises of 4 main sublocations namely Gatanga, Kariara, Kigoro and Kihumbuini. It has several shopping centers (settlements) distributed throughout the district. Figure 1 shows the spatial extent of the district.

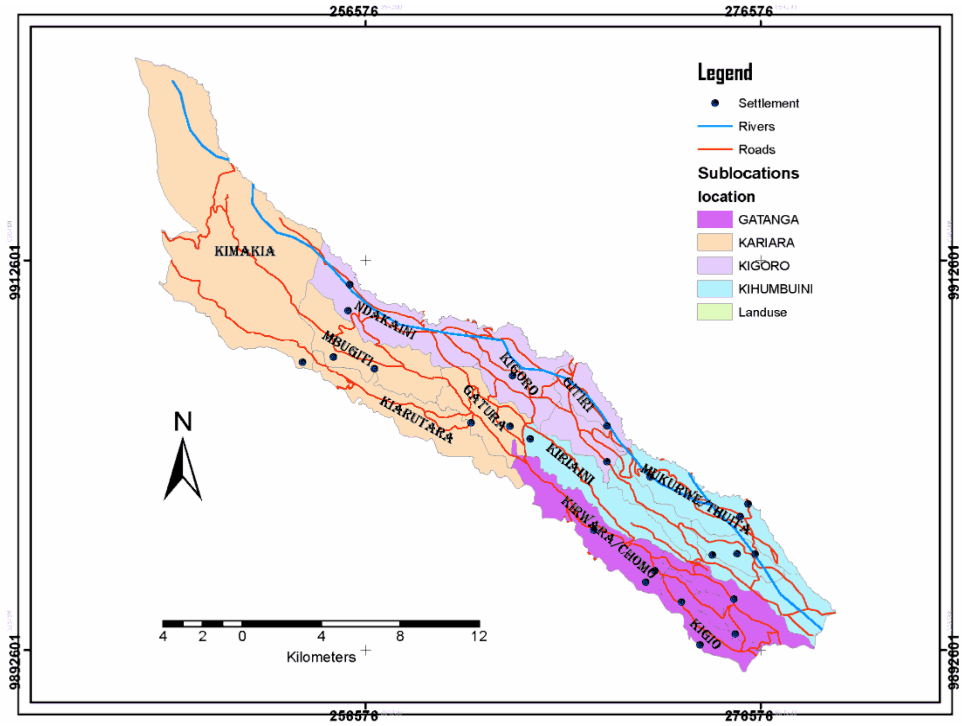


Fig. 1: The study area

The main economic activities of this region are agriculture and forestry with much of Kimakia forest being part of the Aberdare forest system. Kimakia sublocation is mainly covered by the forest with the rest of the sublocations under small-holder coffee and tea plantations.

GWT was formed as a result of the water sector reforms initiated in 2002. It is run by a board of trustees drawn from Gatanga District representing individual locations. The distribution system in the scheme is wholly gravity-induced and is served by two water intakes constructed inside the Kimakia forest. The intakes draw water from the Kimakia and Thika rivers. Initially the GWT had 2000 active connections but since the injection of funds the number rose to 4000. The current water production stands at 7000 m3 per day. It serves approximately 9000 active consumers of which 4000 have been metered. The core functions of the GWT are sourcing of water, treatment and conservation of water, distribution of water, billing and revenue collection (Gatanga, 2010)

The scheme has two subsystems which are independent of each other. They are referred to as North and South of Kiama. The North of Kiama River system gets its water from the old intake constructed on the Thika River. It serves Kigoro, Mukarara, Kiriaini and Kihumbuini locations. The South of Kiama River system gets water from the newly constructed intake on the Kimakia River. It serves Kariara, Gatanga and Mugumoni locations. The pipe network stretches from Kinguri – Gatura – Chomo – Kirwara – Kigio and Gatunyu (Gatanga, 2010).

3 Methodology and Activities

The composite system uses two design approaches geared at coming up with (i) an internet application and (ii) a desktop application.

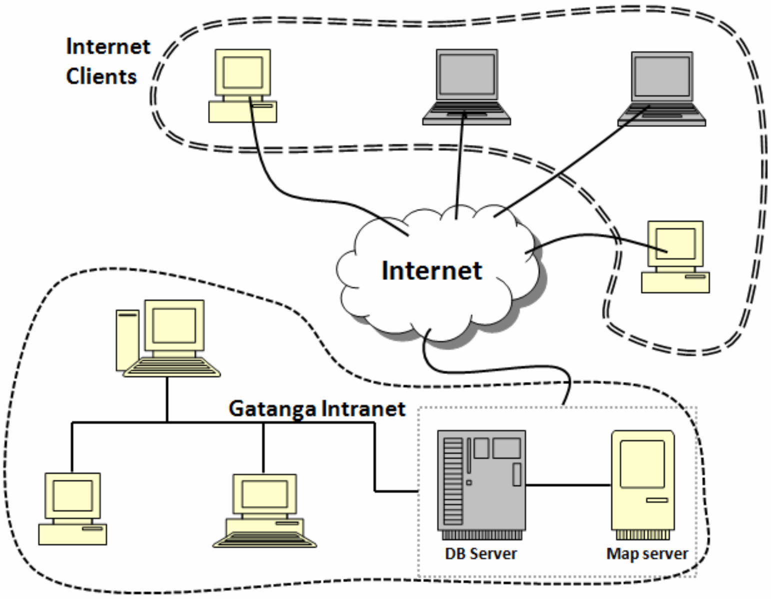


Fig. 2: The envisaged system infrastructure

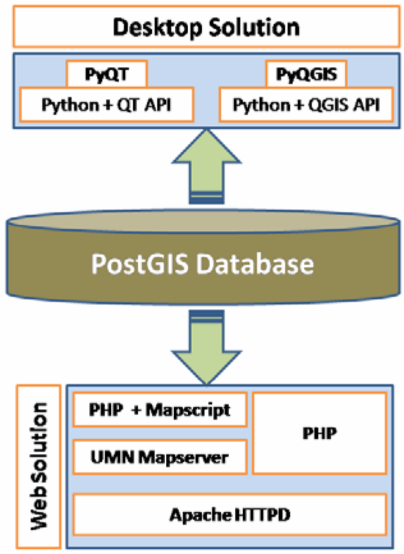


Fig. 3: Open source tools used

Figure 2 captures this design viewpoint where two types of users are anticipated: the intranet user and the internet user. The intranet user is a staff member of the Trust while the internet user is thought of as (i) an account holder or (ii) a general internet visitor or (iii) a staff member working from home or remotely. For this purpose two application approaches have been adopted, with the desktop solution addressing the needs of the intranet user, while the web mapping application addresses the needs of the internet users. The composite system uses the same underlying database server to manage the information. The desktop application connects and communicates with the database server but does not make use of the map server. On the other hand, the internet application connects to the database via the map server. In this case the map server serves as a proxy and as a rendering engine to prepare the maps for onward transmission to the internet client.

Figure 3 shows how the various open source tools were used in the solution development. Figure 4 shows the associated logos which belong to the respective developers and the Open Geospatial Community (OSGeo). For the desktop solution, a standalone application was developed using Python and the Python bindings for QT (PyQT version 4) and QGIS (PyQGIS) allowing access to the respective Application Programming Interfaces (APIs) (Dobias, 2011). The web solution uses P.Mapper framework, which is a custom PHP Mapscript application that utilizes PHP Mapscript and University of Minesota Mapserver as the map rendering interface, with billing implemented using PHP and extending the P.Mapper based application. Both systems utilize a PostGIS database which is a spatially aware PostgreSQL database.

Figure 5 captures the flow of activities that were undertaken to realize this research. It comprises four phases (i) a preliminary (conceptualization) phase, (ii) a development phase, (iii) an evaluation and assessment phase and, (iv) an implementation phase.

UMN Mapserver
PostGIS
Quantum GIS
PostgreSQL Server
QT Framework

Figure 4: The GIS Stack

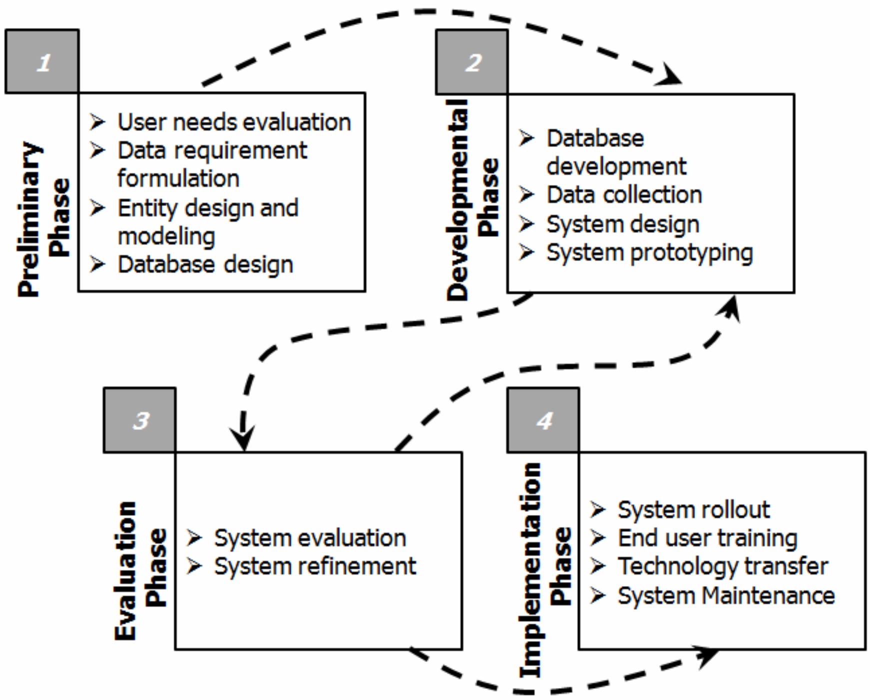


Figure 5: Project Workflow

During conceptualization phase, a detailed inventory of the current and anticipated future needs was carried out based on interviews. This yielded information on the data required to address those needs. In this phase all entities that needed to be stored in the database and their relationships were identified. The entities that were identified in this step were: water meters, customers, pipes, pipe nodes, valves, break pressure tanks, normal tanks, intakes, meter readings, bills, payments and parcels. For the general basemap, other entities identified include: sublocations, roads, rivers, settlements and landuse. There were attributes that were identified and connected to each of the entities identified.

During the developmental phase, the necessary database schema for the entities identified was implemented. In parallel, all necessary data was collected and aggregated into this database. Data collection was done using hand held Global Positioning System (GPS) receivers. The entire system was designed identifying the various features and functionalities that needed to be implemented to answer all (or most) of the user needs. In this phase a prototype of the whole system was made available incorporating as many of the features as possible.

The evaluation phase was used for rigorously testing all the implemented features of the prototype, carefully assessing how well the proposed system was able to address all the needs of the end users. In this phase any refinements required were be undertaken. In case of major refinements, these were developed and incorporated in the prototype and reevaluated. Hence the development and evaluation phases fed back and forward until a stable prototype was achieved. It is during this phase that user manual manuals and system documentation were written.

At the implementation phase, the prototype was migrated to the Trust's network, installed and configured for daily usage. To ensure proper use of the solution, end user training was conducted. This training served as a means to transfer knowledge about the underlying technologies to the Trust. All these phases have already been completed for the desktop solution. Portions of the web solution are still being developed and it is yet to be deployed to GWT. For the desktop solution, a maintenance schedule is currently being discussed with a view of keeping the system up-to-date and incorporating new ideas and needs. This will also help refine the web mapping solution as a consequence.

4 Results

The following mapping features were included in the solution: (i) interface with a map window with tools that allow users to zoom in/out, pan, zoom to full extent or zoom to a window of interest, (ii) tools to allow turning on/off of data layers in the window, (iii) tools to allow users to interrogate the map displayed to retrieve non spatial attribute information for the point under a cursor, (iv) tools that allow the users to display a layer using default symbolization (using symbols from the Gatanga) or allow the user to use other symbolization, display a thematic display of the layer using any of the available attributes, (v) allow the users to perform attribute querying using available attributes, (vi) tools to allow entering of GPS coordinates for new features and their attributes, (vii) tools for deleting data that may need to be removed. Figure 6 show the main desktop interface to the system.

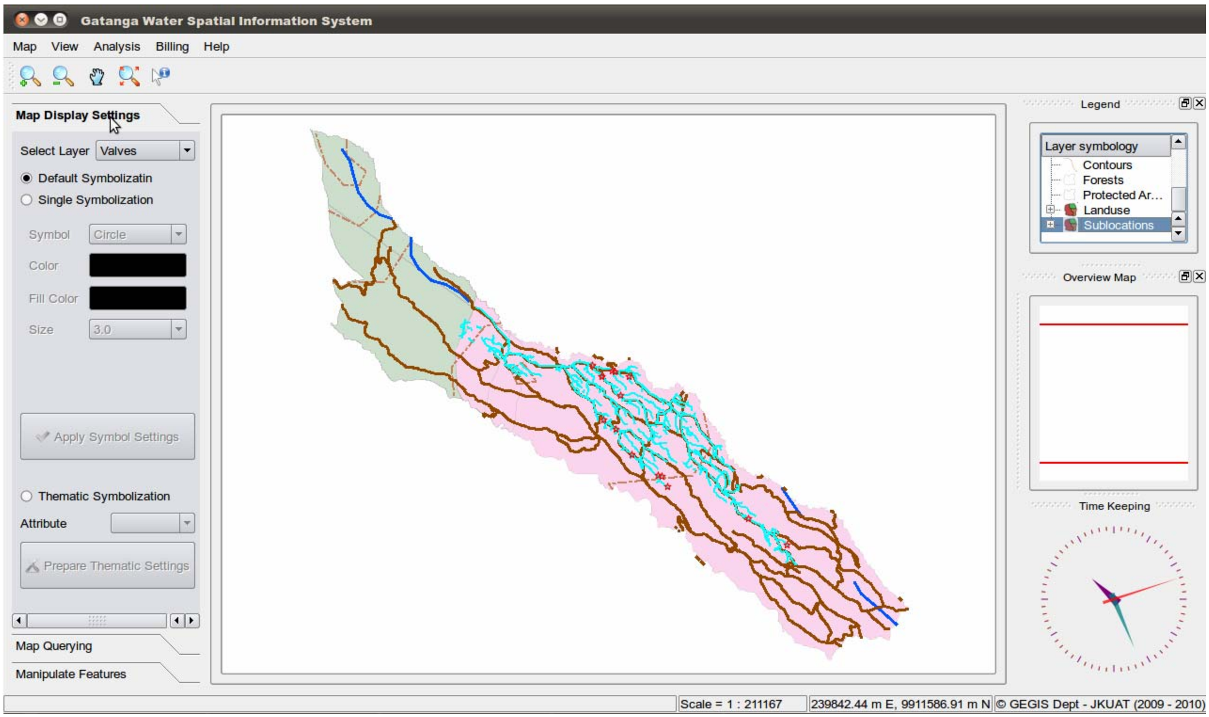
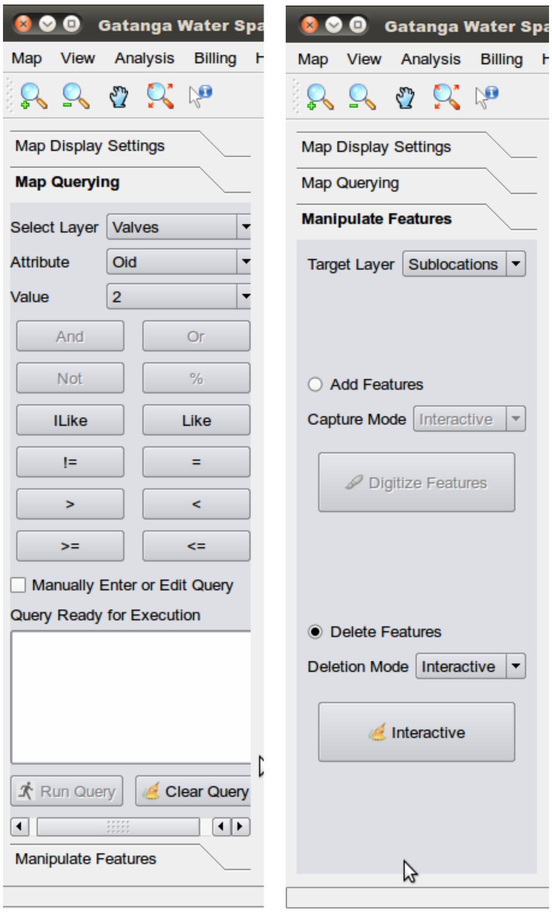
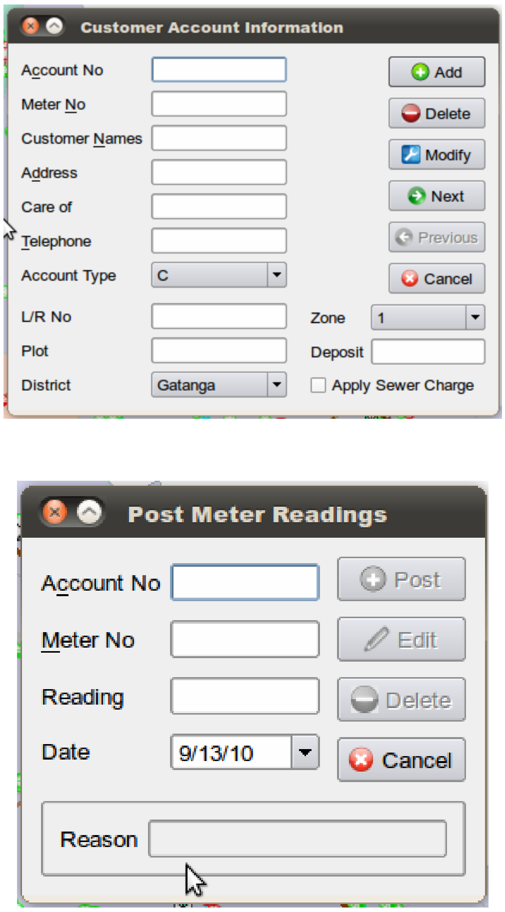


Fig. 4: The main interface of the desktop solution.

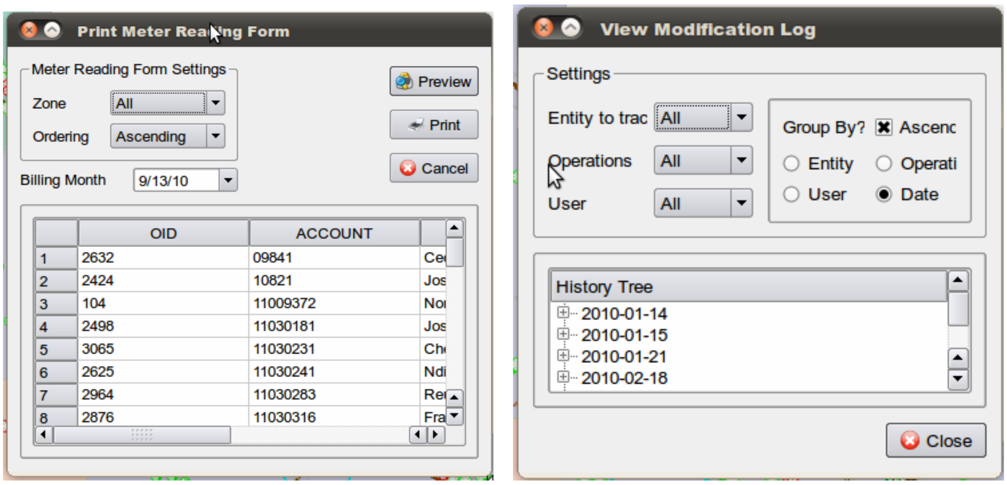
To access this interface the user has to log into the system using credentials that allow tracking in case there are changes made and therefore can assign responsibility for any actions made. On the billing front, the following features were implemented: (i) tools to allow addition of new clients, edit client details, delete former clients, (ii) tools to record meter readings, edit or delete erroneous meter readings and printing out of meter reading forms, (iii) tools to process account billing, allowing printing of receipts. These tools are a sampling of the collection of tools that were developed in this project venture.



a. Map querying functionalities (part of main map interface)



b. Some data entry functionalities



c. Printing functionalities

Figure 2 Some of the implemented functionalities in the desktop application

Figure 7 show some of the interfaces exposing these functionalities, with figure 7(a) showing some of the mapping and spatial analyses capabilities, figure 7(b) showing some of the data entry (insertions) capabilities and 7 (c) showing some of the dialogs for generating reports from the system. The web mapping solution has some of these capabilities (login support, map display and querying, data entry) but report generation was not implemented since it was not anticipated that internet users would require such capabilities.

While no statistics on usage have been obtained so far, the system has been demonstrated as being able to significantly reduce time taken between a new customer (meter) installation and the recording of this in the billing database.

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5 Conclusion

The proposed system has been demonstrated as meeting the objectives set out. The following products have been developed: (i) an open source desktop geocomputing application featuring GIS tools and a billing system, (ii) an open source web mapping solution featuring scaled down GIS tools and billing capabilities (not demonstrated in the paper). To support this system, (iii) a spatially aware database system of the Gatanga water infrastructure was developed and deployed.

This solution can be further customized and extended, with these extensions and customizations being offered to other utility management enterprises. This solution demonstrates that with open source solutions, it possible to come with fairly high quality, production grade products leveraging the strengths of the open source community and geocomputing capabilities, and hence the utility of open source GIS software and the coupling of systems to enhance infrastructure and asset management.

This system has already been deployed on the Gatanga Water Trust's offices and is currently being evaluated and used before it can be fully rolled out. It is therefore recommended that the system, once found to be satisfactory be cascaded to other water service providers.

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References

Aronoff, S., 1989. Geographic information systems: a management perspective. WDL Publications, Ottawa.

Dobias, T. (2011). PyQGIS Developer Cookbook. Retrieved on 13th July 2011 from http://www.qgis.org/pyqgis-cookbook/

Gatanga Constituency (2010). Development Projects Overview. Retrieved on 20th June 2011 from http://www.gatanga.com/projects/20.html

Opadeyi, J., 2007. Road Map Towards Effective Mainstreaming of GIS for Watershed Management in the Caribbean. Caribbean Environmental Health Institute, The Morne, St. Lucia. Retrieved on 17th April 2011 from http://www.cep.unep.org/events-and-meetings/13th-igm-1/IWCAM-2en.pdf.

Sherman, G. (2008). Desktop GIS: Mapping the Planet with Open Source Tools. Pragmatic Bookshelf. 345 pp.

Tomlinson, R., 2003. Thinking about GIS. ESRI Press, Redlands, California.