MODELLING OF AN ALGORITHM FOR DESIGN AND ANALYSIS OF WATER SUPPLY SYSTEMS

A Case of Ministry of Water, Tanzania

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By

Neema Nicodemus

A Dissertation Submitted in Partial Fulfilment of the
Requirements for the Degree of Master of Science (Computer Science) of the
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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the University of Dar es Salaam a dissertation entitled: ***Modelling of an Algorithm for Design and Analysis of Water Supply Systems, in the Ministry of Water Tanzania***, in partial fulfilment of the requirements for the degree of Master of Science (Computer Science) of the University of Dar es Salaam.

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Date: 29/1/2015

DECLARATION
AND
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I, **Neema Nicodemus**, declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for a similar or any other degree award.

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Signature

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I have taken much effort in this dissertation. However, it would not have been possible without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to all of them. I would like to express my sincere gratitude to my supervisors Dr. J. Lungo and Professor E. S. Masawe for their guidance and constant supervision which has led to completion of this study. It has been a challenging study due to its multi-disciplinary nature, however, through their devoted support they made it possible.

This research could not have been accomplished without the kind cooperation of engineers from the Ministry of Water for giving me such attention and time for this research to push through. Furthermore, my thanks and appreciations also goes to my classmates for their constructive ideas and encouragement.

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DEDICATION

This work is dedicated to my husband Samuel G. Mwangi for his love and prayers. Also, to my beloved mother Ginsera N. Lyimo who has been a pillar in my entire life for encouragement, love, endless prayers and support in all levels of my studies to where I am today.

LIST OF ABBREVIATIONS AND ACRONYMS

CSS	Cascading Style Sheets
DAWASA	Dar es Salaam Water and Sewerage Authority
DAWASCO	Dar es Salaam Water and Sewerage Corporation
EPA	Environmental Protection Agency
EPANET	Environmental Protection Agency Network
ER	Entity Relationship
GUI	Graphical User Interface
HGL	Hydraulic Grade Line
HTML	HyperText Markup Language
OOP	Object Oriented Programming
PHP	Hypertext PreProcessor
PN	Nominal Pressure
WSD	Water Supply Design

ABSTRACT

Water supply system is a network of engineered hydraulic components which provide water supply to individuals and organizations. It has been noted that some areas experience shortage of water because of inadequate pressure and flows, illegal connections and leakages. This research focused to address the problem of pressure and flow variations at design stage. This is because the efficacy of a water supply system depends much on its design aspects. This was done through examination of key design aspects and generation of an algorithm for analysis and calibration of designs for water supply systems. The algorithm was developed to provide improvements and modifications until the intended standard is achieved.

Interview and documentation analysis were the techniques applied for data collection. Analysis of data collected provided the foundation for model and algorithm design. Major principles considered were Continuity equation, Hazen William's equations and gravity-flow theory. The generalized model and the algorithm were implemented into software in order to make findings accessible while hiding unnecessary complexity to the user.

Running time efficiency of the algorithm was found to be linear. Both the algorithm and its model proved to be correct through several tests done. Theories, principles and assumptions applied hold to be true for branched (tree or dead end) distribution systems. The prototype system provides a localized tool for design and analysis of water supply systems under local settings.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Water is essential to life and a catalyst to socio-economic development in all countries. Major economic activities such as domestic activities, internal trade, manufacturing industries, education institutions, tourism, transport and communication, urban agriculture, fishing, construction, finance and insurance all these activities account for increasing demand of major resources like water and electricity (Mtasiwa, 2004).

The sole responsibility of water supply in Tanzania has been dedicated to the Ministry of Water. The main function of the Ministry of Water is to ensure that water supply and water resources are developed and managed sustainably in collaboration with all stakeholders. For example in Dar es Salaam, Dar es Salaam Water and Sewerage Authority (DAWASA) and Dar es Salaam Water and Sewerage Corporation (DAWASCO) are the two public sector institutions which are officially involved with water supply (Bayliss and Tukai, 2011).

It has been experienced that some areas face insufficient water supply due to various reasons such as illegal connections, leakages and lack of sufficient pressure and flow. According to Duwe (1996), the affected areas with flow variations have left some consumers to have adequate flow while others to have very low flow rate and experience shortage of water. The efficiency and effectiveness of water supply system(s) depend much on its design aspects. Therefore, this study addressed water supply design challenges in order to solve the problem of pressure and flow variations.

1.2 Statement of the Problem

The yield of a system can be measured by either its value or its net benefit. For a water supply system, the true value or the net benefit is a reliable water supply service having adequate quantity. So far balancing water distribution systems has drawn interest of researchers because of challenges that face the society. Furthermore, due to high rate of population growth, industrial growth, growth of social activities and existence of pressure and flow variations as explained by Pauschett *et. all.* (2012), it was necessary to conduct a research to identify and localize best water supply design practices in order to address the problem of uneven water distribution.

This study addressed the problem of uneven water distribution at design stage. Water distribution system design is a very important stage on which the efficiency of water supply system depends on. Therefore, the study analyzed key design aspects and developed an algorithm for analysis and calibration of models for new systems with the aim of providing improvements and modifications until the acceptable standard is met.

1.3 Research Objectives

The objectives of this research study have two parts, the general objective and specific objectives.

1.3.1 General Objective

The general objective of this research was to develop an algorithm for calibration of the designs for water supply systems in order to provide sufficient pressure and adequate flow of water to the consumer.

1.3.2 Specific Objectives

The specific objectives were

i. To analyse strength and weaknesses of the hydraulic theories and existing models involved in the design of water supply systems.

ii. To design an improved generalized model and an algorithm that can ensure sufficient pressure at the point of supply and an adequate flow to the consumer.

1.4 Research Questions

i. What are the strength and weaknesses of theories and existing models underlie the design of water supply system at the study area?

ii. How can the improved model and algorithm for water supply systems be designed?

1.5 Significance of the Study

The rationale of the study was to provide an improved model and algorithm for design and analysis of new water supply projects. The model and the algorithm were implemented to provide a tool that is very useful for analysis of water distribution systems by providing clues for points with excessive velocity, low velocity and areas where water cannot reach.

On the other hand balancing the existing system provides an immediately feasible solution for reducing the problem of uneven distribution of water in the systems, while, providing a more efficient use of the existing water supplies. In particular, it reduces water losses, to ensure that existing water supplies can meet the increasing demand. Furthermore, longer-term benefits related to whole-of-life asset costs including a reduction in pipe failures (burst frequency), extended asset life and savings in the costs of repairing burst mains. Finally, the study has provided basics for further-work or research for more generalization of other pipe structures for-example a system with grid distribution points.

1.6 Research Scope

The scope of water distribution system is very wide. Water supply system goes through different stages such as design, implementation and maintenance of an operational system. However, this research considered the design stage only. The design stage has an added advantage of allowing some modifications and changes on some parameters which would have been impossible in an operational system. The distribution layout under consideration is branched; however, loop networks have been analyzed at some points.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This Chapter presents literature review of the study. It covers historical approaches for computing pressure and flows in water distribution systems. Secondly, description of basic concepts and theories for design of water supply networks is given. Thereafter, it follows a section that explains some important concepts on algorithm design and analysis. Finally, the last section reviews the existing model proposed by previous researcher.

2.2 Historical Approaches for Computing Pressure and Flow

Ormsbee (2006) presented a brief historical review of various methods for computing flows and pressure in water distribution networks. According to Ormsbee (2006), Martin and Peters were the first researchers to publish a computer algorithm that could be used to simultaneously solve for the hydraulic grades at each junction node in the distribution system. In 1969, Alvin Flower developed a new approach to network analysis that applied the Newton Raphson method to simultaneously solve for the flow adjustment factors associated with the original "loop" method of Cross (Ormsbee, 2006). This had the net benefit of significantly improving the convergence characteristics of the original algorithm. Another method is the Gradient Method; this method has been adopted for use by the EPA in the development of the program EPANET (Rossman, 1994). Finally, another approach was proposed by Duwe (1996) which simultaneously solved a system of nonlinear equations for each junction nodes by using steepest descent and Newton method. In this approach steepest descent was used to get initial approximation for Newton method to speed up the convergence.

2.3 Design of Water Supply Systems

2.3.1 Features of Water Supply Systems

Water distribution networks have a looped and branched configuration of pipelines. Urban water networks have mostly looped configurations, whereas rural water networks have branched configurations. On account of the high-reliability requirement of water services, looped configurations are preferred over branched configurations (Swamee and Sharma, 2008).

According to Swamee and Sharma (2008), the choice between a pumping or a gravity system for a water network depends on a topographic configuration. A gravity system is feasible if the input point is at a higher elevation than all the withdrawal points. Water pumping is required in situations where site conditions do not favour the use of gravity supply. In either case, gravity systems tend to involve high capital costs but low operating costs. On the other hand, pumping systems tend to require lower capital costs but high operating costs. Therefore, the decision between gravity supply, and pump fed supply is an economic one (Nyangasi, 2012).

2.3.2 Water Demand Projections

One of the most difficult tasks facing a designer is that of determining water demand. Under-estimation will result in failure to achieve the design life of a scheme whilst over-estimation, especially of water demand, will tie up scarce financial resources unnecessarily. According to Whittington *et al.*, (2010), water demand estimation in developing countries has also been the focus of numerous articles, but empirical evidence regarding factors driving water demand in developing countries is still scarce. Therefore, one may consider what is being considered as local best practice and different sources of information gathered primarily in different regions of the country.

2.3.3 Flow Hydraulics and Network Analysis

The flow hydraulics covers the basic principles of flow such as continuity equation, equations of motion, and Bernoulli's equation for close conduit. Another important area of pipe flows is to understand and calculate resistance losses and form losses due to pipe fittings (i.e., bends, elbows, valves, enlargers and reducers), which are the essential parts of a pipe network. Suitable equations for form-losses calculations are required for total head-loss computation as fittings can contribute significant head loss to the system. Darcy–Weisbach and Hazen–Williams provided the equations for the headloss computation through pipes (Swamee and Sharma, 2008).

Liou (1998) pointed out the limitations of the Hazen–Williams equation, and in conclusion he strongly discouraged the use of the Hazen–Williams equation. He also recommended the use of the Darcy–Weisbach equation with the Colebrook–White equation. Swamee (2000) also indicated that the Hazen–Williams equation was not only inaccurate but also was conceptually incorrect. Brown (2002) examined the historical development of the Darcy–Weisbach equation for pipe flow resistance and stated that the most notable advance in the application of this equation was the publication of an explicit equation for friction factor. He concluded that due to the general accuracy and complete range of application, the Darcy–Weisbach equation should be considered the standard and the others should be left for the historians.

2.3.4 Pipe PN Classification

According to Eupen (2012), PN is a short term for "pressure rating of a pipe". PN depends on wall thickness, diameter and material type. For example, PN 16 pipe is one that can withstand 16 bar (1.6 mega-pascals or about 232 psi) at 20°C. Generally, one can say, a nominal pressure rating (PN) is the maximum operating pressure on which the pipe is designed to handle (Hobas, 2012). This is a very important factor which has to be considered during design stage because the type of material and pressure rating (PN) can have an effect on pipe life – span (SA Water Cooperation, 2011).

2.4 Algorithm Design and Analysis

Skiena (2008) defined an algorithm as a procedure to accomplish a specific task. An algorithm should have an ordered set of unambiguous, executable steps, a well defined termination of the process. An algorithm design technique or a strategy as explained by Levitin (2007), is a general approach to solving problems algorithmically that is applicable to a variety of problems from different areas of computing. There are various algorithms techniques used to solve problems such as divide and conquer, greedy and backtracking. According to Cooke (2007), divide-and-conquer is the most common approach to solve problems. One big problem is partitioned into smaller parts, find solutions for the parts and then combine solutions for the parts into solution of the whole as shown in Figure 2.1.

During designing the designer should desire to optimize properties for a good algorithm such as correctness and efficiency as well as simplicity of implementation. Key factors to be considered in measuring algorithm efficiency are time efficiency, also called time complexity which indicates how fast an algorithm in question runs. Furthermore, space efficiency, also called space complexity, refers to the amount of memory units required by the algorithm in addition to the space needed for its input and output, (Levitin, 2007).

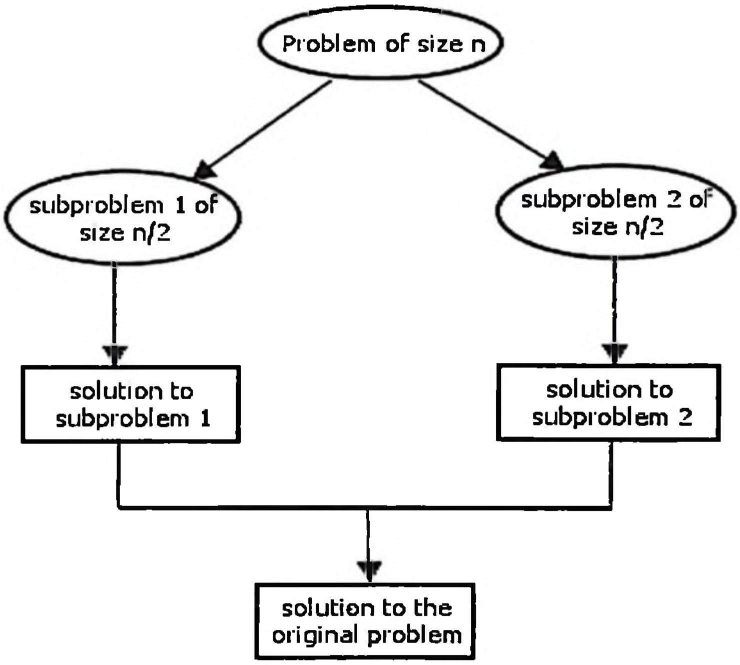


Figure 2.1: A typical case divide-and-conquer technique (Source: Levitin, 2007).

2.5 Previous research done in the study area

Before design of the new model the researcher analysed the previous work done in the same study area in order to get more insight, to avoid repetition and make use of what has already been done. This research was done by Duwe in 1996. It proposed to address the problem of pressure and flow variations by using a model whose computation involved Steepest Descent algorithm and Newton algorithm. The proposed model was built by applying Continuity and Bernoulli's equation.

The major similarity between the previous study and this one is that, both studies addressed water distribution challenges in the same study area however the approach differs. The previous research aimed at balancing water distribution of the existing water supply system (operational system), while the current research focuses on the design of new water supply systems (not yet installed). The previous study had only two unknown variables, while this study has seven unknown variables. However the most important difference is that, this study addressed some design analysis aspects which are useful for verification of water supply designs.

Demand projections, analysis of flow hydraulics, pressure rating classifications are some of the key areas to be considered for an effective and reliable water supply design. As explained above, different scholars have addressed water supply design from various perspectives; however it is vivid that one's approach will largely depend on the area for which it is targeted. Therefore, understanding theories and practices from similar application domains helps the researcher to make more informed decisions.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

Methodology for this study is detailed in this Chapter. It identifies the study area, type of research methods and techniques used for data collection. Furthermore, it explains how data collection and analysis were done.

3.2 Study Area

The area of study was the Ministry of Water, Tanzania. The researcher considered time factor and availability of resources to identify coverage of the study. The study covered design and analysis of branched water supply systems. The researcher visited Ministry of Water main office at Ubungo.

3.3 Type of Research

This study applied a qualitative research methodology. Qualitative methodology is the one that describes and explain experiences, behaviours, interactions and social contexts without the use of statistical procedures or quantification (Davidson *et al.*, 2002). Qualitative research differs from quantitative approach as it develops theory inductively. Quantitative research methods use mathematical and statistical techniques to identify facts and causal relationships between objects under study. Qualitative research methodology has been used in this work the reasons being its ability to explain complex relationships among concepts needed for this study.

3.4 Data Collection Methods

Data collection techniques such as interviews and document analysis enabled the researcher to get the required information for the study. The following subsections explain how data was collected by using each method:

3.4.1 Interview

Interviews provided a general overview of challenges related to water supply design and different ways of addressing them. Furthermore, they were essential for clarification of documented data in order to provide a critical analysis of water supply design procedures and computations. Three interviews were conducted.

Interviews can be highly structured, semi-structured or unstructured. Structured interviews consist of the interviewer asking each respondent the same questions in the same way (Hancock, 2002). A highly structured schedule of questions is used, very much like a survey. Whereas, semi-structured interviews (which sometimes referred to as focused interviews) involve a series of open-ended questions based on the topic areas the researcher wants to cover. Using semi-structured face to face interviews, three engineers from Ministry of Water were interviewed who included: water project design engineer, the principle engineer for approval of water project designs and the design architect. All interviews were recorded by a digital voice recorder. Shared experience and knowledge by those interviewees enabled the researcher to gather information to design and revise the algorithm for designing water supply system.

3.4.2 Documentation Analysis

Document analysis helps to get detailed and useful information related to the researcher's interest, and supplement other forms of data collection (Creswell, 2003). This data collection technique was necessary for this study in-order to provide a deep insight of key concepts and for clarification on procedures and computations involved. Some reviewed documents include gravity flow system guideline, sample water supply designs (for gravity and / or rising main) projects and project design verification reports.

3.5 Data Analysis and Algorithm Design

Data analysis is the process of reducing large amounts of collected data to make sense of them (LeCompte 2000). Three main things occurred during analysis; data organization, summarization and categorization, patterns in the data were identified. Once data was collected as described in previous sections, they were analyzed and a list of parameters which produce reliable results identified. Thereafter, a mathematical description identifying the relationships of given parameters was derived on these grounds a mathematical model and Water supply Design algorithm was built.

According to Puntambekar (2009), an algorithm is a systematic method containing a sequence of instructions to solve a computational problem and should produce output for given set of input in finite amount of time. The algorithm was specified by using pseudo-code which is a mixture of a natural language and programming language like constructs (Levitin, 2007). Figure 3.1 shows steps applied during the design and analysis of the algorithm.

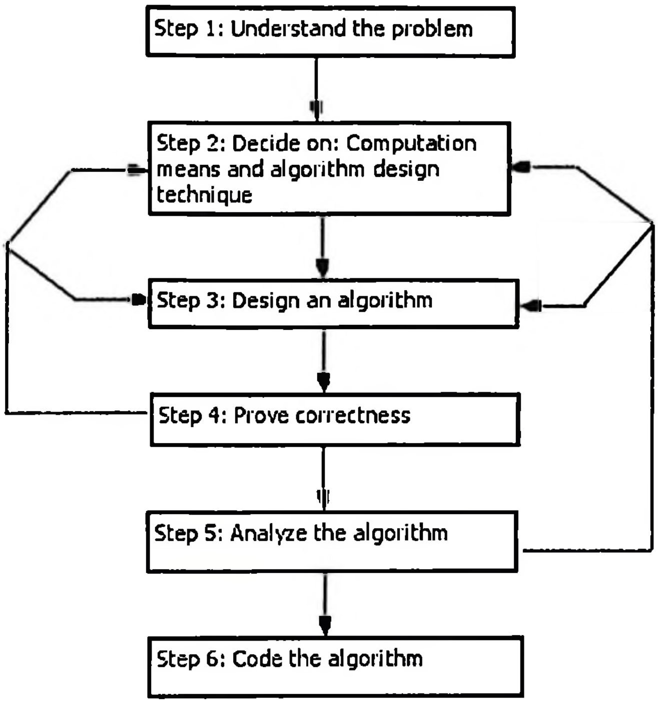


Figure 3.1: Algorithm design and analysis process (Source: Levitin, 2007).

Before designing an algorithm one needs to have a clear understanding of the problem domain as described in figure 3.1 as the initial step. The researcher reviewed relevant literatures to understand the existing challenges and efforts that have been made so far to address the problem. Furthermore, through data collection and analysis of the problem domain the researcher was then in a position to say she had a good understanding of the problem which was being addressed. Algorithm design technique chosen for this study was divide-and-conquer technique; this is because of its simplicity. An algorithm can be characterized according to their complexity or space and time efficiency. Simple algorithms may be computed by hand but for complex ones one may need an advance computational means such as a computer program. In this study it was expected to develop a computer program that will be used for computation of the algorithm.

After designing the algorithm proving its correctness is a mandatory. These procedures were iterative in the sense that if an error occurred during correctness testing then necessary changes were done in the design. In order to prove for correctness the algorithm should yield required results for every legitimate input. Once it was proved to be correct then,.we moved to step 5 in Figure 3.1 above. Thereafter, analysis of the algorithm followed in order to assess qualities such as efficiency or complexity. Levitin (2007) explained that, due to technological innovations computer speed has improved much such that an extra space needed by an algorithm is not of as much concern in comparison to time, therefore, this study considered time efficiency or in other words time complexity. The efficiency of the algorithm was measured by using order of growth of large input size(s). If the algorithm was found to have poor qualities for example if its efficiency is very low then revisiting the design would have been necessary. This means the designer would have gone back to step 2 and 3 as described in Figure 3.1 above. However in this case the time efficiency was found to be reasonable and this allowed coding of the algorithm.

3.6 Software Development Method

Implementation of the algorithm followed prototyping techniques in software engineering. As it has been suggested by Dennis *et al.*, (2008), prototyping method is the best choice when timelines are short as it allows adjustments on functionality of the system depending on the deadline. There are two main varieties of prototyping techniques namely throw-away prototyping and evolutionary prototyping technique. This study applied evolutionary prototyping technique.

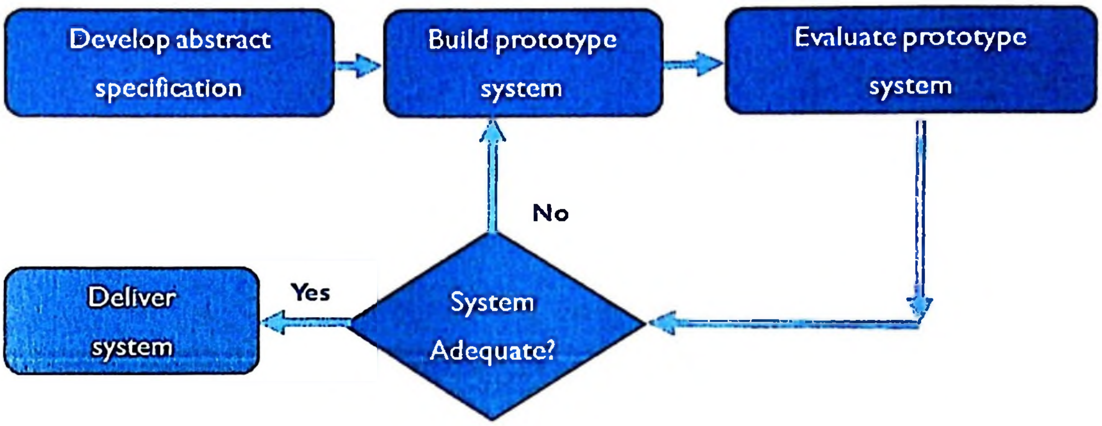


Figure 3.2: Evolutionary prototyping approach (Source: Kamal, 2011)

Evolutionary prototyping is a prototype that aims to build a very robust prototype and constantly improve it with the objective to deliver a working system to the end user. Figure 3.2 shows different stages under evolutionary prototyping model. In this approach the researcher did critical analysis of previous research(s) done in similar area and developed a simple prototype. This prototype was then presented to the users (the Ministry of Water). After data collection and analysis water supply design algorithm was developed whose implementation was the refinement of the initial prototype.

3.7 System Testing and Evaluation

According to Sargent (1999) evaluation should be done to determine whether the theories and assumptions underlying are correct and that the model representation of the problem entity is reasonable for the intended purpose. Te'eni *et al.*, (2007) grouped evaluation methods into two categories which are analytical evaluation and empirical evaluations. The former includes methods such as heuristic evaluation, guideline review and cognitive walk-through. The latter includes lab experiment, survey, interview and focus group, field study, and field experiment. The main difference between the two is that analytical evaluations do not need collected evidence from the user but rely on evaluators using structured approaches for inspections and evaluations, while empirical evaluations draw conclusions based on empirical data, which can be qualitative or quantitative in nature.

This study applied three evaluation techniques from two categories suggested by Te'eni *et al.*, (2007) in the previous paragraph. The first one was cognitive "walk-through" which is under analytical evaluation methods. The researcher did the first evaluation by "walk-through" the prototype from the beginning to the end and checking if the implemented model and the algorithm work as expected. The second evaluation method was empirical method which was conducted by involving users to test and evaluate the prototype.

CHAPTER FOUR

RESEARCH FINDINGS AND DISCUSSION

4.1 Introduction

This Chapter presents research findings and discussion. The findings section is divided into two main subsections which include findings with respect to each of the two research question governing this study. Discussion of the findings follows underneath.

4.2 Findings

4.2.1 Analysis of Strength and Weaknesses of the Existing Model(s)

In response to the first research question analysis of the strength and weaknesses of the existing model(s) underlying the design of water supply system as per research findings of this study were as follows:

At the beginning the researcher reviewed the existing model aiming at identifying its strength and weaknesses, see section 2.5 which summaries general concepts in that model. Based on the analysis results the researcher could have either chosen to extend the model or come up with a new one according to data collected from the field. However, during generalization of that model to the problem domain for which it is claimed to have been developed for, the researcher encounter an error. This error occurred whenever trying to calculate inverse of the derived matrix. After, a lot of inspection the researcher realized that whenever a generalization was done from a closed loop (Grid Iron) distribution layout ends up with inconsistence system of equations, hence no solution. After such an encounter the researcher applied some of the suggested principles from that study which include continuity principle and the law of conservation of energy. These principles were used to develop a model on a different pipe structure a branched distribution layout and solved by using Gauss algorithm. The results were proved to be correct, thus the model was adopted as part of the new model.

4.2.2 Model and Algorithm Development

This part responds to the second research question about the model and design of a water supply design algorithm. Chapter 5 provides a detailed explanation on how the model and algorithm was designed and implemented based on these findings. However, some key findings on the model and algorithm development have been highlighted in the following paragraphs:

It was found out that, for clarification purposes the model should be designed from a specific case to general. Before generalization the scope has to be identified. Theories and principles pointed out in the previous subsection works for a branched distribution network. Therefore, the scope of the generalized model should be restricted to branched water supply systems which use gravity flow as transmission technology. The generalization should be defined such that, the output of this research can work for the design with *n* branches and *n* junctions.

Development of Water supply design algorithm was done after a detailed analysis of data collected from the field. The algorithm was designed to take design parameters, do necessary computations and verify whether the suggested input makes an effective water supply system otherwise resets the inputs. One of the input parameters includes discharge values from Gauss algorithm but the rest are design parameters from the designer. Diameter reset occurs if velocity is not within acceptable range. Ground elevation, material and distance are reset when there is no sufficient pressure to take water to its destination. Basic principles applied were Continuity equation, Hazen William equation and theories for balancing water equilibrium according to gravity-flow scheme. In other words all procedures and subroutines in the water supply design algorithm were according to data collected from the area of study.

4.3 Discussion

This study has been generalized for branched distribution layout. Development of the model extracted only a few valid ideas from previous work, which was the application of continuity equation to balance water demand for each junction or distribution point in the distribution system. Discharge values resulted from computation of the model with Gauss algorithm proved that no junction or distribution point would receive excess or less amount of water according to their demand. However, knowing discharge values from the model does not guarantee that water reached its destination. Here is when water supply design algorithm comes into play. The water supply design algorithm used gravity-flow water schemes at each point to check whether there was sufficient gravitational energy to take water to the intended point. Not only that, but also the algorithm had to verify that velocity was within the stipulated standard to insure long life of assets by reducing water hammer caused by excessive velocity and to avoid additional costs for flushing the system frequently when velocity is below the average.

Modelling and algorithm design was considered as one of the major successes for this study. However, it was found necessary to implement them into software in order to make these findings accessible. Moreover, this software is a prototype tool whose application is to improve water distribution designs, hence reducing the existing water supply challenges.

CHAPTER FIVE

MODEL AND ALGORITHM DESIGN, TESTING AND EVALUATION

5.1 Introduction

This Chapter presents two major components of the study: a model and algorithms; both of them have been designed following research findings presented in Chapter 4. The model computation involved two algorithms which are Gauss algorithm and a Water Supply Design algorithm which was developed as part of this study. Also, this Chapter describes how the model and algorithms were implemented to provide a software prototype. Finally, testing and evaluation of the model and the algorithm through the implemented prototype follows.

5.2 Model Design

This section explains how a model for designing water supply systems was developed. The model design was done for a gravity flow transmission and distribution. For illustration part of Ng'uruhe village water project was considered as a specific model area. Once the model was designed for this specific case, it was then generalized for implementation so that it can be applied for any size of water distribution system with similar characteristics. The sketch for this area (Figure 5.1) is part of Ng'uruhe water project from the Ministry of Water. Water intake for this model area is Kalinga River that feeds into two reservoirs RES1 and RES2. The gravity transmission main has many points; however, for simplicity three points were considered: Junction 1049, Junction 1050 and Junction 1053. For the distribution main eight points were considered from Ng'uruhe distribution system. Both networks use gravity-flow schemes from the reservoirs to distribution points.

This study generalized the solution for unknown hydraulic variables. That means equation formulation and method of solution has been generalized in such a way that its implementation can generate and solve *n* equations for *n* junctions of a branched water supply system.

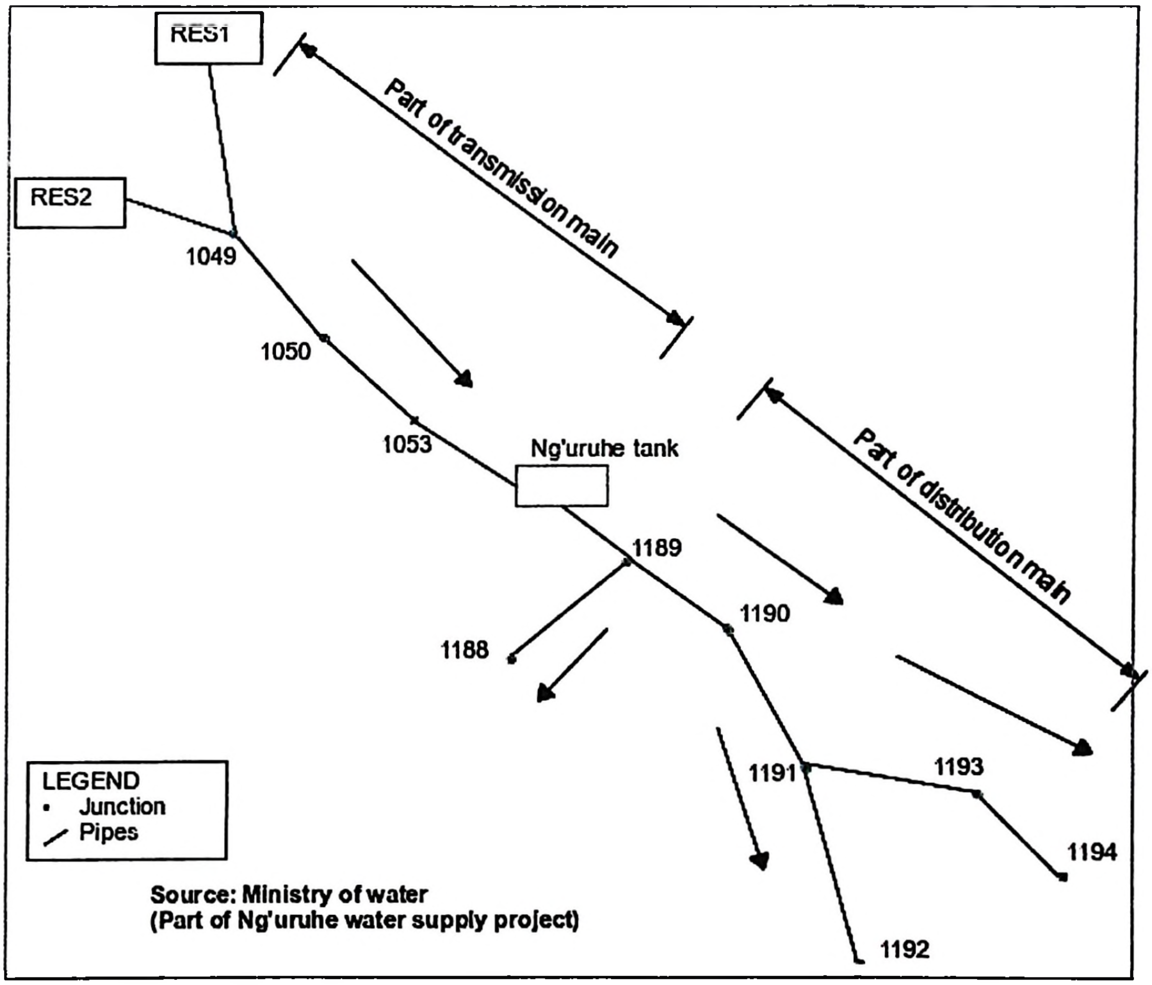


Figure 5.1: Ng'uruhe water supply project (Source: Ministry of Water, 2013)

5.2.1 Continuity Equations for the Model

The continuity equation was considered at each point in Figure 5.1 above. According to the continuity equation, $A_1V_1 = A_2V_2 = Q =$ Constant, when there is no water demand at a point of consideration. If at a point there is consumption of water, then,

Q_{in} – Water consumed = Q_{out}

Where Q_{in} is discharge entering the junction, Q_{out} is the discharge leaving the junction and Water consumed is water demand at a junction.

i. Consider Junction 1049

Junction 1049 receives water from two reservoirs RES1 and RES2 via pipe P_1 and P_2, thereafter moves in the pipeline P_3 connecting to Junction 1050. Let the flow from pipe P_1 and P_2 be Q_1 and Q_2 respectively and the water leaving the junction be Q_3. Water demand at this junction be denoted as wd_{1049}. Then by applying continuity equation we have,

$$Q_1 + Q_2 - wd_{1049} = Q_3$$

Since this junction is at the transmission main then no water consumed hence water demand is equal to zero. i.e. $wd_{1049} = 0$. Therefore equation becomes,

$$Q_1 + Q_2 = Q_3$$

$$f_1 = Q_1 + Q_2 - Q_3 = 0 \tag{5.1}$$

Note: For each case inflow from each reservoir must be known.

ii. Consider Junction 1050

Let the discharge leaving Junction 1050 be Q_4, while the one that enters be Q_3. Water demand at this junction is denoted as wd_{1050}. Then by applying continuity equation we have,

$$Q_3 - wd_{1050} = Q_4$$

Since this junction is at the transmission main then, no water consumed hence water demand is equal to zero i.e. $wd_{1050} = 0$. Therefore after some substitution the equation becomes,

$$f_2 = Q_3 - Q_4 = 0 \qquad (5.2)$$

iii. Consider Junction 1053

Let the discharge leaving Junction 1053 be Q_4, while the one that enters be Q_3. But since this junction is at the transmission main then no water consumed hence water demand is equal to zero. Therefore equation becomes,

$$Q_5 = Q_4$$

$$f_3 = Q_4 - Q_5 = 0 \qquad (5.3)$$

iv. Consider junction 1189

Let the discharge entering Junction 1189 be Q_6, while the one that leaves be Q_7 and Q_8. But at this junction there is no water consumed hence water demand is equal to zero. Therefore equation becomes,

$$Q_6 - wd_{1189} = Q_7 + Q_8$$

$$f_4 = Q_6 - Q_7 - Q_8 = 0 \qquad (5.4)$$

v. Consider junction 1190

Let the discharge entering Junction 1190 be Q_8, while the one that leaves be Q_9. But at this junction water consumed is equal to wd_{1190}. Therefore equation becomes,

$$Q_8 - wd_{1190} = Q_9$$

$$f_5 = Q_8 - Q_9 - wd_{1190} = 0 \quad (5.5)$$

vi. Consider junction 1191

Let the discharge entering Junction 1191 be Q_9, while the one that leaves be Q_{10} and Q_{11}. But at this junction water demand is equal to wd_{1191}. Therefore equation becomes,

$$Q_9 - wd_{1191} = Q_{10} + Q_{11}$$

$$f_6 = Q_9 - Q_{10} - Q_{11} - wd_{1191} = 0 \quad (5.6)$$

vii. Consider junction 1193

Let the discharge entering Junction 1193 be Q_{11}, while the one that leaves be Q_{12}. But at this junction water demand is equal to wd_{1193}. Therefore equation becomes,

$$Q_{11} - wd_{1193} = Q_{12}$$

$$f_7 = Q_{11} - Q_{12} - wd_{1193} = 0 \quad (5.7)$$

viii. Consider junction 1192

Let the discharge entering Junction 1192 be Q_{11}, while the one that leaves be Q_{12}. But at this junction water demand is equal to wd_{1192}. Therefore equation becomes,

$$Q_{10} - wd_{1192} = Q_{13}$$

$$f_8 = Q_{10} - Q_{13} - wd_{1192} = 0 \quad (5.8)$$

5.2.2 Continuity Equations Model Generalization

Continuity equation at junction is given by:

$$\sum Q_{in} - \sum Q_{out} - wd_i = 0 \qquad (5.9)$$

Where Q_{in} is the flow entering the junction, Q_{out} is the flow leaving the junction and water demand is equal wd_i.

Water demand at a junction is equal to zero under following conditions:

(a) If the junction is at the transmission main.

(b) If no water consumed at the junction.

Substituting $wd_i = 0$ to equation 5.9 above, to get

$$\sum Q_{in} - \sum Q_{out} = 0 \qquad (5.10)$$

Transmission main reservoirs outflow:

If a junction received an inflow from reservoir, then Q_{in} from reservoir should be equal to Q_{res_i}. Further-more a minimum flow from each reservoir must be known in advance.

5.2.3 Coding the Model Equations

The aim of this section was to process equations for the continuity model so that they fit into Gaussian algorithm steps. In the model equation there were six equations formed by the application of continuity equation denoted by the function f_1 to f_8. This system had 8 equations and 8 unknown variables. This was after assuming that the discharge Q_7 equal to water demand at node 1188, Q_{12} and Q_{13} are equal to demand at 1194 and 1195 respectively, hence discharge Q_{12} and Q_{13} are known variables also Q_1 and Q_2 should be known. Note that the flow entering Ng'uruhe tank was not necessary to be the same as the flow that leaves the tank. In this sample project our convectional direction was such that, water flows from the reservoir at Ng'uruhe tank to junction 1189 to 1188, and then from junction 1189 to 1191 via junction1190, from 1191 the flow of water branches to point 1193 and 1192.

Let us define our inputs in the process of programming the solution of systems of equations formed by continuity equations. Let the inputs x_i, for i = 1, 2, ...,8 represent the flow Q_i for i = 3,4,5,6,8,9,10 and 11. The main objective of this notation is to identify unknown variables to be solved by Gauss Jordan algorithm. In view of these notations, it seems as if, we were solving for x_i's, which true, but the final result were assigned to the original values of discharge parameters within the program. So according to the notation defined above 5.1 to 5.8 becomes:

$$\left\{\begin{array}{l} f_1 = Q_1 - Q_2 - x_1 = 0 \\ f_2 = x_1 - x_2 = 0 \\ f_3 = x_2 - x_3 = 0 \\ f_4 = x_4 - x_5 - Q_7 = 0 \\ f_5 = x_5 - x_6 - wd_{1190} = 0 \\ f_6 = x_6 - x_7 - x_8 - wd_{1191} = 0 \\ f_7 = x_8 - Q_{12} - wd_{1193} = 0 \\ f_8 = x_7 - Q_{13} - wd_{1192} = 0 \end{array}\right\} \qquad (5.11)$$

The system of equations at 5.11 can be described in terms of unknown variables, coefficients and constants as follows:

(a) Unknown variable(s) x_i where i is equal to 1, 2, 3...

(b) Coefficient(s) a_{ij} where i refer to the corresponding unknown and j is the number of equation.

(c) Constant(s) b_i, where i is equal to 1, 2, 3...

By using above denotation, a generalized formulation of continuity equation with n unknown flows at given junction points, forms such equations as follows:

$$\left\{\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \quad \ddots \quad \vdots \quad \vdots \quad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m \end{array}\right\} \tag{5.12}$$

This is called a system of m (linear) equations for m junctions with n unknowns flow (i.e unknown variables).

This study chose to solve by using Gaussian elimination because of the characteristics of the equations formed. The augmented matrix for the system of equations 5.13 can be presented as follows:

$$\left(\begin{array}{cccccccc|c} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & Q_1 + Q_2 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & Q_7 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & wd_{1190} \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & -1 & wd_{1191} \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & Q_{13} + wd_{1192} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & Q_{12} + wd_{1193} \end{array}\right) \tag{5.13}$$

which was generally represented as:

$$\left(\begin{array}{ccc|c} a_{11} & \cdots & a_{1n} & b_1 \\ \vdots & \ddots & \vdots & \vdots \\ a_{m1} & \cdots & a_{mn} & b_n \end{array}\right) \tag{5.14}$$

The augmented matrix was solved by gauss elimination algorithm. Gauss elimination is a well known algorithm for solving systems of linear equations, therefore, it was just mentioned here, but for details see appendix B.

5.2.4 Pending Challenges

The output of Gauss algorithm was a set of evenly distributed flow(s) for the water supply system. So far, we succeeded to solve for unknown discharges that means at this point we are confident that each junction gets sufficient flow according to their demand. However, it is yet to be known that, at what diameter(s) water should flow within acceptable range of velocity. Excess velocity can cause water hammer and the system with excessive low velocity needs flushing from time to time. The effect of these factors is significant.

On the other hand, sufficient flow was not the only factor that can insure water to reach its intended destination. Ones design needed further verification to see whether there was sufficient pressure head to reach each intended designation. Therefore, because of all factors elucidate above the researcher developed an algorithm which can take calculated flows from Gauss algorithm and other design parameters specified by the designer and perform further hydraulic computations. The goal of the designed algorithm was to verify and rectify until it reaches the desired design standard. The developed algorithm was namely Water Supply design algorithm.

5.3 Design of the Water Supply Design Algorithm

The algorithm has been designed by using divide-and-conquer technique as explained in section 3.5 After dividing a big problem into smaller parts according to divide-and-conquer strategies, each part was then formulated with top-down stepwise refinement approach as follows:

First, let's generalize our problem (**Top level representation**):

> Develop an algorithm that performs computation where by verifying and rectifying hydraulic values until they reach the desired design standard.

The top is a single statement that conveys the program's overall function. As such, the top is, in effect, a complete representation of a program. So we now begin the refinement process. We divide the top into a series of smaller tasks and list these in the order in which they need to be performed. This results in the following **first refinement**.

First Refinement:

a) Let the user define the pipe structure

b) Calculate hydraulics of the pipe structure and rectify design errors found.

c) Output the results

To proceed to the next level of refinement, i.e., the **second refinement**, we commit to specific variables. Also, after each part was simplified then a pseudo-code representation was provided.

Second refinement:

i. Get reference points REF_PT, distance Sm, ground elevation Y, diameter D, and material M from the user or extracted from the database.

ii. Get discharge values Q_i from Gauss elimination algorithm where i = 1,2...n reference points.

Pseudo-code:

```
INPUT reference points $PT(pt_1, pt_2, \ldots pt_n)$; flow $Q(Q_1, Q_2, \ldots Q_n)$; diameter
$D(d_1, d_2, \ldots d_n)$; ground elevation $Y(y_1, y_2, \ldots, y_n)$; material $M(m_1, m_2, \ldots, m_n)$;
distance $Sm(s_1, s_2, \ldots, s_n)$; point type $TYPE(type_1, type_2, \ldots, type_n)$; design part
$PART(part_1, part_2, \ldots, part_n)$; and total reference points n, Maximum iteration $N$.
```

a) Calculate hydraulics of the pipe structure and rectify design errors found.

i. Calculate velocity, Hydraulic gradient, Head loss, Piezometric head, Residual head and Static head for each reference point in the pipe structure.

ii. Check whether velocity and residual head for each point is within given standards for water supply systems.

iii. For each error found replace it with an appropriate error message.

Pseudo-code:

```
Step 1: set k = 0.
        Step 2: while $k \leq N$ do step 3 to 12
    Step 3: for $i \leftarrow 1$ to $n$ do step 4 to 11
```

```
Step 4: Velocity $v_i \leftarrow \frac{(Q_i*4)}{(\pi*d_i*d_i)}$
        if $velocity_i$ <0.6 or $velocity_i$ >2
          then $v_i \leftarrow$ 'error'
Step 5: if $type_i ==$ 'reservoir' OR $i == 0$
          $c_i \leftarrow 0$
        else if $type_{i-1} ==$ 'reservoir'
          $c_i \leftarrow s_i$
        else $c_i \leftarrow c_{i-1} + s_i$
Step 6: if $diameter_i == 0$
          $hGrad_i \leftarrow 0$
        else $hGrad_i \leftarrow 10.67*\left(\frac{Q_i*1.85}{(k^{1.85}*d_i)^{4.87}}\right)$
Step 7: Head loss $hLoss_i \leftarrow hGrad_i * s_i$
Step 8: if i = 0 AND technology = 'rising main'
          then Get $h \leftarrow$ total hloss
          $pz_i \leftarrow h + y_{n-1}$
        else if $part_i$ =transmission OR $part_i$ = distribution
          $pz_i \leftarrow y_i$
```

```
        else $pz_i \leftarrow pz_{i-1} - hLoss_i$

Step 9: if technology $\neq$ 'rising main' AND ($i$= 0 OR $type_i$ = 'reservoir')

        then $rhead_i \leftarrow 0$

        else $rhead_i \leftarrow pz_i - y_i$

Step 10: if $rhead_i < 0$

                $rhead_i \leftarrow$ 'error'

Step 11: if part $\neq$ 'rising main' AND $i \leftarrow 0$

        then $shead_i \leftarrow 0$

        else $shead_i \leftarrow pz_0 - y_i$

//end of for
```

b) Output the results

i. Check if there is any error in the design

ii. If there is one or more error and the iteration is less than or equal to the maximum number of iterations then reset specific input values that lead to error(s) then go back to section (b).

iii. Else if there is one or more error and the iteration is greater than the maximum number of iterations then display "Maximum iterations exceeded but with design errors ".

iv. Else if there will be no error then display the message "Procedures has been completed successfully!" followed by the results.

Pseudo-code:

```
Step 12:
if $k < N$ AND if number of errors in $\underline{V} \| \underline{RHead}$ is > 0    then
        if $velocity_i = 'error'$ then
            Reset INPUT: diameter $d_i$
            set k = k + 1
          Go to back to step 3
        else if $rhead_i < 0$ then
            Reset INPUT: elevation $y_i$, material $m_i$ OR distance $s_i$
            set k = k + 1
            Go to back to step 3
else if $k > N$ AND if number of errors in $\underline{V} \| \underline{RHead}$ is > 0 then
      OUTPUT ('Maximum iterations exceeded but with design errors!');
      STOP.
else if number of errors in $\underline{V} \| \underline{RHead}$ is <0 then
    OUTPUT('Procedures has been completed successfully!');
```

```
        OUTPUT V($v_1, v_2, \ldots, v_n$); HGRAD($hgrad_1, hgrad_2, \ldots, hgrad_n$);
            C($c_1, c_2, \ldots, c_n$); HLoss($hloss_1, hloss_2, \ldots, hloss_n$);
            PZ($pz_1, pz_2, \ldots, pz_n$); RHead($rhead_1, rhead_2, \ldots, rhead_n$);
            SHEAD($shead_1, shead_2, \ldots, shead_n$);
        STOP.
    //end of while
```

5.3.1 Analysis of the Algorithm

Algorithm efficiency can be measured as a function of parameter indicating the inputs size *n* and represented in terms of order of growth. While measuring the running time, the first thing to do was to identify the most important operation of the algorithm called basic operations. These operations are those which contribute the most to the total running time. Usually the most time-consuming operation in the algorithm involves loops. For this case Water Supply Design Algorithm has two repetition structures which are *while* and *for* loop. While loop is repeated *k* up to *N* times where *N* being the maximum number of iterations. For loop has been nested inside the while loop and it will be executed *n* times where *n* is the input size. The rest are simple sequential or branched statements whose running cost is constant and independent of the input size.

Based on the analysis in the previous paragraph it can be concluded that in big O representation the growth rate function for a Water Supply Design Algorithm is $O(n)$. This means the time requirement for this algorithm is linear. In a linear algorithm the running time increases directly with the size of the problem. However, the running time may not only depend on the input size but also on the specifics of a particular input. In the worst case, when each reference point contains some errors each time the input is reset, the algorithm should have the maximum running time of $c_{worst}(n) = n*N$, where n is the input size and N is the maximum number of iterations. While, the best-case for this algorithm with reference points of size n whose design elements has no error will be $c_{best}(n) = n$.

5.3.2 Limitations of the Model and the Algorithm

The generalized model and Water Supply Design algorithm is limited to branched water distribution network using gravity flow water scheme. The network was assumed to consist of circular pipes which were in good condition filled with water, no leakages or bursts throughout and the end points were assumed to be dead ends. The flow was assumed to be laminar, continuous, steady and uniform. Also, water was taken to be an incompressible with a constant density.

5.4 Model and Algorithm Implementation

The generalized model and algorithms were implemented into software because of two major reasons. Firstly, was to enable testing for correctness of the model and algorithms while hiding unnecessary complexity to the user. Secondly, was to provide a tool for design and analysis of water supply systems.

5.4.1 System Software Analysis

5.4.1.1 Functional Model of the System

The aim of functional model was to present the functionality of the system, the water supply design system functions are divided into functional and non functional requirements. The functional requirement indicate the general functions or operations of the system while the non functional requirements describe aspects of the system that are concerned with how well it supports the functional requirements (hence the name non-functional, or quality requirements).

The functional requirements undertaken by the Water Supply Design System are:

a) Design projects (add projects, provide demand projections, allow user to estimate losses, peak demand factors and pipeline design parameters).

b) Manage submitted projects (view, update, delete projects and their details).

c) Calculate chainage, distance, velocity, hydraulic gradient, head loss, piezometric level, residual head and static water head as well as comment on the design results of each component in the gravity/rising main and distribution main pipeline system.

d) Export results to PDF (Save or Print).

The non functional requirements of the Water Supply Design System are:

a) It enable user to track progress and status of the project design.

b) Reliability requirements-the system should not crash easily.

c) Performance criteria-desired response times should be adequate.

d) Usability requirements-system should be easy to use and friendly too.

5.4.1.2 Use Case Modelling of Functional Requirements

The core items of use case modelling are use cases and actors. A use case describes how the system should respond under various conditions to a request from the actor to deliver a specific goal. Actors are external entities that interact with the system. See use case diagram Figure 5.2.

The system is composed of the functional requirements as illustrated above. The system is composed of databases, mulfiple project design form pages, calculator page. Actor in the system is designs engineer his/her role is discussed below.

The system actor has the following roles

a) Design a new projects

b) To update existing projects

c) To delete project(s)

d) Export results to PDF

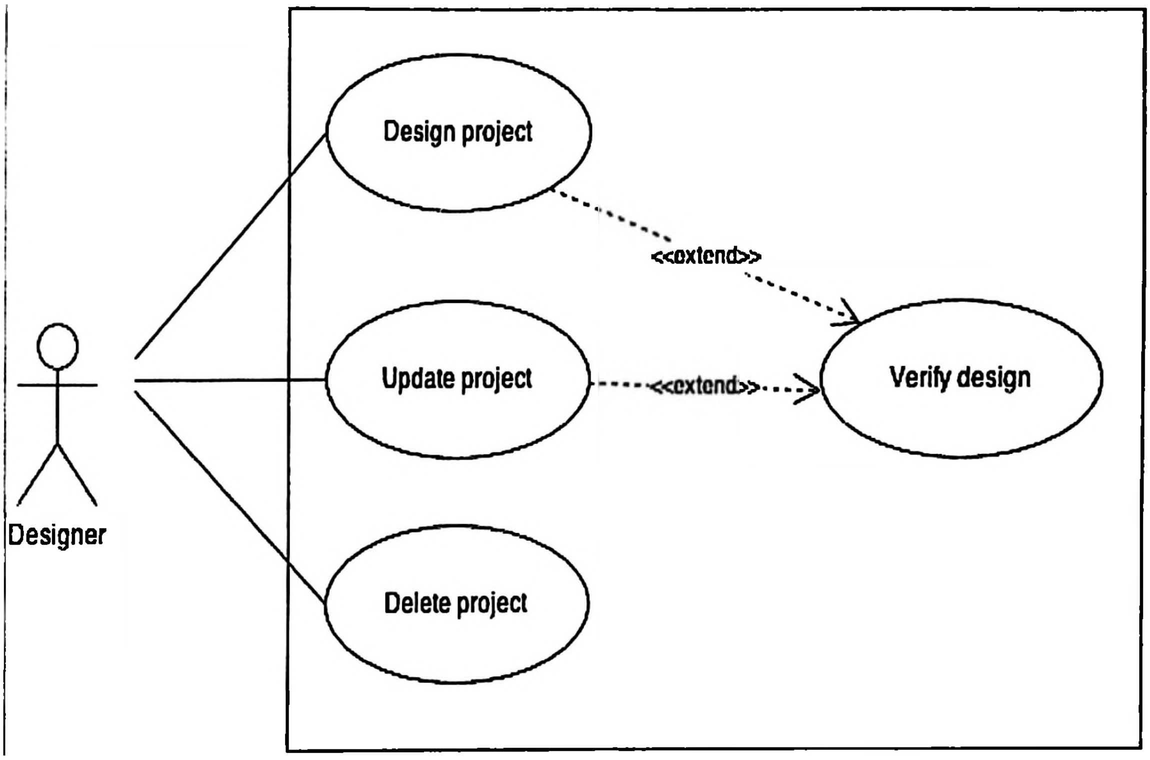


Figure 5.2: Water Supply Design System Use Cases

5.4.2 System Design

5.4.2.1 Quality Goals

Daughtrey (2002) discussed seven software quality attributes namely correctness, reliability, efficiency, integrity, usability, maintainability, testability, flexibility, portability, re-usability and interoperability. According to them, correctness is a measure of the extent to which a program satisfies its specifications and fulfills user's mission objectives. On the other hand, reliability was identified as a very important factor; it can be viewed as the extent to which a program can be expected to perform its intended function with required precision. Based on their primary meaning these two former factors were given much consideration during each phase of the research work to ensure that the intended users of this research get the intended benefits and avoid potential risks such as excess or low hydraulic setting that can destroy water supply assets, or lead to insufficient of water supply to consumers.

Table 5.1: Water Supply Design Quality Goals

Quality Attribute	Very Important	Important	Less important	Irrelevant
Correctness	V			
Reliability	V			
Maintainability		V		
Portability	V			
Usability	V			
Efficiency	V			
Testability		V		

On the other hand, usability of the system was highly considered to make users understand the system easily and be able to use it as intended. Moreover this study applied localization approach such as use of local terminologies, local techniques and standards considered for design of water supply projects so as the outputs can be realistic and applicable to users. Usability of the system includes understandability attributes of software that relate to the users' effort for recognizing the logical concept and its applicability, furthermore learnability of software has to be taken into account to evaluate the users' effort for learning its application (for example, operation control, input, output), and lastly operability attributes of software, this metric relate to the users' effort for operation and operation control and compliance which is the attributes of software that make the software adhere to application related standards or conventions or regulations in laws and similar prescriptions (Drazen *et al.*, 2005).

5.4.2.2 System Architecture

The system has been developed following 3-tier architecture because of its scalability and performance. Ramez *et al.*, (2004) describes a 3-tier architecture as an architecture where there is an intermediary server which splits up the architecture. The intermediate server accepts requests from the client, processes the request and sends database commands to the database server, and then acts as a conduit for passing (partially) processed data from the database server to the clients, where it may be processed further and filtered to be presented to users in GUI format. Thus, the user interface, application rules, and data access act as the three tiers as described in Figure 5.3.

The system was designed to operate on both personal computers (PC) and laptop computers. Recommended hardware and operating system are as follows:

i. Operating system: Win XP, Win Vista, Win 7

ii. RAM: not less than 128MB

iii. Processor: 500 MHz or higher

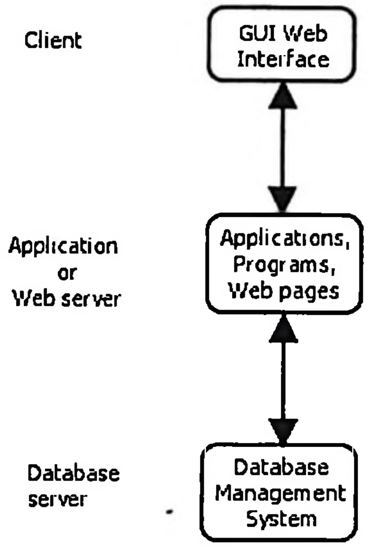


Figure 5.3: Logical three -tier client/server architecture (Source: Ramez et al., 2004).

The most appropriate technologies were chosen to fulfil the well-defined user needs, on the server side the following software are supposed to be installed:

i. PHP version 5 and above. PHP is supported by most OS e.g. Microsoft Windows, UNIX, and Linux.

ii. MySQL is required to manage the database of the system as it is widely available in the market and provides a good security system.

iii. Web server Apache is used to establish communication between the computers since the system is accessed through the Internet connection.

5.4.2.3 Sequence Diagram

Dynamic model was used to describe the dynamic behaviour of the system. The dynamic behaviour of the system is represented by interactions diagrams. Interaction diagrams are used to model the dynamic aspects of a software system. They help to visualize how the system runs.

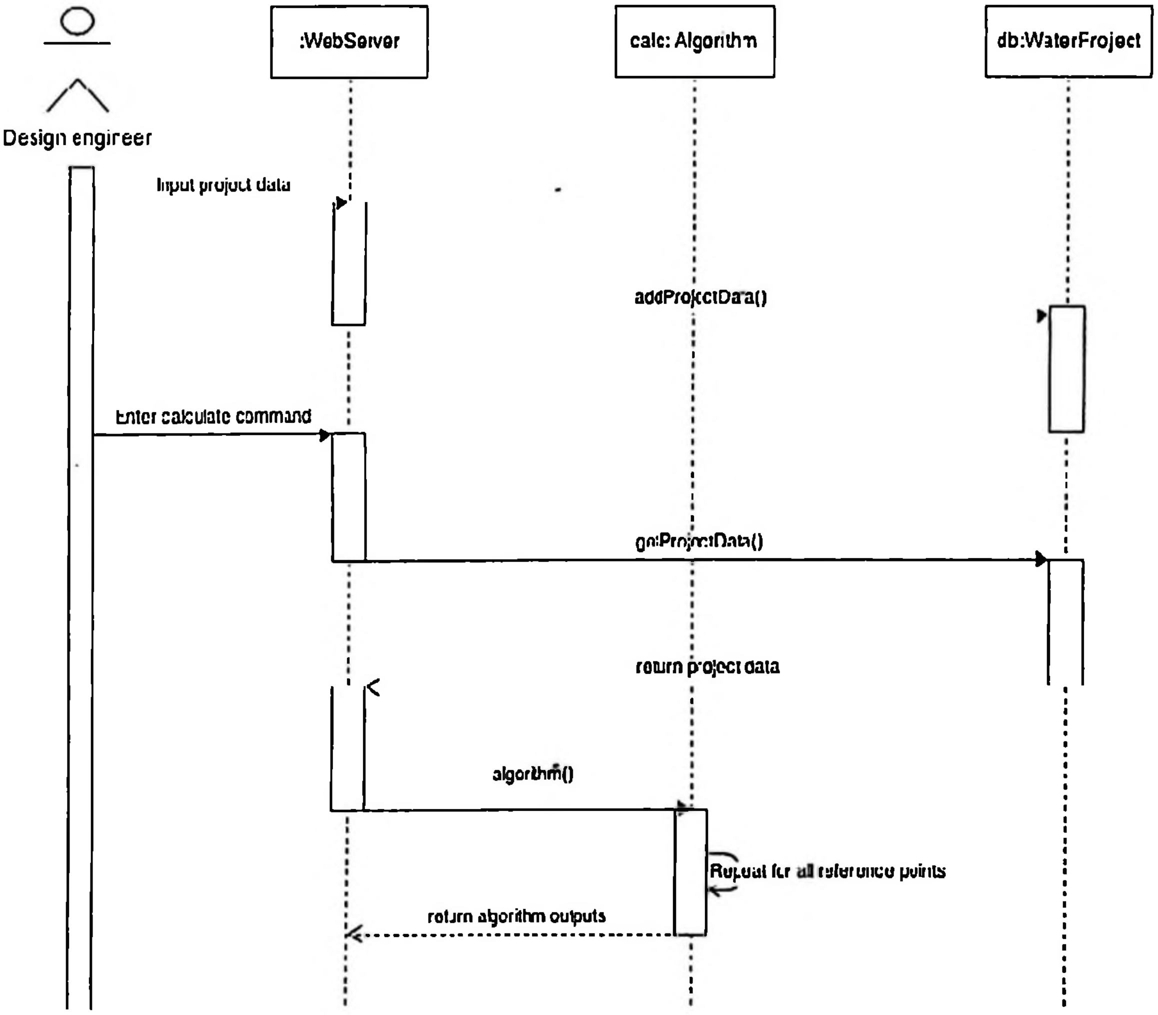


Figure 5.4: Sequence Diagram

Figure 5.4 illustrates sequence of steps followed by system users to interact with Water Supply Design System. The design engineer is one who is responsible to design and manage projects. She/he can design a new project by defining design parameters such as population, accept/change per capita values, estimate expected loss and peak factors, and finally has to define the pipe structure.

Upon defining all required data for a particular project, he/she can click on calculate button on the user interface to call Water Supply Design algorithm to do calculation. Once the algorithm finds an error resulting from poor design parameters it is expected to refine the design until it reaches the standards set.

5.4.2.4 Database Design

The system has one database composing of five entities which are Project, Population, PerCapita, DesignFactors and PipeStructure. The ER diagram in Figure 5.5 includes entities and their respective primary keys.

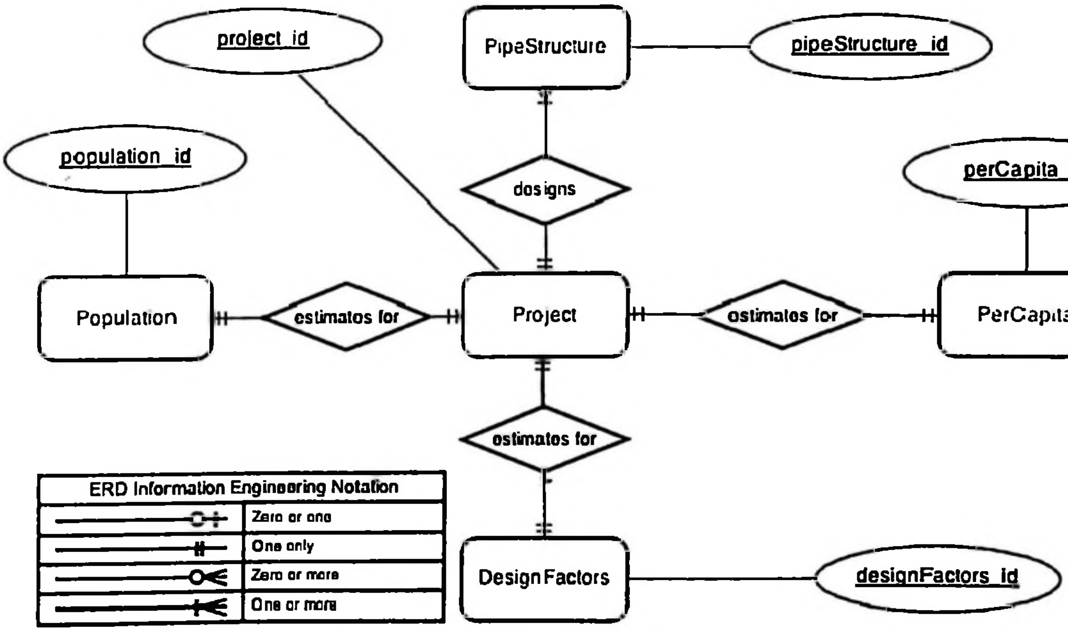


Figure 5.5: ER Diagram for Water_Project database

Database schema

1. Project (<u>project_id</u>, project_name, region, council, division, ward, coordinate, source, sump_flow, l_take, capacity)

2. PerCapita (perCapita_id, *project_id*, publicHTap, multiHTap, singleHTap, medium, high, hotel, bar, shop, hCattle, lCattle, sheepG, donkey, dispensary, hospital, church, office, day, boarding, water_intensive, med_water, dry)
3. Population (population_id, *project_id*, publicHTap, multiHTap, singleHTap, medium, high, hotel, bar, shop, hCattle, lCattle, sheepG, donkey, dispensary, hospital, church, office, day, boarding, water_intensive, med_water, dry)
4. DesignFactors (factors_id, *project_id* loss, day_factor, hr_factor, trans, conn, pLoss, dayDemand, dayDemandHr, hrDemand, riserH, tankH, fitLoss, const)
5. PipeStructure(pipeStructure_id, *project_id*,ref_pt, from_pt, pp_label, distance, ground_y, flow, point_type, part, material, diameter)

5.4.2.5 Web Page Design

Figure 5.6 illustrates the design of web page model. The web pages and the interactions between those pages and users, is explained in the following paragraphs:

According to the Web page model in Figure 5.6, the project design engineer should first be directed to the home page, where he/she had a choice of options to whether design a new project or to use the existing one from the project list. If a designer selected to design a new project, he/she is directed to Design project page stage one in order to provide background information about the project. Upon successful completion the user should be taken to the second stage to provide population data and accept or modify proposed per capita demand for each item in the population.

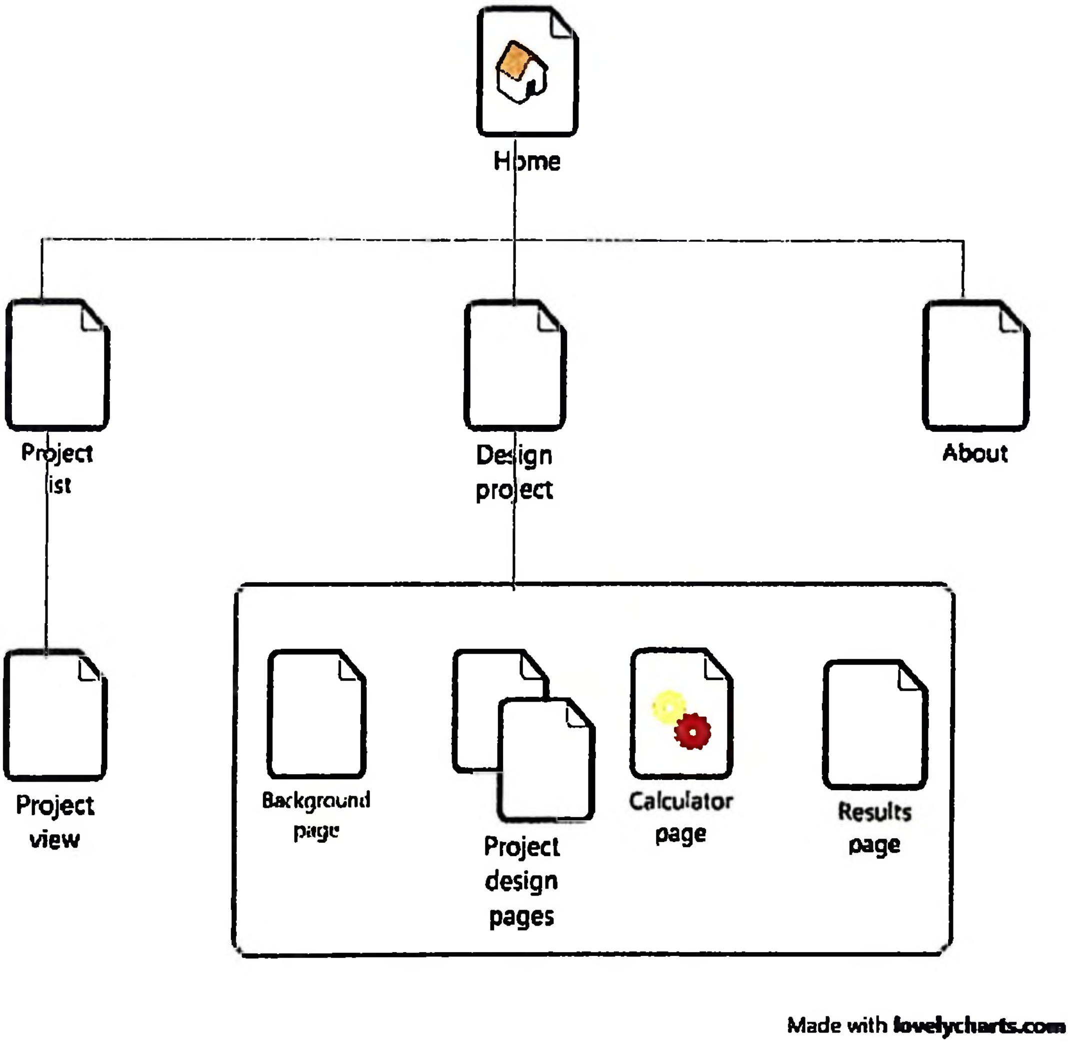


Figure 5.6: Water Supply Design System Diagram

Thereafter at stage three, the designer provides an estimate of design factors needed for the project, this could be refereed as an engineering decision base on nature of project area, budget and his experience. After that, the designer has to be taken to stage four and five, to design pipe structure. This is divided into two rising or gravity main stage four and distribution main in stage five. After each of them, the designer can compute hydraulics and if the system found any error it was expected to redesign until it all meet design standard.

On the other hand, if the user chose to use the existing project, he/she would have been taken to project list page to select a project to view. Upon selection, the specific project menu page should be presented with links to specific parts of a project. Furthermore, the status of a project indicates whether it is complete or not and the designer could choose which ever part he/she want to view or edit. Project view page also provides an option to export project data to PDF where a user can save or print. Apart from the later project view option, project list page provides an option for deletion of a project. The designer has to be prompted to confirm delete action before a project and all its details been deleted.

5.4.2.6 System Implementation

The system has been implemented using PHP, MySQL and APACHE software. With PHP 5.3.10 the researcher was able to implement the system in Object Oriented approach which implies that the system has adopted many benefits of OOP such as re-usability, extensibility, maintainability and efficiency. Furthermore, APACHE 2.2.22 has been used because it is more stable, fast and more secure than the previous versions. Adding to that, MySQL 5.5.34 server has been used for database implementation. A MySQL 5.0 version (dynamic SQL) has MySQLi extension that introduced prepared statements for better security and flexibility (Hayder, 2007). SQL queries used prepared statements. Advantages offered by using prepared statements, according to Hayder (2007) it provides better performance and prevention of SQL injection. See appendix D for details.

Web pages of the system were designed using HTML5 and CSS3, data validation and event handling were handled by JavaScript. In HTML5 there are a number of new semantic elements, as well as several related technologies and APIs whose additions and changes to the language have been introduced with the goal of web pages being easier to code, use, and access. CSS3 allows the developer to include design elements in a forward-thinking manner that leads to so many benefits such as clean markup that is accessible to humans and machines, maintainable code, fewer extraneous images, and faster loading pages (Goldstein *et al.*, 2011). Finally, it was found very useful to validate forms, handling events and control of some user navigations by use of client-side script language JavaScript, it was faster and more flexible.

5.5 Model and Algorithm Testing and Evaluation

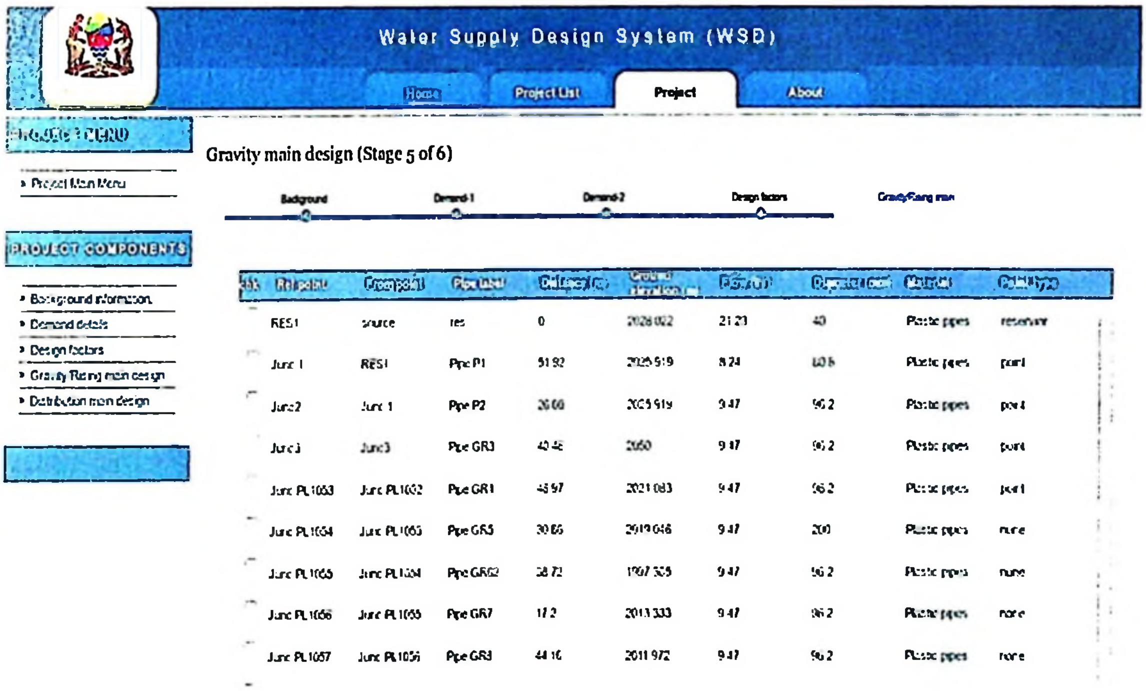
The designed model and the algorithm were implemented to provide a software, as it has been explained in previous subsections. Thereafter, the software was presented to the users in order to test and evaluate the model. There were five tested cases of the system the case of designing a project, the case of verifying the design the case of updating a project, case of deleting an existing project and the case of exporting the project to PDF.

During system testing, five water supply engineers (system testers and expected users) were invited for evaluation but due to their schedule only three managed to attend. Among them one had 35 years of experience in the field and currently responsible for approval of rural water supply project designs. The second one has 20 years of experience and the last one has seven years of experience in design, implementation and maintenance of the water supply systems. The researcher started by demonstrating the system, and provided the general overview of what the system does and how it works. Thereafter, each user had the chance to use and evaluate the system.

System test cases were as follows:

i. Design new project

With little assistance each of them managed to design new projects. It was found that the system was easier for them to understand and use because it has been localized according to their local practices of designing water supply systems.

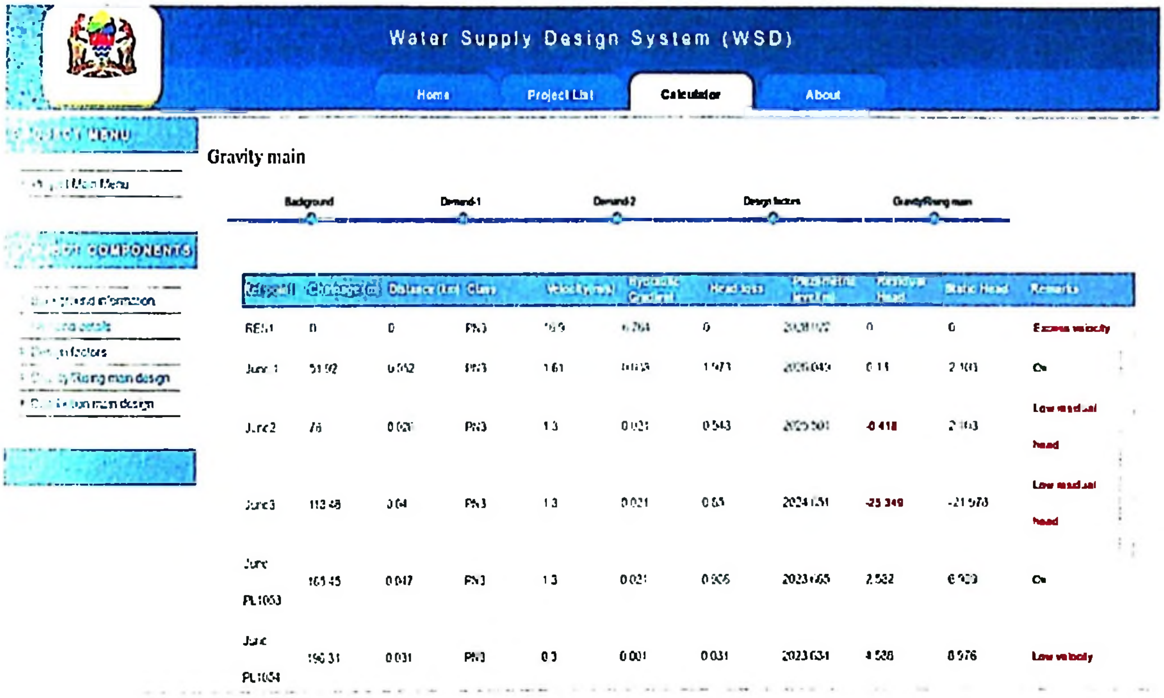


Gravity main design (Stage 5 of 6)

Figure 5.7: Water Supply Design

ii. Design verification

After defining all design parameters the designs were verified. Some of the designs had reference points with error of "Excess velocity" which is the result of velocity been above the acceptable range. The system redirected the designer back to redesign to fix the error. Other projects verification column displayed "low residual head" for some reference points, which means residual head was not sufficient for water to reach its destination. The user was also redirected back to fix the error.



Ref point	Chainage (m)	Distance (km)	Class	Velocity (m/s)	Hydraulic Gradient	Head loss	Piezometric level (m)	Residual Head	Static Head	Remarks
RES1	0	0	PN3	[illegible]	[illegible]	0	[illegible]	0	0	Excess velocity
Junc 1	51.92	0.052	PN3	1.61	[illegible]	1.973	[illegible]	0.11	2.101	Ok
Junc2	76	0.02	PN3	1.3	0.021	0.543	2025.501	-0.418	2.103	Low residual head
Junc3	113.48	0.04	PN3	1.3	0.021	0.85	2024.151	-25.349	-21.978	Low residual head
Junc PL1053	165.45	0.047	PN3	1.3	0.021	0.906	2023.165	2.532	6.[illegible]	Ok
Junc PL1054	190.31	0.031	PN3	0.3	0.001	0.031	2023.634	4.528	8.976	Low velocity

Figure 5.8: Water Supply Design Verification

iii. Update project

Tested projects were of two types: gravity main based projects and rising main based projects. The update function for gravity flow projects worked just fine, and was able update all information needed. Updates of other projects also worked as expected and successful updated.

iv. Delete project

Water supply design system allows a user to delete one or more projects at a time. During program testing all testers managed to delete a single and two projects at a time.

Table 5.2: Summary of the System Testing Results

	SYSTEM BEHAVIOR AND PERFORMANCE TOWARDS THE TESTED CASES		
TEST CASE	No. of users Invited to test	No. of users Attended the test	System performance on the test case
1.Design new project	5	3	System did well, the testers were able to design gravity based and rising main projects.
2.Design verification	5	3	The system behaved well and displayed appropriate errors related to wrong design estimation. The system redirected them to fix the error.
3.Update project	5	3	The system did well, and testing engineers were able to update information for their projects.
4.Delete project	5	3	System successfully deleted, deleted projects.
5.Export to PDF	5	3	All tested project and calculated values were successfully exported to PDF.

v. Export to PDF

All tested projects were successfully exported to PDF. The exported data included design parameters defined by the project design engineer and calculated output values from the algorithm.

In general, the testers found a great potential in this system in their work and recommended the researcher to add user accounts and grant different privileges and roles in order to enable them to adopt it. To quote exact words one of the testers said, "This software is one of the best to be used by technical organization dealing with water supply project, because it can easily be modified to fit any technical developments". On the other hand, it is viewed as a simple tool to be used by new engineers joining the field. Further-more, they insisted to make it available for others to get access and use it so that they can give a constructive ideas to improve it to full a featured system to be used for design and management of projects.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This Chapter provides conclusion for each research question based on the findings, model and algorithm evaluation results presented in Chapter 4 and 5 respectively. Also, this Chapter elucidates key contributions of this research in the field of computer science, research and the society in general. Finally, basing on what had been experienced in this study the researcher recommends area that needs further research.

6.2 Conclusions

From the research findings, discussion, testing and evaluation results the following conclusions are made basing on the research questions:

6.2.1 Research Question One

The study addressed two main challenges: adequate flow and pressure needed to transport water consumers. In Chapter 5 the existing model was analyzed and basing on its weaknesses, it should be considered invalid for the grid distribution layout. On the other hand, because majority of the projects conducted in the study area were for rural areas by nature, therefore a branched distribution network should be considered the best layout for water supply services. Furthermore, according to analysis of the existing theories, principles and best local design practices the following should apply to balance the flow and pressure to the consumers: the law of conservation of energy, Continuity and Hazen William's principles as well as the gravity flow theory.

6.2.2 Research Question Two

The model and algorithm were designed based on best local design practices, theories and assumptions as described by the first research question. Both the generalized model and the algorithm were further implemented to provide a software prototype. Based on the results obtained and discussed in chapter 5, this prototype should be considered as a useful milestone towards development of a localized tool for design and analysis of water supply systems in the rural settings.

6.3 Research Contribution

This research provided two major research contributions. Firstly, analysis of strength and weaknesses of the existing model which was addressing a similar problem in the same area of study. Secondly, it has provided a generalized model and a localized algorithm for analysis and rectification of water supply design which was further implemented to provide a prototype tool; a tool here means computer software for design and analysis of water supply systems.

6.4 Recommendations

In view of the above findings, discussion and conclusions the study recommends the following:

1) Due to the weaknesses of the existing model the study recommends application of the new model and algorithm proposed by this research to address the problem of pressure and flow variations in the study area.
2) Furthermore, based on testing and evaluation results of the developed prototype, the researcher recommends further implementation of the software prototype to

be done so as to provide a full functional system for design and management of water supply projects in the given study area.

3) Finally, the researcher recommends further research to be done for other kinds of distribution systems such as ring main (circular) and radial systems in order to optimize their designs with respect to our local settings and standards.

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APPENDICES

Appendix A: Interview Questions

I. Open ended interview questions as part of data collection exercise.

1. Discuss the strength and weakness of the initial prototype based on the existing model.
2. Explain key elements to be added which can lead to an effective water supply design.
3. Elucidate theories, principles and procedures to be considered for the design of water supply systems?
4. Among theories and procedures identified in (3) above, which ones are considered the best practices and why?
5. What assumptions underlying those design principles?
6. What are the major water supply design challenges?

II. Open ended interview questions for system evaluation.

1. Have you used new water supply design prototype? If yes, how did you find it?
2. Do you think this system can bring any added value to your work?
3. If yes or no in (2) above, explain why.
4. Have you ever used any other software for design and analysis of water supply designs?
5. If yes in (4) above, what are they?

6. If yes in (4), how can you compare this system and those other tools?
7. If no (2), why?
8. What are your recommendations about this system?

Appendix B: Gauss Elimination

The following algorithms implement Gaussian elimination with partial pivoting followed by back substitution to compute the solution of Ax= **b**, where Ais an **nxn** matrix with ij^th^ entry aijand **b**is an n-vector with i^th^ component bi.

GAUSSIAN ELIMINATION WITH PARTIAL PIVOTING ON A:

```
For $k = 1, \ldots, n-1$
    Find $i_k \geq k$ such that $|a_{i_k k}| = \max_{k \leq i \leq n} |a_{ik}|$.
    If $i_k > k$, interchange $a_{kj} \leftrightarrow a_{i_k j}$ for $j = k, \ldots, n$.
    For $i = k+1, \ldots, n$
        $a_{ik} \leftarrow -a_{ik}/a_{kk}$
        For $j = k+1, \ldots, n$
            $a_{ij} \leftarrow a_{ij} + a_{ik}a_{kj}$
```

ROW OPERATIONS ON b:

```
For $k = 1, \ldots, n-1$
    If $i_k > k$, interchange $b_k \leftrightarrow b_{i_k}$.
    For $i = k+1, \ldots, n$
        $b_i \leftarrow b_i + a_{ik}b_k$
```

BACK SUBSTITUTION:

```
$b_n \leftarrow b_n/a_{nn}$
For $i = n-1, \ldots, 1$
    $b_i \leftarrow \left(b_i - \sum_{j=i+1}^{n} a_{ij}b_j\right)/a_{ii}$
```

Appendix C: Data Dictionary

Below is the data dictionary for Water Project database of Water Supply Design System.

No	Field name	Data types	Description	Index
1	project_id	int(50)	Project unique ID	Primary Key
2	project_name	varchar(100)	Name of the project	
3	Region	varchar(50)	Region in which the project is going take place	
4	Source	varchar(50)	The source of water supply for the project.	
5	population_id	int(50)	Population unique ID	Primary Key
6	perCapita_id	int(50)	PerCapita unique ID	Primary Key
7	PublicHTap	int(50)	Number of households with public tap	
8	Medium	int(50)	Medium income households with sewer/septic tank	
9	High	int(50)	High income households with sewer/septic tank	
10	Hotel	int(50)	Average number of customers in hotels	
11	Shop	int(50)	Average number of shops	

12	Hospital	int(50)	Average number of patients per day	
13	Boarding	int(50)	Total number of boarding school students	
14	factors_id	int(50)	Project design factors unique ID	Primary Key
15	day_factor	Float	Peak day factor	
16	hr_factor	Float	Peak hour factor	
17	pLoss	Float	Calculated water loss	
18	pipeStructure_id	int(50)	pipeStructure unique ID	Primary Key
19	ref_pt	Varchar(15)	Pipe references point	
20	ground_y	Double	Ground elevation of a point	
21	Flow	Double	Water flow in lps	
22	Diameter	Float	Pipe diameter in mm	

Appendix D: Pseudo codes

The following sections present part of the source code used to implement algorithms:

(a) Part of SQL queries using prepared statements to select specified project data as follow:

```
<? php
include 'dbConfig.php';
    .
    .
    .
functiongetProject($project_id) {
    $connfn = $this->dbconnect();
    $query = "SELECT * FROM Population WHERE project_id = ?";
try {
        $stmt = $connfn->prepare($query);
        $stmt->bindParam(1, $project_id, PDO::PARAM_INT);
        $stmt->execute();
        $this->project = $stmt->fetch();
return $this->project;
        } catch (PDOException $e) {
print $e->getMessage();
    }
    $connfn = null;
```

```
    }

         .

         .

//Get more project data from other tables in a similar approach as the above query for
//Population table

         .

?>
```

(b) Algorithm implementation: The follow is just part of codes that show how the Water supply design algorithm has been implemented.

//**ALGORITHM** *watersupplysystemhydrauliccomputations*

//**INPUT** population, percapita, percentage losses, peak day factor, peak hour factor, technology, Riser height, Height of tank, Fitting losses, Riser constant, reference points, distance, flow, diameter, ground elevation, material, point type, part design and total reference points N.

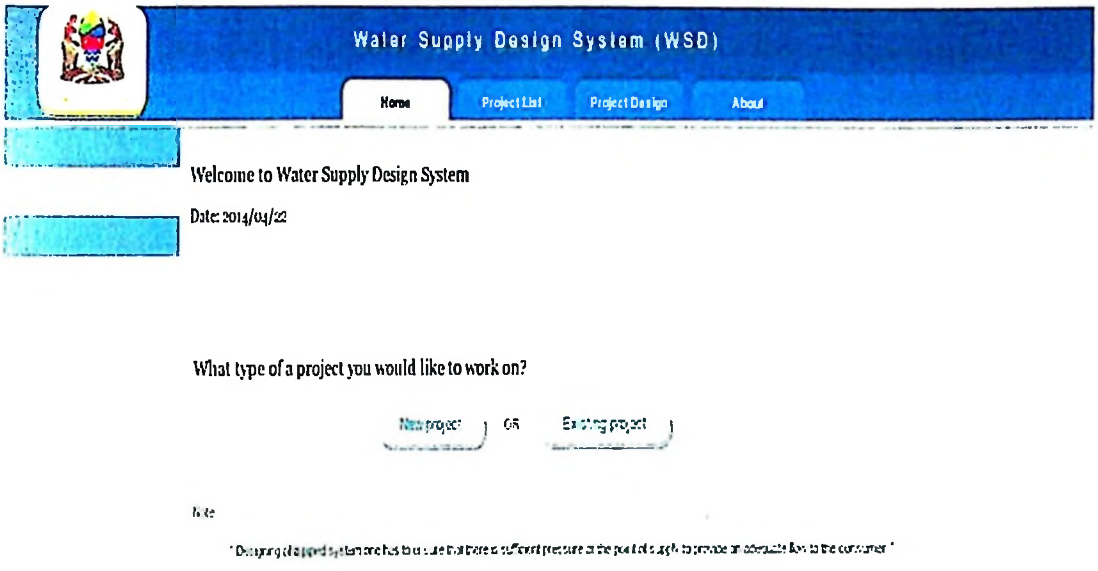
```
<?php

require '../classes/functions.php';

require '../classes/calculator.php';

        $function = new functions();

        $calc = new Calculator();

if (isset($_GET['project_id'])|| ($_POST['project_id'])) {

        $project_id = $_GET['project_id'];

        $part = $_GET['part'];

         .
```

```
        .

        .

        $popln = $function->getPopulation($project_id);

        $perCapita = $function->getPerCapita($project_id);

        $factors = $function->getFactors($project_id);

}

        .

        .

        .

//Step 1, 2, 3 and 4:

        .

        .

//demand method calculates demand for individual population item

        $total_demand = $calc-> demand($popln, $perca);

// sumDemand method calculates total demand

        $total_demand = $calc->sumDemand();

    .

    .

    .

//Step 5 and 6

        $ploss = $calc->percent($percent, $Demand);

        $gross = $calc->subtract($Demand, $ploss);

        $dayDemand = $calc->multiply($dayFactor, $gross);

        $dayDemandhr = $calc->hrDemand($dayDemand);
```

```
        $hrDemand = $calc->multiply($hourfactor, $dayDemandhr);

        .

        .

//Step 7, 8, . . . 11

        .

        .

        .

        $rows = $function->getPipeDesign($project_id,$part);

        if (count ( $rows )  != 0 ) {

        $chainage   = $calc->chainage ( $rows);

        $calc->hazenConstant();

        $kmDistance   = $calc->kmDistance( $rows);

        $velocity = $calc->velocity( $rows );

        $hydGrad = $calc->hydGrad($rows );

        $headLoss = $calc->headLoss(  $rows) ;

        .

        .

        .

        if(trim($part) == trim('rising main')){

        .

        .

        $piezometric =$calc->piezometric(  $key,  $array, $riserH ,. . . . ,$const);

        }elseif((trim($part) == trim('gravity main'))) {

        $piezometric =$calc->piezometric_gd($rows);

        }
```

```
$residualH = $calc->residualH($rows);

$calc->PN_class($residualH);

$pn = $calc->getPn();

$joint_type =$calc->getJointType();

$staticH= $calc->staticH( $key, $array);

$remarks = $calc->remarks( $key, $array);
```

Appendix E: Some System Screenshots



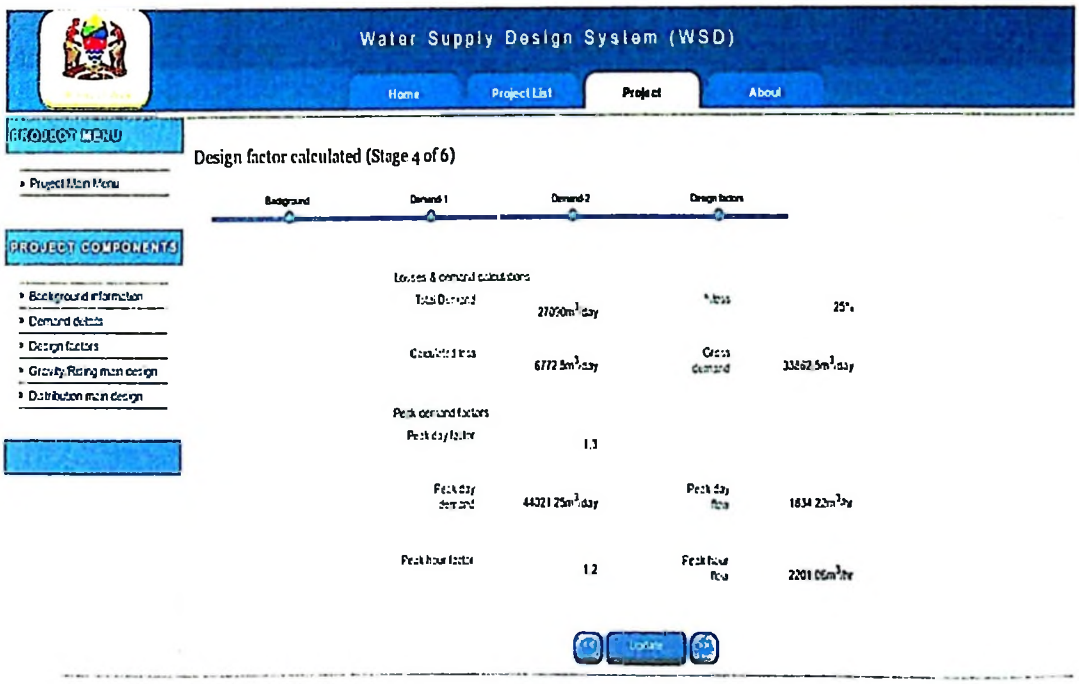
Welcome to Water Supply Design System

Date: 2014/04/22

What type of a project you would like to work on?

Note

" Designing of a piped system one has to ensure that there is sufficient pressure at the point of supply to provide an adequate flow to the consumer "



Design factor calculated (Stage 4 of 6)

Losses & demand calculations

Total Demand 27090m³/day

% loss 25%

Calculated loss 6772.5m³/day

Gross demand 33862.5m³/day

Peak demand factors

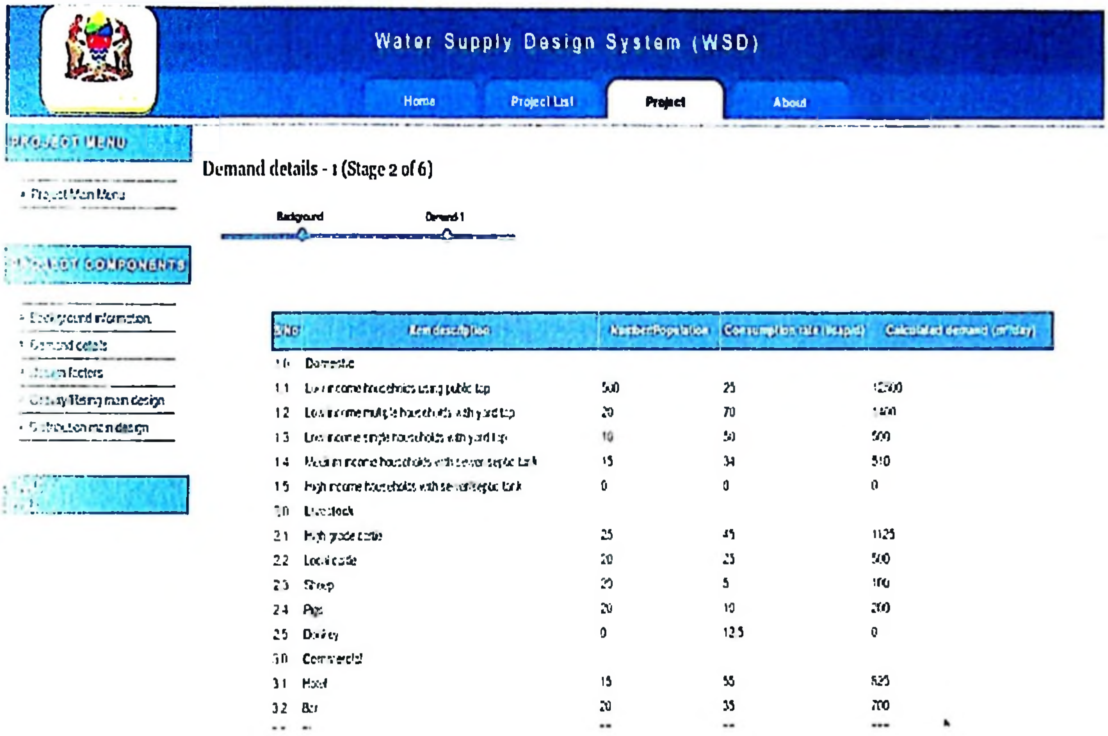
Peak day factor 1.3

Peak day demand 44021.25m³/day

Peak day flow 1834.22m³/hr

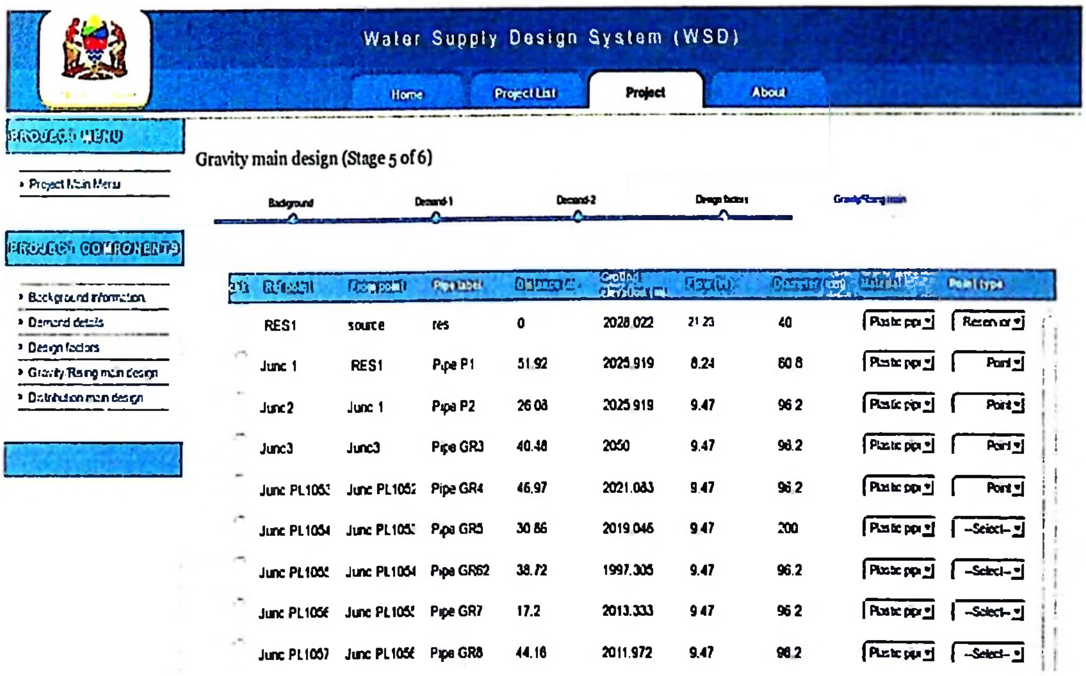
Peak hour factor 1.2

Peak hour flow 2201.06m³/hr



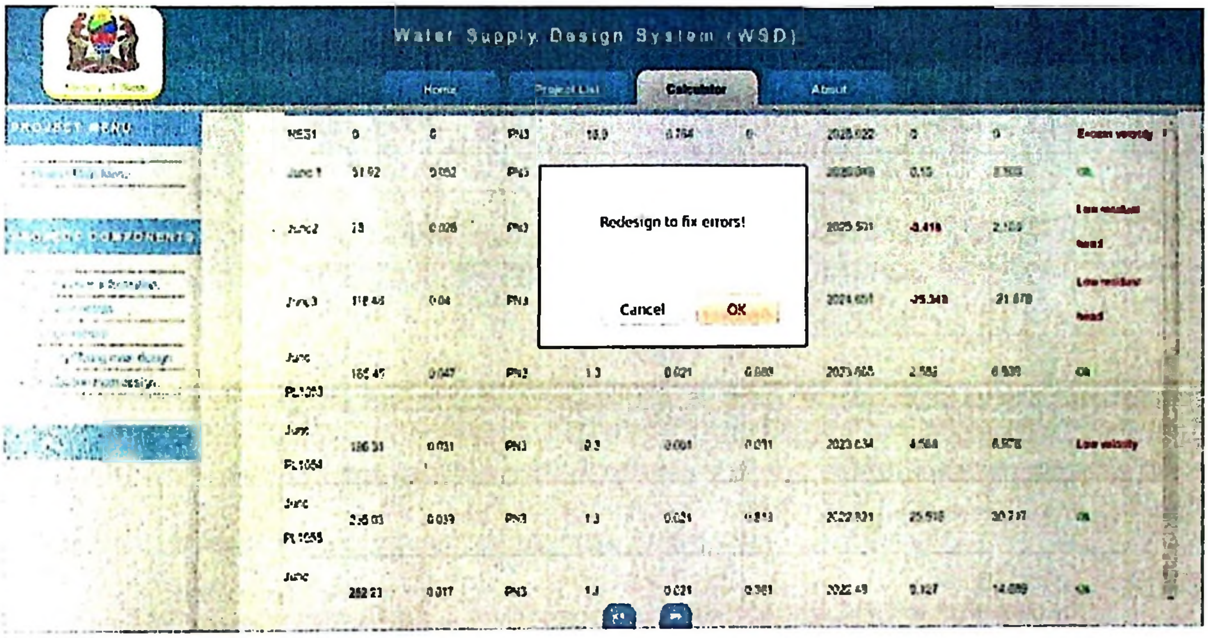
Demand details - 1 (Stage 2 of 6)

S/No	Item description	Number/Population	Consumption rate (l/cap/d)	Calculated demand (m^3/day)
1.0	Domestic			
1.1	Low income households using public tap	500	25	12500
1.2	Low income multiple households with yard tap	20	70	1400
1.3	Low income single households with yard tap	10	50	500
1.4	Medium income households with sewer septic tank	15	34	510
1.5	High income households with sewer/septic tank	0	0	0
2.0	Livestock			
2.1	High grade cattle	25	45	1125
2.2	Local cattle	20	25	500
2.3	Sheep	20	5	100
2.4	Pigs	20	10	200
2.5	Donkey	0	12.5	0
3.0	Commercial			
3.1	Hotel	15	55	525
3.2	Bar	20	35	700
--	--	--	--	---



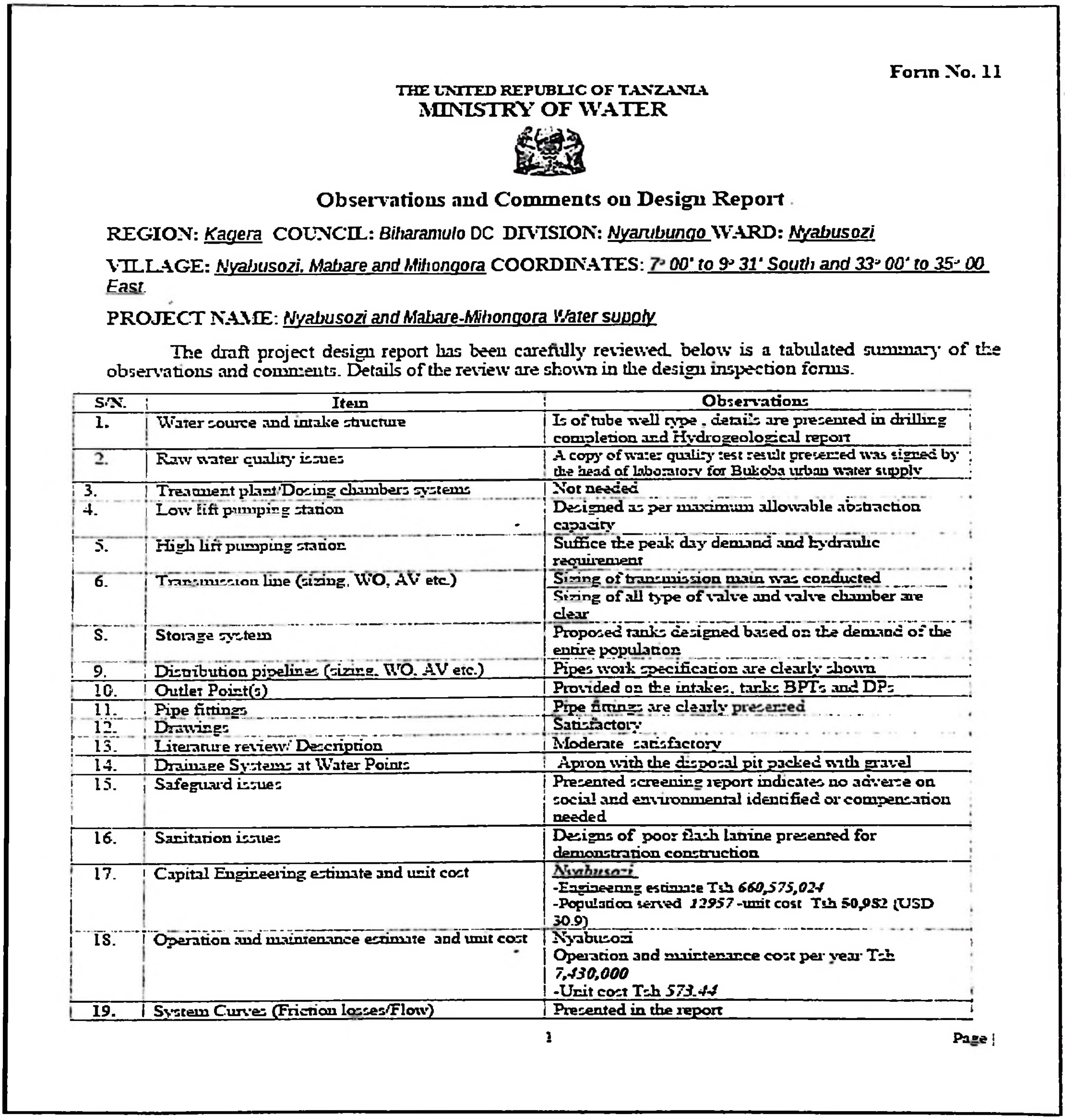
Gravity main design (Stage 5 of 6)

S/N	Ref point	From point	Pipe label	Distance (m)	Ground elevation (m)	Flow (l/s)	Diameter (mm)	Material	Point type
	RES1	source	res	0	2028.022	21.23	40	Plastic pip	Reservoi
	Junc 1	RES1	Pipe P1	51.92	2025.919	8.24	60.8	Plastic pip	Point
	Junc2	Junc 1	Pipe P2	26.08	2025.919	9.47	96.2	Plastic pip	Point
	Junc3	Junc3	Pipe GR3	40.48	2050	9.47	96.2	Plastic pip	Point
	Junc PL105	Junc PL105	Pipe GR4	46.97	2021.083	9.47	96.2	Plastic pip	Point
	Junc PL1054	Junc PL105	Pipe GR5	30.86	2019.046	9.47	200	Plastic pip	--Select--
	Junc PL105	Junc PL1054	Pipe GR62	38.72	1997.305	9.47	96.2	Plastic pip	--Select--
	Junc PL105	Junc PL105	Pipe GR7	17.2	2013.333	9.47	96.2	Plastic pip	--Select--
	Junc PL1057	Junc PL105	Pipe GR8	44.16	2011.972	9.47	96.2	Plastic pip	--Select--



Redesign to fix errors!

Appendix F: Some Documents from Data Collection



Form No. 11

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF WATER

Observations and Comments on Design Report

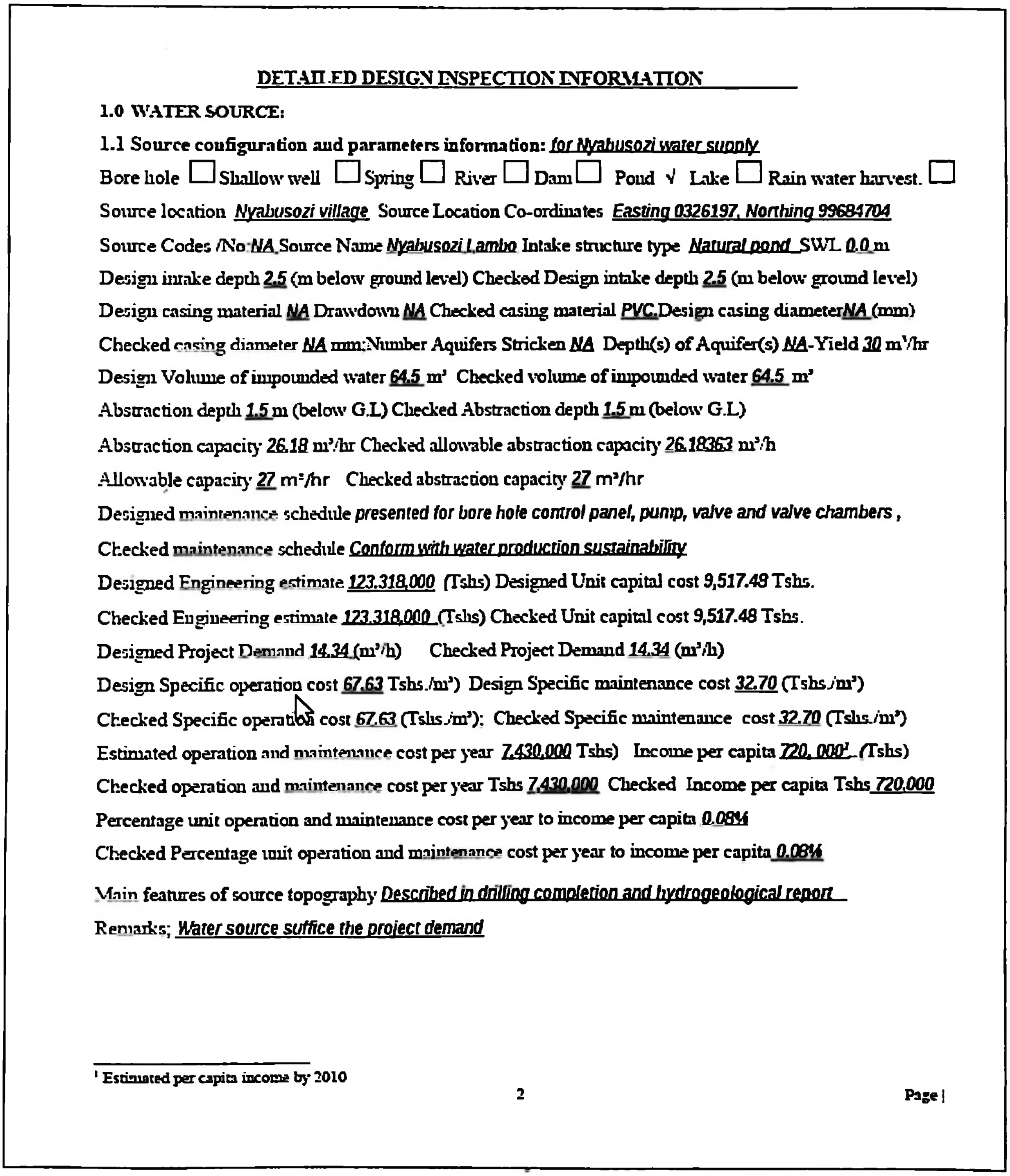
REGION: *Kagera* **COUNCIL:** *Biharamulo* DC **DIVISION:** *Nyarubungo* **WARD:** *Nyabusozi*

VILLAGE: *Nyabusozi, Mabare and Mihongora* **COORDINATES:** *7° 00' to 9° 31' South and 33° 00' to 35° 00 East*

PROJECT NAME: *Nyabusozi and Mabare-Mihongora Water supply*

The draft project design report has been carefully reviewed. below is a tabulated summary of the observations and comments. Details of the review are shown in the design inspection forms.

S/N.	Item	Observations
1.	Water source and intake structure	Is of tube well type , details are presented in drilling completion and Hydrogeological report
2.	Raw water quality issues	A copy of water quality test result presented was signed by the head of laboratory for Bukoba urban water supply
3.	Treatment plant/Dosing chambers systems	Not needed
4.	Low lift pumping station	Designed as per maximum allowable abstraction capacity
5.	High lift pumping station	Suffice the peak day demand and hydraulic requirement
6.	Transmission line (sizing, WO, AV etc.)	Sizing of transmission main was conducted Sizing of all type of valve and valve chamber are clear
8.	Storage system	Proposed tanks designed based on the demand of the entire population
9.	Distribution pipelines (sizing, WO, AV etc.)	Pipes work specification are clearly shown
10.	Outlet Point(s)	Provided on the intakes, tanks BPTs and DPs
11.	Pipe fittings	Pipe fittings are clearly presented
12.	Drawings	Satisfactory
13.	Literature review/ Description	Moderate satisfactory
14.	Drainage Systems at Water Points	Apron with the disposal pit packed with gravel
15.	Safeguard issues	Presented screening report indicates no adverse on social and environmental identified or compensation needed
16.	Sanitation issues	Designs of poor flash latrine presented for demonstration construction
17.	Capital Engineering estimate and unit cost	*Nyabusozi* -Engineering estimate Tsh *660,575,024* -Population served *12957* -unit cost Tsh 50,982 (USD 30.9)
18.	Operation and maintenance estimate and unit cost	Nyabusozi Operation and maintenance cost per year Tsh *7,430,000* -Unit cost Tsh *573.44*
19.	System Curves (Friction losses/Flow)	Presented in the report



DETAILED DESIGN INSPECTION INFORMATION

1.0 WATER SOURCE:

1.1 Source configuration and parameters information: *for Nyabusozi water supply*

Bore hole ☐ Shallow well ☐ Spring ☐ River ☐ Dam ☐ Pond √ Lake ☐ Rain water harvest. ☐

Source location *Nyabusozi village* Source Location Co-ordinates *Easting 0326197, Northing 99684704*

Source Codes /No *NA* Source Name *Nyabusozi Lambo* Intake structure type *Natural pond* SWL *0.0* m

Design intake depth *2.5* (m below ground level) Checked Design intake depth *2.5* (m below ground level)

Design casing material *NA* Drawdown *NA* Checked casing material *PVC* Design casing diameter *NA* (mm)

Checked casing diameter *NA* mm:Number Aquifers Stricken *NA* Depth(s) of Aquifer(s) *NA*-Yield *30* m^3/hr

Design Volume of impounded water *64.5* m^3 Checked volume of impounded water *64.5* m^3

Abstraction depth *1.5* m (below G.L) Checked Abstraction depth *1.5* m (below G.L)

Abstraction capacity *26.18* m^3/hr Checked allowable abstraction capacity *26.18363* m^3/h

Allowable capacity *27* m^3/hr Checked abstraction capacity *27* m^3/hr

Designed maintenance schedule *presented for bore hole control panel, pump, valve and valve chambers* ,

Checked maintenance schedule *Conform with water production sustainability*

Designed Engineering estimate *123.318,000* (Tshs) Designed Unit capital cost *9,517.48* Tshs.

Checked Engineering estimate *123.318,000* (Tshs) Checked Unit capital cost 9,517.48 Tshs.

Designed Project Demand *14.34* (m^3/h) Checked Project Demand *14.34* (m^3/h)

Design Specific operation cost *67.63* Tshs./m^3) Design Specific maintenance cost *32.70* (Tshs./m^3)

Checked Specific operation cost *67.63* (Tshs./m^3): Checked Specific maintenance cost *32.70* (Tshs./m^3)

Estimated operation and maintenance cost per year *7,430,000* Tshs) Income per capita *720, 000*[1] (Tshs)

Checked operation and maintenance cost per year Tshs *7,430,000* Checked Income per capita Tshs *720,000*

Percentage unit operation and maintenance cost per year to income per capita *0.08%*

Checked Percentage unit operation and maintenance cost per year to income per capita *0.08%*

Main features of source topography *Described in drilling completion and hydrogeological report*

Remarks; *Water source suffice the project demand*

---

[1] Estimated per capita income by 2010

2

Page |

1.2 Laboratory Test Results *for Nyabusozi village*

1. 2.1 Physical Test
Sand Content *N.M* mg/l); Other Suspended Solids *NIL* (mg/l); Total suspended solid *NIL* .(ppm); Temperature *23.4* (°c); Color 6 Turbidity 5 (NTU); Total dissolved solid 258 mg/l:

1.2.2 Bacteriological Test:
Total Coli form *N.D* (ppm). Faecal Coli *N.D* (ppm)

1.2.3 Chemical Test:
Nitrate *0.8* (mg/l); Manganese *N.D* (mg/l); Sulphate 22 (mg/l); Chloride *N.M* (mg/l): Fluoride *.N.D* (mg/l);

$KMnO_4$ *N.D* (mg/l); Carbonate *N.D* (mg/l); Calcium *128* (mg/l); Magnesium *26* (Mg/l); Potassium *4.16* (mg/l)

Ferric Materials *N.D* (mg/l); Ph *8.12* Electrical Conductivity *516* (μS/cm); Alkalinity *109.5* (mg/l); Hardness *235*(mg/l); Non Filtrate residue *N.D* (mg/l); Magnesium *26*(mg/l); Salinity *0.2*(mg/l):

Sodium *7.92* (mg/l) Orthophosphate *0.43* (mg/l) Ammonium *0.06* (Mg/l) Dissolved Iron *0.05* (mg/l)

1.2.4 Laboratory recommendation: Water is acceptable for human consumption

2.0 Water Demand *for Nyabusozi water supply*

S/No.	Item Description		Design Data			Checked Demand (m³/day)	Remarks
			Number/ Population	Consumption rate (l/cap/d)	Demand (m³/day)		
2.1	**Domestic**						
	Yard Stand Tape						
	Public Tape		12,957	25	323.93	323.925	Ok
2.2	**Live stock Unit (L.S.U)**				-		
	Cattle		-	25	-		
	Goat		77	5	0.39	0.385	Ok
	Sheep		88	5	0.44	0.44	Ok
	Donkey		-	12.5	-		
	Pig		-	10	-		
2.3	Commercial (shops)		-	5	-		
2.4	**Industrial**				-		
	Commercial (Rest house and restaurant)				-		
2.5	**Institutions**				-		
	Day School Students		1712	10	17.12	17.12	Ok
	Boarding Students				-		
	Church/Mosque		218	10	2.18	2.18	Ok
	Dispensaries/health Centre		353	10.00	3.53	Ok	
		Visitor					
	TOTAL				344.05	347.58	Ok
	20% loss				69.824	69.516	
	Gross Water demand for the project (m³/d)				418.94	417.096	Ok
	Peak demand		Peak factor	m³/day	m³/hour	Corrected values	

THE UNITED REPUBLIC OF TANZANIA

MINISTRY OF WATER

Ng'uruhe Water Project Design Data

Flow to Sump (l/s)	3.00
Name of transmission main	Ng'uruhe Gravity Main
Points of transmission	From RES 1 and RES 2 to Ng'uruhe Tank

Ref. Point				Pipe Selection	
Name	Pipe Label	Ground Elevation	Distance in m	Material	Diameter
Resvr RES1		2028.022	0.0	HDPE PE 100	43.7
Junc PL1049	Pipe P1	2025.919	51.92	HDPE PE 100	43.7
Resvr RES2		2028.035	0.0	HDPE PE 100	43.7
Junc PL1049	Pipe P2	2025.919	26.08	HDPE PE 100	43.7
Junc PL1050	Pipe GR3	2023.899	40.48	HDPE PE 100	98.2
Junc PL1053	Pipe GR4	2021.083	46.97	HDPE PE 100	98.2
Junc PL1054	Pipe GR5	2019.046	30.86	HDPE PE 100	98.2
Junc PL1055	Pipe GR6	2016.491	38.72	HDPE PE 100	98.2
Junc NG1057	Pipe GR7	1997.305	17.2	HDPE PE 100	98.2
Junc PL1058	Pipe GR8	2013.333	44.16	HDPE PE 100	98.2
Junc PL1059	Pipe GR9	2011.972	34.16	HDPE PE 100	98.2
Junc PL1070	Pipe GR10	2009.181	20.7	HDPE PE 100	98.2
Junc PL1071	Pipe GR11	2009.036	32.04	HDPE PE 100	98.2
Junc PL1072	Pipe GR12	2008.92	25.56	HDPE PE 100	98.2
Junc NG1074	Pipe GR13	2008.867	11.7	HDPE PE 100	98.2
Junc NG1073	Pipe GR14	2008.83	8.29	HDPE PE 100	98.2
Junc PL1075	Pipe GR15	2009.707	8.54	HDPE PE 100	98.2
Junc PL1076	Pipe GR16	2010.838	29.81	HDPE PE 100	98.2
Junc NG1078	Pipe GR17	2011.556	17.02	HDPE PE 100	98.2
Junc NG1077	Pipe GR18	2011.782	5.36	HDPE PE 100	98.2

Junc NG1079	Pipe GR19	2012.218	9.05	HDPE PE 100	96.2

RESERVIOR INFORMATION

Ref. Point	Flow
Resvr RES1	1.16
Resvr RES2	1.84

Distribution Main for Nguruhe Water Supply					
	Ministry of water- Project				
Storage Tank	Nguruhe Tank				
Ref. Point				Pipe Selection	
Name		Ground Elevation	Distance in m	Material	Diameter
Junc PL1189	Pipe GR62	1996.585	0	HDPE PE 100	96.2
Junc PL1189	Pipe GR63	1995.953	36.61	HDPE PE 100	48.2
Junc PL1190	Pipe GR64	1994.394	49.41	HDPE PE 100	78.6
Junc PL1191	Pipe P165	1991.667	31.99	HDPE PE 101	78.6
Junc PL1191	Pipe P69	1991.922	38.24	HDPE PE 102	46.8
Junc PL1193	Pipe P70	1991.293	74.13	HDPE PE 103	48.6
Junc PL1194	Pipe P71	1990.283	60.48	HDPE PE 104	48.6
Tank S/T1	Pipe GR65	1991.342	33.87	HDPE PE 100	48.6
Junc PL017	Pipe P72	1990.749	85.88	HDPE PE 105	48.2
Junc PL018	Pipe P73	1987.692	66.08	HDPE PE 106	48.2
Junc PL019	Pipe P74	1983.734	128.16	HDPE PE 107	48.2
Junc PL020	Pipe P75	1985.728	58.63	HDPE PE 108	48.2
Junc PL024	Pipe P76	1980.44	103.13	HDPE PE 109	48.2
Junc PL027	Pipe P77	1978.475	72.97	HDPE PE 110	78.6
Junc RD027	Pipe P78	1974.391	132.7	HDPE PE 111	78.6
Junc PL032	Pipe P79	1970.306	81.9	HDPE PE 112	78.6
Junc CP035	Pipe P80	1952.607	325.85	HDPE PE 113	78.6
Junc PL038	Pipe P81	1947.788	94.65	HDPE PE 114	78.6
Junc PL039	Pipe P82	1941.655	119.23	HDPE PE 115	65.6
Junc PL040	Pipe P83	1936.983	107.03	HDPE PE 116	65.6

Junc RD041	Pipe P84	1933.364	64.91	HDPE PE 117	65.6
Junc CP045	Pipe P85	1931.781	35.42	HDPE PE 118	65.6
Junc CP043	Pipe P86	1931.133	10.91	HDPE PE 119	65.6
Junc PL045	Pipe P87	1929.958	25.93	HDPE PE 120	65.6
Junc PL046	Pipe P88	1924.339	130.08	HDPE PE 121	65.6
Junc CP0049	Pipe P89	1918.023	156.75	HDPE PE 122	65.6