# *AN EVALUATION OF THE MINIMUM REQUIREMENTS FOR THE DESIGN OF RURAL WATER SUPPLY PROJECTS*

by

MPW CHIRWA

Thesis presented in partial fulfilment of the
requirements for the degree of
Master of Science in Engineering (Civil)
at the University of Stellenbosch

Mr J.A. Du Plessis
Supervisor

Stellenbosch December 2005

# DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signed ……………………

Mtampha-palombo Wadonda Chirwa

Date ………………………

# ABSTRACT

In this study, the minimum standards required for the design of rural piped water supply projects as set by the Department of Water Affairs and Forestry (DWAF) are evaluated with respect to capital pipe cost using the *Nooightgedacht* rural water supply scheme selected as a case study. It is considered that the application of the minimum standards has a cost effect associated with it.

The main aim is to investigate in terms of cost, the feasibility of applying the minimum standards on residual pressure (10 m), demand rate (25 ℓ/c/day) and abstraction rate (10 ℓ/min) in the design of rural water supply projects as set by Department of Water Affairs and Forestry (DWAF), and to investigate the possibility of increasing the standard on demand rate to 50 ℓ/c/day without incurring significant capital pipe cost in order to satisfy DWAFs' intention of increasing the demand quantity to 50 ℓ/c/day as a basic level of service.

The *Nooightgedacht* water supply project is a gravity fed system and was considered to be representative of most gravity fed systems designed for rural water supply.

As a secondary aim, the study was carried out to investigate which system of rural water supply (conventional reticulated pipeline, hauling and borehole systems) can be cost effective to apply on the selected *Nooightgedacht* water supply scheme considering the economic life and cash flow budgets of each system based on the net present value cost.

Sensitivity analysis on economic factors (maintenance and operation costs, inflation rate and interest on capital redemption) was also done with the aim of establishing which economic factors affects the net present costs, of the different rural water systems, the most.

Analysis of the minimum standards with respect to cost was conducted using *Wadiso SA* computer program as a design and analysis tool on the selected case study. Economic cost analysis of the different water supply systems was conducted using *Microsoft Excel net present value tool*.

The results suggest that the standards on residual pressure (10 m) and demand rate (25 ℓ/c/day) are feasible to be achieved at a relatively low cost and that the demand rate can be increased to 50 ℓ/c/day without significant increase in capital pipe cost.

The standard on abstraction rate (10 ℓ/min) proves to be too high to be achieved at relatively low capital cost. However it was further investigated that the high costs can be overcome with the use of on-site storage tanks which can be used to meet the standard of 10 ℓ/min. The introduction of on-site storage tanks will result in the residual pressure of 10 m not being available to the user at the tap but will nonetheless be available at the connection point which could at a later time be utilised for upgrading.

The investigation on the economic analysis proved that the conventional reticulated pipeline system is a cost effective system to use in the Nooightgedacht water project (gravity fed system) followed by hauling and lastly borehole systems.

The sensitivity analysis proved that the net present value cost of the systems is more sensitive to maintenance and operation costs, followed by interest on capital redemption, and less sensitive to inflation rate.

It is recommended that the findings of this study based on the Nooightgedacht rural water supply project could be applied to similar projects of which the Nooightgedacht is representative.

# SAMEVATTING

In hierdie studie word die minimum standaarde wat benodig word vir die ontwerp van landelike watertoevoer per pyplyn soos voorgeskryf deur die Departement van Waterwese en Bosbou, evalueer, veral met betrekking tot die kapitaal koste van pype. Die *Nooightgedacht* landelike toevoer skema is gekies as ‘n koste effek.

Die hoofdoel is om ‘n ondersoek te loods in terme van koste, die haalbaarheid van die toepassing van minimum standaarde op die oorblywende druk,(10 m), die aanvraagkoers (25 ℓ/c/dag) en die onttrekkingskoers (10 ℓ/min) in die ontwerp van die landelike toevoer projekte soos voorgeskryf deur die Departement van Waterwese en Bosbou en om ondersoek in te stel na die moontlikheid om die aanvraagkoers te vergroot to 50 ℓ/c/dag sonder om merkbare kapitale pyp onkostes aan te gaan en om sodoende die Departement van Waterwese se doelwit te bereik om die aanvrag hoeveelheid te vergroot tot ‘n aanvraag hoeveelheid van 50 ℓ/c/dag as ‘n basiese vlak van diens.

Die *Nooightgedacht* water-voorsienings projek werk met swaartekrag en daar word gevoel dat dat die resultate wat verkry is vanaf hierdie studie van toepasing is op die ontwerp van soortgelyke swaartekrag water toevoer-sisteme waarvan hierdie gevalle studie verteenwoordigend is.

Die tweede doelwit van die studie is om ondersoek in te stel na watter sisteem van landelike water toevoer (konvensioneel netvorming pyplyn, vervoer, en boorgat sisteme) koste-effektief kan wees om toe te pas op die gekose *Nooightgedacht* water toevoer skema as ‘n mens die ekonomiese leeftyd en kontantvloei begrotings van elke sisteem in ag neem, baseer op die netto huidige waarde koste.

Sensitiwiteitsontleding van ekonomiese faktore (instandhouding- en bedryfskoste, inflasie koerse en rente op kapitaaldelging) is ook gedoen met die doel om vas te stel watter ekonomiese faktore die huidige netto koste affekteer.

Ontleding van die minimum standaarde betreffende koste is gedoen met behulp van die Wadiso SA rekenaarprogram as ‘n instrument vir ontwerp en ontleding van die gekose gevallestudie. Ekonomiese koste ontleding van die verskillende watertoevoer sisteme is gedoen met behulp van *Microsoft Excel* Net Present Value.

Daar is ‘n oorsig van die landelike water toevoer bronne en die metodes waarvolgens die water ontwikkel word in drinkwater. Daar is ook ‘n oorsig van die verskillende water distribusie sisteme, en die minimum standaarde soos voorgeskryf deur die Departement van Waterwese en Bosbou word bespreek.

Die resultate baseer op die *Nooightgedacht* gevalle studie bewys dat:

Daar kan aan die standaarde betreffende oorblywende druk (10 m) die aanvraagkoers (25 ℓ/c/dag) voldoen word teen relatiewe lae kapitaalkoste.

Dit is moontlik om die aanvraagkoers tot 50 ℓ/c/dag te verhoog sonder ‘n groot vermeerdering in kapitaalkoste.

Die standaard betreffende onttrekkingskoers (10 ℓ/min) is te hoog om aan voldoen te word teen ‘n ralatiewe lae kapitaalkoste. Daar is egter ook gevind dat die probleem van hoë kostes oorkom kan word deur om van stoortenke gebruik te mak en dat dan aan die standaard van 10 ℓ/min voldoen kan word. Die gebruik van stoortenke by die bron self sal beteken dat die oorblywende druk van 10 m nie beskikbaar is vir die verbruiker by die kraan nie maar wel beskikbaar is by die konneksie punt en dat dit later gebruik kan word om die sisteem op te gradeer tot ‘n hoër vlak van diens.

Die konvensionele netvormige pypleiding sisteem is ‘n koste effectiewe sisteem vir gebruik in die *Nooightgedacht* water projek (swaartekrag sisteem) gevolg deur die vervoer van water en laastens boorgate.

Die sensitiwiteits ontleding bewys dat die netto huidige waarde koste van die sisteme baseer op lewenssiklus koste baie sensitief is vir kapitaal delging.

# ACKNOWLEDGEMENTS

1) I wish to thank the following people for their contributions to the project and this thesis

2) My supervisor, Mr. *J.A. Du Plessis* who played a key role in the guidance and development of the approach to this study to ensure the objectives are achieved, and was always available and keen to help and give advice.

3) Mr. *D.E. Bosman*, the internal examiner, who made valuable inputs and helped with the refinement of this thesis.

4) Mr. *O. Jonker* (MVD Consulting Engineers), for his guidance and assistance in using *Wadiso SA* computer program to design the *Nooightgedacht rural pipe water supply project* and evaluate the minimum standards using the program.

5) Mr. *P. Ravenscroft* (Maluti water) who provided valuable cost information on the different types of rural water supply systems and information on the minimum standards as set by the Department of Water affairs and Forestry (DWAF) for the design of rural piped water supply projects.

6) My parents for their loving support.

# MASTER OF SCIENCE IN WATER ENGINEERING COURSES

The following courses have been successfully completed

| Code | Course | Credits |
|---|---|---|
| MT02 | Probability and Risk Analysis in Civil Engineering | 20 |
| MT03 | Project Economics and Finance | 20 |
| MT07 | Advanced Hydrology | 20 |
| W07 | Rural Water Supply | 13 |
| T06 | Transportation Planning | 13 |
|  | Thesis | 160 |
|  | Total | 246 |

# TABLE OF CONTENTS

# INDEX

## LIST OF FIGURES

# LIST OF TABLES

# 1.0 Introduction

## *1.1 Background*

As stated in the *White Paper on Water Policy* (1997a) one of the overriding priorities of the South African Government is the need to make sure that all people have access to sufficient water.

In order to achieve this priority, the *South African Department of Water Affairs and Forestry (DWAF)* has set a basic level of service with compulsory minimum standards which have to be incorporated in the design criteria of rural water supply systems by all water service institutions *(DWAF 2002)*.

The minimum standards which have to be incorporated in the design criteria of rural water supplies to achieve the basic level of service are defined as follows (*DWAF, 2002*):

- Demand rate - *25 litres per capita per day* (*ℓ/c/day)*
- Abstraction rate (Flow rate) - 10 *litres per minute (ℓ/min)* at the abstraction point
- Residual pressure – *10m at the abstraction point* (*DWAF, 1999*)

It is recognized that the design of rural pipe water supply systems to meet these minimum standards has a cost effect associated with it.

Considering that water services institutions and local authorities are faced with a constraint of tight budgets, but have to meet these standards in delivering basic water services (Illemobade & Stephenson 2003). It is important to ensure that in designing rural water supply schemes, the minimum standards can be met at a reasonable low cost so that the available funds can be used to maximize water services development.

This study, therefore, has the primary aim of evaluating the minimum standards for the design of rural water supply projects as set by *DWAF* in order to achieve the minimum level of service in the rural areas. The evaluation of the standards is done with respect to the cost that is incurred in satisfying the minimum standards.

The study intends to investigate, using a case study, the feasibility of adopting the current minimum standards of design based on the current levels of investment and whether the investment matches the benefit that can be realised from adopting the minimum standards at a reasonable low cost.

In view of the Government’s approach to allow for the progressive increase in the standards of basic service (*DWAF, 1997a*), it is also the intention to investigate the possibility of increasing the minimum standards within acceptable levels of investment, to satisfy the limit of water usage in the rural areas where the minimum level of service uses a communal standpipe (*DWAF, 1999*). However it is noted that different water service levels have different minimum standards.

Different water supply systems are available with which the minimum standards are applied and these include the conventional reticulated pipeline, borehole and hauling systems. However the system chosen will have to consider different factors and among them is the economic consideration.

For a particular area, an important economic consideration is to select a feasible option for service delivery and how much each option would cost both in terms of capital, operation and maintenance costs. In most cases the government subsidises the capital cost of rural water supplies but users are expected to finance the maintenance and operation costs (Webster, 1999).

Sustainability of a chosen system is an important factor to consider in selecting a rural water supply system and this among other things is dependent on the ability of the system users to maintain and operate the system.

Therefore depending on the conditions available, the system to be selected should ensure that it will be sustainable to run in terms of operation and maintenance costs. Maintenance and operation costs should be low since the users will be willing to pay for this system over its economic life than for a system whose costs are high for the same service that they require (Webster, 1999).

It was also considered necessary therefore to carry out an economic cost analysis of the different types of water supply systems that are used in rural water supply, in addition to the evaluation of the minimum standards. This is a secondary aim of this study.

The economic analysis was done in order to obtain an indication of which type of system considering life cycle costs can be cost effective to apply in a rural community in order to ensure that lowest monetary investments are made.

It should be mentioned that the focus of this study is on evaluating pipe supply systems with respect to minimum standards that are required in design, as set by DWAF in order to ensure access to a minimum level of service.

### *1.2 Objectives of this study*

This study has been carried out with the objective to:

a) Evaluate and recommend **minimum standards** used in the design of **rural piped water supply projects,** in order to achieve the basic level of service, with respect to **cost**. This is the main objective of the study.

b) Carry out an **economic cost analysis** of different **rural water supply systems** and recommend a **cost effective system of supply**. This is the secondary objective of the study.

### *1.3 Scope of study*

Since the emphasis of this study is on the evaluation of minimum standards for rural pipe water supply systems certain limitations have been placed on the scope of the study, namely:

- The analysis in this study has used data from part of an existing rural water supply project which can be considered to be representative of the whole project as a case study. The project is called the "*Nooightgedacht rural water supply project*". The evaluation of the minimum standards used for the design of rural piped water systems and the economic analysis of different water supply systems have both been carried out using this case study.

  The "*Nooightgedacht water supply project*" is a gravity fed system and therefore conclusions and recommendations reached from the results of this study are applicable to a gravity system and specifically to gravity systems which the Nooightgedacht case study project is representative of.

- The considerations in the selection of a rural water supply system to be used for a particular area are dependent on a number of factors in particular social, technical, economical, financial, institutional, environmental, political and legal constraints. This study considers the economic and financial issues in the economic analysis, i.e. capital costs, operation and maintenance costs.

### *1.4 Outline of study*

In order to achieve the objectives of this study the research has been structured by dividing it into several chapters as follows:

**CHAPTER 2** is a literature review which discusses:

- Different sources of water and methods by which they can be developed for rural water supply.

- The relevant water supply systems applicable in rural areas namely:

  a) Wells and boreholes including types of handpumps that are appropriate for rural water supply,
  b) Conventional reticulated pipeline systems
  c) Hauling systems.

- The compulsory minimum standards for pipe supply systems that are currently considered in the design of rural pipe water supply projects as required by the Department of Water Affairs and Forestry in order to ensure that the minimum level of service is met.

**CHAPTER 3** explains the methodologies employed in this research.

First the methodology performed in order to evaluate and analyse minimum standards for rural piped water supply systems with respect to capital cost is explained.

The methodology employed for the evaluation of the minimum standards for piped water supply systems has been done with the use of *Wadiso SA* software which is a design and analysis tool for water distribution systems (*GLS Engineering Software Ltd, 2003*). *Wadiso SA* software has been used as a tool to design and analyse the standards based on data on the "*Nooightgedacht water supply project*" used as a case study, and will ensure that the designed system will meet the specified standards for the piped water distribution scheme.

Secondly, the third chapter explains the methodology used in the economic analysis in order to obtain an indication of the cost effectiveness when reticulated pipeline, hauling and borehole rural water supply systems are compared.

The methodology employed in the economic analysis is based on the use of economic evaluation tools to compare these systems, in terms of their economic life and the cash flows budgeted over their economic life span, when the minimum standards are followed.

The economic analysis for reticulated pipeline, hauling and borehole supply systems was also performed using the "*Nooightgedacht water supply project"* as a case study whereby each type of system was considered as an option for supplying water for the project.

The comparison involved using discounting cash flow techniques such as the Net Present Value. A sensitivity analysis was also carried out to obtain an indication of the influence of economic factors on the Net Present Value cost of the different options.

**CHAPTER 4** comprises the results and findings of the investigations done on both the evaluation of minimum standards of piped water supply systems and the economic analysis of the relevant rural water supply technology options.

**CHAPTER 5** and **6** discuss the conclusions that have been drawn from the results and recommendations made from the conclusions.

# 2.0 Literature Review

## *2.1 Introduction*

In this study on the evaluation of the minimum requirements of rural water supply projects, the literature review discusses the following:

- Water sources, namely groundwater and surface water. This is followed by a review of the different water systems that are used for the collection of water from these sources.

  The different types of water systems have been reviewed according to their working principles, design, and advantages and disadvantages.

- The different common types of handpumps that are available on the market for the abstraction of groundwater for rural water supply have been summarised.

  Since in most cases schemes are operated and maintained by the villagers, the handpumps summarised are those which are relevant and appropriate for village level operation and maintenance (VLOM).

- The minimum standards required in the design of a piped water distribution system.

- The conventional piped water distribution system, hauling and borehole water supply systems highlighting their working principles, advantages and disadvantages.

## *2.2 Sources of water supply*

### 2.2.1 Classification

*Turneaure and Russel* (1947) divided sources of water into the following classes according to the general source and the method of collection:

a) Groundwater sources

   - Water from shallow wells
   - Water from deep and artesian wells
   - Water from infiltration galleries

b) Surface water sources

   - Water from springs and seeps
   - Ponds and lakes
   - Streams and rivers
   - Rain-water harvesting from roofs

Great care should be taken in identifying sources of water supply from groundwater and surface water to make sure that the source has enough water to meet the needs of the people that it is going to serve.

In a document titled *Guidelines for the Development and Operation of Community Water Supply Schemes* (*DWAF, 1999*) it has been stated that the common cause of scheme failures is the overestimation of the availability of water from water sources. The task of identifying good water sources from groundwater and surface-water sources should therefore rather be left to qualified professional geohydrologists and hydrologists who will determine whether a source yields enough water to meet the demand of the community to be served now and in the future.

## *2.3 Groundwater sources*

### 2.3.1 Background

*Pearson et al (2002)* has reported that approximately 75% of the fresh water on earth is fixed as ice, mainly in the polar ice caps. Of the remaining 25%, 24% is groundwater, and the remaining 1% is surface and atmospheric water. Thus, groundwater is the largest source of fresh water in storage on our planet, and this points to the vital importance of groundwater as a resource for fresh water supplies. However, its distribution in many parts of the world varies greatly with the distribution of suitable underground water-bearing rocks.

Groundwater is a particularly important source of fresh water supply and many communities can only be served from groundwater resources. *Harvey & Reid (2004)* have attributed this to the fact that in most cases the respective population is low to justify the costs of construction, operation and maintenance of dams and treatment works, which are often required in surface water sources. It may also be that there are no suitable dam sites nearby. In such cases, the communities often have to rely on groundwater.

Groundwater is stored underground in porous layers called aquifers. These aquifers are water saturated geologic zones which have connected pores or fractures that will yield water to springs and wells, and may be visualized as underground storage reservoirs (*Pearson et al, 2002*).

Basically there are two types of aquifer in which groundwater is present (*Pearson et al*, 2002):

- Primary Aquifers. These are aquifers in which water occurs and moves principally in the pores and interstices between the rock grains, and unconsolidated or consolidated porous sediments such as loose sand and sandstones.

- Secondary Aquifers. These are aquifers in which water occurs and moves principally in the cracks between impermeable rock fractures and joints, fissures, or cavities in soluble rocks such as dolomite.

Aquifer layers can be continuous, discontinuous or mixed. According to *Todd (1980)* primary and secondary aquifers are classified into confined and unconfined, depending on the presence or absence of a boundary stratum of the water table, while a leaky aquifer represents a combination of primary and secondary aquifers.

(a) Confined Aquifer

Confined aquifers occur where groundwater is confined under pressure greater than atmospheric and the upper and lower boundaries are impervious strata. Thus, the water held by such an aquifer is restricted to this aquifer only and its flow is limited within the structure of the aquifer.

When such an aquifer is penetrated water will rise above the top of the confining bed and will flow under pressure.

(b) Unconfined Aquifer

An unconfined aquifer is one in which the upper boundary is defined by the water table and the water is at atmospheric pressure. The water table varies by rising and falling in form and in slope, depending on areas of recharge and discharge, and permeability.

The stratum surrounding an unconfined aquifer is usually pervious and allows water to percolate through it.

The undulating form and slope of unconfined aquifers is due to changes in the volume of water in storage within the aquifer *(Chow, 1969)*. This rise and fall is due to the movement and distribution of the water available within the aquifer since there are no boundaries that will limit the flow of water in or out of the aquifer.

For instance, when a well is sunk into an unconfined aquifer and water is drawn from the aquifer, the level of the water table goes down. The aquifer is able to be replenished through rainfall or recharge from adjacent aquifers or other water sources since the strata enclosing the aquifer are pervious and water from other sources is able to move through the pores of the strata into the aquifer.

(c) Leaky Aquifer

Leaky aquifers are semi-confined in that they have characteristics of both the confined and unconfined aquifers.

They are usually found where a permeable stratum is overlain or underlain by a semi-confining layer. Wells sunk in leaky aquifers do not dry out easily since there is a constant movement of water within the aquifer and also through the semi-confining layers.

The types of aquifers mentioned can be situated at any depth within the profile of the ground and they can be used as sources of water for rural water supply through the use of wells and boreholes. When wells are sunk in the ground to make use of the water of a particular aquifer, the depth at which the aquifer is located will also determine the type of well to be drilled.

Wells are categorized as shallow or deep wells *(Todd, 1980)*. Shallow wells are generally dug where the water to be used will be abstracted at a depth of less than 15 m and deep wells are constructed where the aquifer to be used to abstract the water is at a depth of greater than 15 m.

### 2.3.2 Locating potential groundwater sources

Groundwater supplies should be carefully sited, so that drilling only occurs where there is a high probability of successfully penetrating into water bearing formations (aquifers), and where these groundwater supplies can be effectively used, maintained, and protected from contamination.

It is very difficult to predict where to find the best sources of groundwater and to estimate the quantity of water which can be obtained at a particular site. Therefore careful consideration should be given to locating potential groundwater sources.

The *CSIR (2000)* recommend that in planning for a water supply scheme in an area, the potential sources of water should first be assessed and consideration should be given to the quantity of water available to meet present and future needs in the area as well as the health quality of the water.

If the health quality of groundwater is not suitable for human consumption, treatment is required before it can be distributed to the people. A water source should therefore be tested to ensure that it is free from disease-causing organisms and other impurities. However, often groundwater sources do not require treatment (*Steel, 1960*).

If groundwater supplies are not carefully sited, drilling can take place where water is not available in significant quantities to meet the water demands of the people, and in the short-term the water source will dry up. Such a situation can result in a significant amount of funds being wasted.

To ensure successful drilling, the task of locating potential groundwater supply sources and estimating the quantity of water for long-tem production can be done best by employing a well-qualified professional geohydrologist who has a better understanding of the geological and geohydrological conditions which give rise to good water supplies.

*Pearson et al (2002)* states that a geohydrologist can accurately locate potential water supply sources by using methods also recommended by the *CSIR (2000).* These methods are:

- Estimation based on previous experience
- Scientific methods

a) Estimation based on previous experience

This method can generally be used where only small boreholes or wells with yields of 200 litres per hour or less are required in unconsolidated aquifers in high rainfall areas. The history of old water wells will indicate how far down the water table drops during the dry season and will indicate how deep the water supply sources are.

A local driller who has many years of experience in a particular area may be able to achieve success without the need for further exploration.

b) Scientific methods

Scientific methods can improve greatly the chances of locating potential groundwater sources and hence provide useful information for siting and designing of boreholes and wells.

Groundwater exploration using scientific methods involves

(i) Obtaining geohydrological information.

Geohydrological information consists of geological and hydrological information.

Geological information includes types of geological formations present and their potential as aquifers, and geological features such as faults, dykes, fractures and sills.

Hydrological information includes rainfall characteristics of the area and the groundwater recharge potential from rainwater, streams and lakes in the area.

Information on geohydrology and other physical factors can be obtained from the Water Research Commission and the National Groundwater Database which is maintained by DWAF (*CSIR, 2000*).

(ii) Geophysical exploration techniques

Together with the geohydrological information which gives an indication as to the possible presence of underground water, an assessment of site characteristics using geophysical exploration is required to confirm the presence of water. Geophysical exploration techniques include the following:

- Electrical restitivity
- Electromagnetic methods
- Magnetic methods
- Gravimetric methods

The use of the above methods by qualified and experienced geohydrologists can lead to the successful locating and siting of potential groundwater sources.

### 2.3.3 Groundwater development

Different methods are used in order to abstract groundwater. Depending on the depth at which the water is found and the type of soil in the area, a method can be chosen that will enable the water to be abstracted efficiently.

It must be ensured that the method chosen will fit the type of development that is required to abstract the water and that correct development procedures are followed in order to make sure that the correct resources are used while developing the site and that funds are not wasted.

### 2.3.4 Methods used to develop drinking-water sources from groundwater

#### 2.3.4.1 Background to wells

The development or abstraction of groundwater for rural drinking-water supplies is frequently done through the use of wells and boreholes equipped with a handpump *(Carter et al, 1996)*.

A well is a hole that pierces an aquifer so that water may be pumped or lifted out. It is sunk by drilling or digging through one or more layers of soil or rock to reach an aquifer that is at least partially full of water.

The provision of wells as a method of rural water supply is considered carefully at the design stage to ensure a sustainable water supply. *Harvey and Reed (2004)* have recommended that the important factors to consider should be:

- Correct design
- Correct construction
- Correct development/completion

The main objectives of a good well design should be to ensure the following for a water supply borehole *(NORAD & DWAF, 2003)*:

- The highest sustainable water yield with proper protection from contamination
- Water that remains sediment-free to protect pumps and to prevent the silting up of boreholes
- A borehole that has a long life
- Optimum operating costs in the short and long term.

Therefore, when designing a well it is important to consider correct materials and dimensional factors to ensure good borehole performance, this amongst other factors contributes to the long life of a well.

The materials considered in design include: well head, casing and screen, filter pack, annular seal and grout *(USACE, 1999)*. These materials constitute the basic well parts. Figure 2.1 illustrates typical well components.

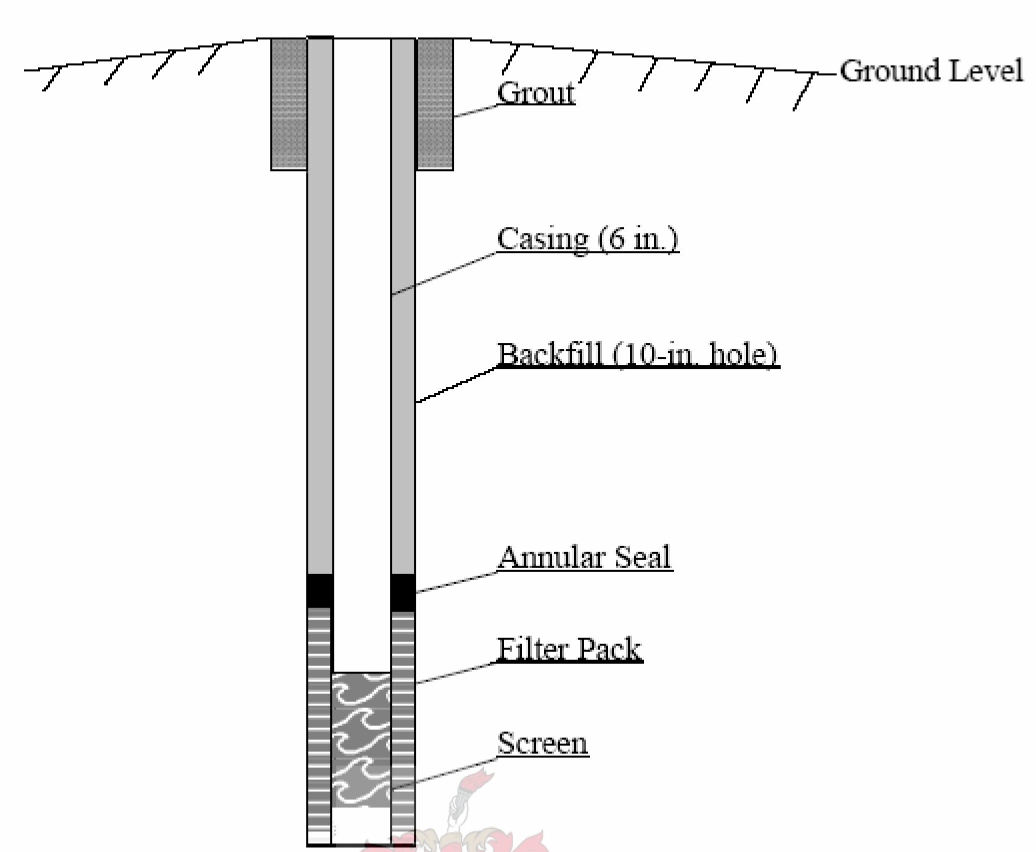

***Figure 2.1: Typical basic well components (United States Army Corps of Engineers, 1999)***

The different components of a well are briefly discussed below

(a) Well head

The structure of a borehole should be finished with a well head. A well head is a structure built on and around the casing at ground level. It is usually made of concrete. The purpose of a well head is to provide a base for a water lifting device, to prevent contaminants from entering, to keep people and animals from falling into the well and to drain away surface water.

The well head should be built on an earthen mound 15 to 20 cm above the ground level so that water will drain away from the well.

The water lifting device can be a pump, windlass, windmill or other method of extraction. The purpose of the lifting device is to get water out of the well. Handpumps used with wells and boreholes are discussed in Section 2.4

(b) Casing

The casing consists of the solid casing and the perforated portion (NORAD & *DWAF, 2003*).The solid casing is the upper section which extends between the ground level and the top of the aquifer and serves as a lining to maintain an open hole from the ground surface to the aquifer. Its function is to seal out surface water and any undesirable groundwater and it provides structural support against caving materials surrounding the well.

When designing a casing, one should look at the casing diameter, material and the estimation of the borehole depth.

(c) Screen Section

This is the perforated section of the casing and serves as the intake portion of the casing in a well. The length of screen section is chosen in relation to the thickness of the aquifer to which the borehole has been drilled, as well as the available drawdown in the borehole.

(d) Gravel pack

Gravel packing is necessary when pumping of water from a borehole may bring fine material such as sand out of the formation into the borehole and therefore cause problems in the hydraulic performance of the borehole as well as abrasion in pumps. Therefore gravel packing is introduced to create a stable envelope of coarser and more permeable material in the annular space surrounding the borehole casing.

(e) Grout and annular seal

As stated by *Todd (1980)* wells should be grouted and sealed in the annular space surrounding the casing to prevent the entrance of water of unsatisfactory quality, to protect the casing from corrosion, and to stabilize caving rock formations.

After the drilling of wells, a process called well development is conducted. The basic purpose of developing a well is to agitate the finer material surrounding the well screen so that the finer materials are carried into the well and pumped out, hence improving on the well hydraulic performance during its use. Thus a new well should be developed to increase its specific capacity and prevent silting.

Development procedures are varied and include: pumping, surging, hydraulic jetting, and addition of chemicals.

Drilled wells and boreholes are classified according to their method of construction which depends on the geological formations through which they must pass and the depth to which they must reach. There are different types of wells, however in this study five types of wells that are more suited to rural water supply are reviewed (*Todd, 1980*):

- Hand dug wells
- Driven wells
- Jetted wells
- Bored wells
- Cable tool wells

### 2.3.4.2 Hand-dug wells

Hand-dug wells are water points that source water from shallow water tables and are excavated in unconsolidated and weathered rock formations such as clay, sands, gravels and mixed soils by the use of picks and shovels or hand held excavation machinery like jack hammers. Soil can be excavated out with a bucket and rope.

The volume of the water in the well below the standing water-table acts as a reservoir, which can meet demands on it during the day and should replenish itself during periods when there is no abstraction.

Depths of hand dug wells range up to 20 m deep. Wells with depths of over 30 m are sometimes constructed to exploit a known aquifer (*Watt & Wood, 1985*).

For practical and economic reasons, an excavation of about 1.5 m in diameter provides adequate working space for diggers and will allow a final internal diameter of about 1.2 m after the well has been lined with casing. However, the diameter of the well will depend on the people to be served, since the larger the diameter the faster it will recharge and this also depends on the characteristics of the aquifer.

Lining (casing) of the well is done using caissoning and dig-and-line methods. According to *CSIR (2000),* the following materials can be used for casing the well:

- Reinforced concrete rings (Caissons)
- Curved concrete blocks
- Masonry
- Cast in-situ ferrocement
- Curved galvanized iron sections
- Wicker work (saplings, reeds, bamboo, etc)

*Harvey and Reid (2004)* recommend that sealing of the annular space surrounding the casing should be done by grouting with either cement or clay-based grout to prevent contamination by water draining from the surface downward around the outside of the casing into the well.

The bottom of the well should be covered by gravel or stone layer to prevent silt from being moved up as the water percolates upwards.

The land surface around the well should be raised so that surface water runs away from the well and is not allowed to pond around the outside of the well head.

A properly constructed dug well penetrating a permeable aquifer can yield 2500 to 7500 $m^3$/day, although most dug wells yield less than 500 $m^3$/day *(Todd, 1980)*.

The advantages of hand dug wells include:

- Equipment, labour and materials are readily available
- The equipment needed is light and simple and suitable for use in remote areas
- The community can be involved in construction and this will enhance ownership
- Common construction techniques are employed

- Can act as a reservoir
- A variety of handpumps can be used and the well can still be used if the pump breaks down

The disadvantages of hand dug wells are:

- Hard work to construct and hence time consuming
- Can easily be contaminated by surface water and airborne material
- Extracting large quantities of water with motorized pumps is not feasible
- Limited depth as most dug wells are less than 20 m deep.
- They are affected by water-table changes, hence unpredictable and unreliable
- Hand digging below the water-table is difficult
- Not suitable for formations with hard rock or large boulders

Thus, hand dug wells are more suited to individual water supplies and to situations where the water can be sourced at shallow depths and the fluctuations of the water-table are such that they cannot cause the well to be dry during some periods.

It is important to identify potential problems of contamination before constructing the well so that appropriate measures to reduce the risk of contamination are taken. The well should also be employed where the use of motorized equipment will not be economical.

#### 2.3.4.3 Driven well-points

These wells are simple to construct and more suited to domestic water supply (*Todd, 1980*). *Stapleton (1983*) stated that the soil types to which driven wells are best-suited are sand formations and silt.

The well construction consists of a series of connected lengths of pipe casing connected on its end to a driving point, slightly greater in diameter than the casing (*Steel, 1960*). Above the driving point is a screen through which water enters the casing.

The driving point is driven by repeated impacts into the ground until the aquifer is reached.

Driving is done using one of the following methods: a sledge hammer, a weighted driver, a driving bar or a driving weight. Selection of which method to use will depend on the depth required, the funds available and the complexity of the job.

Water enters the well through a drive point once it has been driven to the lower end of the well

*Todd (1980)* has indicated that for best results the diameter of driven well-points should fall in the range of 30 to 100 mm in diameter. The well can be driven to a maximum of 10 m (*Pearson et al, 2002*) although depths exceeding 15 m are known to be reached depending on the geology and availability of groundwater in the area (*Todd, 1980*).

The water table should be within 2 to 5 m of ground surface in order to provide adequate drawdown without exceeding the suction limit. Yields of driven wells are small, with discharges of about 100 to 250 $m^3$/day.

The well point serves as the intake of the well and the pipe is the casing.

As most suction type pumps are used to abstract water from driven wells, the water table must be near the ground surface if a continuous water supply is to be obtained.

The most common types of screens used with the well-points include: continuous slot screen, shutter or louver screen and a wrapped-on pipe screen (*Water for the World, RWS 2.D.2*).

The continuous slot screen consists of a triangular shaped wire wrapped around an array of rods creating slots through which water can enter. The louver type screen consists of a metal tube with slots stamped out with a metal die while a wrapped-on pipe screen consists of a perforated pipe wrapped by one or more screens. The screens are mounted on the hard steel drive point.

Figure 2.2 shows the details of the types of well-points and screens that are used.

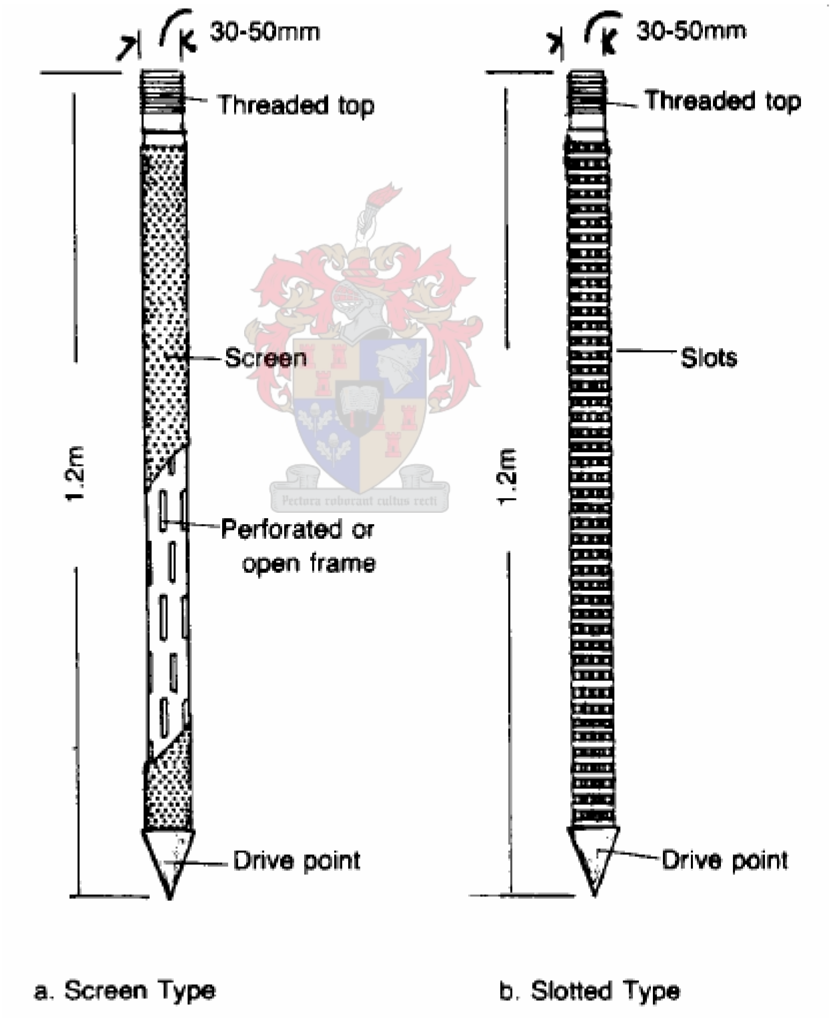

***Figure 2.2: Types of well points (Water for the World, RWS 2.D.2).***

The advantages of driven well-points are:

- They are relatively inexpensive to install
- They are simple to construct since one man is able to drive the well
- They can be constructed in a short time
- Water is not essential to the construction

The disadvantages of driven well-points are:

- Hard formations cannot be penetrated and problems occur in aquifers which contain gravels
- Little may be known about the material through which the well pipe is passed. This may result in drilling a well at a site where the soil is not permeable and hence the recovery rates of the well may be low in comparison to the demand.
- They can easily be contaminated from nearby surface sources

Driven wells are therefore limited to cases where small diameter wells are needed. They can be effectively employed where the number of people available to drive the well is small, as one person can effectively drive the well.

It is important to follow the same precautionary measures of reducing the risk of contamination of the well as described under hand dug wells.

#### 2.3.4.4 Jetted wells

Jetted wells are constructed by the cutting action which is made possible by pumping water into the hole being sunk through a casing pipe equipped with a special cutting bit at the bottom. The casing pipe is held upright by a tripod, and is attached by a hose to a pump and a supply of water (*Kerr, 1989*).

The pipe is manually rotated. The chopping action of the cutting bit, coupled with the jetting action of the water, causes the pipe to sink into the ground. The soil in the area surrounding the hole is removed by being forced to flow outside the pipe to the surface because of being displaced by the incoming pumped water

When the aquifer is reached, the casing pipe is lifted from the hole. If the casing pipe is to be used as the casing, the cutting bit is removed from the first section of pipe and replaced with a well screen. The casing pipe has an inside diameter large enough to carry the well point screen assembly to be fitted.

It is important to ensure that the water used in the jetting does not contaminate the aquifer.

Jetted wells are best suited to silt, sand or gravel types of soils and can be used in thick unconsolidated alluvial sands such as silted up dams or riverbeds, or coastal sands bearing fresh water (*Pearson et al, 2002*). Jetting is not suitable for hard rock or tight clays because the drilling bit can be damaged.

The water-table depth for which jetted wells are best suited is 2 to 5 m and the usual maximum depth to which the well is dug is 20 m. The diameter of jetted wells is in the range 40 to 80 mm and the yield of the well can be up to 150 $m^3$/day (*Todd, 1980*).

However, for practical reasons of pumping water under sufficient pressure during construction, jetted wells seldom exceed 10 m in depth (*Pearson et al, 2002*).
Screens for jetted wells are usually commercially, rather than locally made. The types of screens that are available include the continuous slot type, the shutter or louver type and the wrapped on pipe type of screen.

The advantages of jetted wells are:

- The equipment is simple to use and can drill fast
- It is possible to employ the method above and below the water table

The disadvantages of jetted wells are:

- Water is required for pumping
- Only suitable for unconsolidated rocks
- Boulders can prevent further drilling
- Equipment for drilling may not be locally available

Where drilling equipment and spare parts are locally available this type of method can be best employed where water is readily available for the drilling of the well. In situations where the depth of the water table is near the surface, but the depth of the well has to be deep, this method can also be employed as digging below the water table over a considerable depth can be done.

### 2.3.4.5 Drilled wells

Drilled wells are also called augered or tube wells. They are dug by power augering or manually rotating an earth auger which operates with cutting blades at the bottom that bore into the ground with a rotary motion and fill with soil (*Water for the World, RWS 2.D.4*).

The auger consists of a cylindrical steel bucket with a cutting edge projecting from an opening in the bottom. The bucket is filled by rotating it in the hole by a drive shaft of adjustable length.

The full bucket is pulled out from the ground and emptied. As the hole gets deeper, additional sections of drilling line are added. To facilitate the operating and emptying the auger, an elevated platform or tripod is constructed over the well site. When the shaft has sufficiently penetrated the aquifer, the auger is removed and the casing and well screen are lowered into the shaft.

Drilled wells should be drilled where the depth to water table is about 2 to 9 m where hand augering is involved. When using power augering the depth to the water table should be about 2 to 15 m. Drilled wells are more suited to clay, silt, sand and gravel soils.

Usually the depth to which these wells are dug is 10 to 20m and the diameter of the well is about 100 to 150 mm (*Stapleton, 1983*). A casing is used to line the well. *Kerr (1989)* reported that the casing can be made of clay tile, concrete, metal or PVC pipes. There are two basic methods for installing the casing:

- The well shaft is dug and the casing is lowered into place
- The casing is lowered as the shaft is dug

The method used depends on the soil conditions. If the soil is fairly firm and does not cave in, the first method can be used and if the soil tends to cave in the second method is used.

The yield of drilled wells is about 15 to 250 $m^3$/day for hand augured wells and that for power augered wells is 15 to 500 $m^3$/day *(Todd, 1980)*.

The advantages of drilled wells are:

- It is a fast method for drilling shallow wells
- When digging, continuous soil samples are available so the water bearing layer is easily known
- They have a large diameter and hence expose a large area to the aquifer
- They are able to obtain water from less permeable materials such as very fine sand, silt or clay
- They need no de-watering during sinking
- Involve less maintenance

The disadvantages of drilled wells are:

- Only formations having enough clay to support the borehole walls can be bored
- Drilled wells can easily be contaminated since they are shallow
- They can go dry during periods of drought if the water table drops below the well bottom
- Usually augering cannot be used below the water table and cannot penetrate hard formations

Drilled wells can be sunk where the recovery rate of the well is expected to be low, such as in soils which are less permeable, since the well acts as a reservoir for water at times when water is not being drawn, and hence the risk of having the well dry during use can be minimised.

#### 2.3.4.6 Cable tool wells

Cable tool wells are also known as percussion drilled wells and the equipment consists of a standard well drilling rig, percussion tools and a bailer. This method is used for drilling deep wells and uses a mechanism of repeatedly raising and dropping a chisel-edged bit to break loose and pulverize material from the bottom of the hole as drilling progresses (Water *for the World, RWS 2.D.5*).

A small amount of water is kept in the hole, so that the excavated material will be mixed with it to form slurry. Periodically the percussion bit is removed, and a bailer is lowered to remove the slurry containing the excavated material.

The bailer or bailing bucket consists of a tube with a check valve at the bottom and a bail for attaching a cable or rope to the top. The valve permits the cuttings or slurry to enter the bailer but prevents them from escaping.

When the percussion tools and drilling rig have been raised and dropped a number of times to break the soil, drilling stops, and the bailer is used to fill it with the slurry and brought to the surface for emptying. Bailing is repeated until the hole has been adequately cleaned, at which time drilling is resumed; drilling and bailing is then alternated.

If the hole is unstable, the casing is lowered and driving of the casing is alternated with drilling and bailing. In loose granular material, such as sand, bailing alone may be sufficient to remove the material from the bottom of the hole and allow the casing to be sunk.

Cable tool wells are most suited to drilling in unconsolidated and consolidated medium hard and hard rock. They are also suited for drilling to any water table depth.

The usual maximum depth of the well is in the range of 15 to 500 m in consolidated hard rock materials (*Pearson et al, 2000; Todd, 1980*), however greater depths can be reached with heavier equipment. The diameter range is 80 to 600 mm. The well can give a yield in the range of 15 to 15000 $m^3$/day (*Todd, 1980*).

When the aquifer is reached, it is generally drilled completely through before the casing and well screen are installed. In sandy soil, the shaft is sunk from the inside of the casing and the shaft and casing descend together.

To finish the well, an earthen mound and a concrete wellhead or apron is built for drainage. Then a pump is installed. The design of cable tool wells involves the selection of a screen. Considerations on the type of well screens are the same as those for the other types of wells already mentioned.

The advantages of cable tool wells are:

- Simple to operate and maintain
- Suitable for a wide variety of rocks
- Operation is possible above and below the water table
- It is possible to drill to deep depths
- Less water is required for drilling

The disadvantages of cable tool wells are:

- Equipment can be heavy and it is difficult to install the casing in deep holes
- Problems can occur with unstable rock formations especially in unconsolidated soils
- Expenditure on equipment is high

The percussion method can be used in many situations, allowing almost all types of materials to be penetrated. However, in unstable rock formations progress is slow.

While this method is frequently associated with large, motorized, truck-mounted equipment, it can be successfully scaled down and used with manpower, or small engines. It may be used in conjunction with other methods when certain conditions are encountered such as hard or loose materials which make it more suitable.

This type of well should be used in situations where there is a large population of people to be served by one well since the well is able to yield a lot of water per day, and can thus meet the demand of a bigger population. It is more economical for deep water wells.

The *CSIR (2000)* and *Pearson et al (2002)* recommend that drilling of the wells using the methods of developing groundwater sources for water supply that have been mentioned should be done by reputable drilling contractors registered with the Borehole Water Association of South Africa who have the technical expertise to employ the design and drilling of the boreholes according to accepted procedures and standards.

### *2.4 Handpumps for rural water supply*

The development of groundwater sources using wells and boreholes uses pumps which are suited to the well structure in order to bring the water to the surface. The factors to be considered in the selection of handpumps and the types of handpumps that can be used for shallow and deep wells are discussed below.

It is important to choose the correct pump for an area. How it will be used is important. It is also important that the people should be able to maintain the pump during its economic life. Choosing the wrong pump will result in inefficiency and non-sustainability.

According to *Hazelton (2000)* international experience has demonstrated that high failure rates are not inevitable and that hand pump installation can be transformed into an effective low cost solution through the systematic adoption of appropriate design technologies and implementation policies.

*Skinner & Shaw (1999)* indicated that in cases where handpump failures have occurred this has been due to:

- The absence of a sustainable system of handpump maintenance and repair
- The installation of pumps which were not suitable for the heavy usage they received
- The use of pump components which were damaged by corrosive groundwater
- A lack of community involvement in important aspects of the project planning

Therefore when using hand pumps, it is imperative to use technologies that are low cost, appropriate to the local financial and geographic conditions, and within the technical capacity of the benefiting community to operate and maintain the pumps in order to ensure sustainability.

A key factor in overcoming handpump failures as reported and motivated by the World Bank is to adopt the Village Level Operation and Maintenance (VLOM) concept. A VLOM pump is described as one which can be operated and sustained using village level operation and maintenance *(Carter et al, 1996)*.

This concept starts with the selection of specifically designed hand pumps. It extends to the benefits of community participation, management and ownership, and the reduction but not elimination of the rural communities' dependence on external support systems.

It is this concept that is used in a review on the currently available technologies of handpumps that can ensure low cost in terms of both installation and management and still be able to meet the expected delivery rates depending on the situation in which they are being used.

In South Africa, there are different types of pumps that are used for rural water supply which may be grouped into shallow and deep well pumps. This study has focused on the common types of handpumps that are available on the market with regard to specific conditions in which the respective pumps can be applied.

*Harvey & Reed (2004)* recommend the following procedure to be followed as a guideline to selecting an appropriate handpump for an area:

(a) A thorough assessment of the groundwater conditions should be made. This should include:

- Depth of operation

Measurement of groundwater levels and seasonal variations, so that the maximum lift required of the pump is estimated. The maximum lift should be measured from at least 2 metres below the lowest recorded water level to ground level.

- Level of usage (number of users/litres to be pumped)

The number of users and corresponding flow rate required should be estimated and the yield of the borehole should be measured. Depending on the number of users the required flow rate can be estimated using the formula:

$$\text{Required flow rate (litres/min)} = \frac{1.1\,PgW}{60H} \qquad (2.1)$$

where

P = population to be served

g = population growth rate if taken into account

W = water usage per capita per day (ℓ/c/day)

H = Pumping period (hours)

The required flow rate is the flow rate the chosen handpump should be able to lift and the yield of the borehole must be sufficient to support this flow rate. *Harvey and Reed (2004)* have further recommended that if the pumps available cannot lift this flow rate the hours of pump operation should be increased subject to the acceptance of the water users.

- Groundwater pH

Groundwater pH has an influence on the operation of a handpump in that corrosive water can shorten the useful life of a pump. In areas where corrosion of pumps can occur and lead to failure within a short time, handpumps with down-hole parts which are corrosion resistant should be chosen.

(b) A review should then be conducted of all existing pumps used in the area or country and of any policies affecting choice, such as standardization. The following points should be noted for each pump:

- Maximum lift
- Materials from which components are made
- Maximum pumping rate at required lift (i.e. depth from which water must be pumped).

These data should then be matched to the groundwater conditions assessed in step (1) above to see which pumps, if any, are capable of meeting the pumping requirements.

(c) The next step is to conduct a thorough assessment of the Operational and Maintenance requirements for each of the pumps identified. This should consider:

- Spare parts, skills and tools required
- Estimated costs of maintenance, repair and replacement over time
- Projected maintenance and management requirements over time

The performance data and operation and maintenance requirements for each of the handpump options should be compared to determine the more appropriate option. The operation and maintenance requirements for each must be matched against local operation and maintenance capability. It is therefore necessary to assess whether appropriate skills, tools, spare parts and finances are available for each remaining pump. This should be done through consultation with local communities and pump manufacturers and suppliers.

(d) The selected pump should be the one that fulfills the necessary pumping requirements and for which there is local capacity for operation and maintenance.

Selection of pumps should ensure that the handpump can easily be maintained within the area by the users so as to ensure that downtime periods are reduced. It must be kept in mind that specialist attention to fix the pump may not always be readily available.

*Hazelton (2000)* reported that achieving full effectiveness in choosing a technology, is a complex issue and in addition to the above considerations, it is also important to take into account government policies and environmental issues concerning health.

The factors considered above follow the VLOM concept recommended by the World Bank and United Nations Development Programme considering that most water projects are managed and maintained by the people in the rural communities.

Though pumps that conform to the VLOM concept are mentioned in this study, other pumps that have proved to be efficient in delivering service are *(Hazelton, 2000; Harvey and Kayaga, 2003; Harvey and Reid, 2004)*:

Shallow well handpumps:

- Vergnet
- Mono
- cemo
- Bucket
- Tara
- Consallen
- Barry
- Afridev

Deep well handpumps:

- Volanta
- Bush pump
- Afridev
- cemo
- India Mark II
- India Mark III
- Vergnet
- Mono
- Consallen

A table summarizing the specific applications of each of the handpumps, indicating the depth of operation, delivery rate, advantages and disadvantages is summarized in Appendix A.

## *2.5 Surface water sources*

Water that does not infiltrate the ground is called surface water. Surface water appears as direct runoff flowing over impermeable or saturated surfaces and then collecting in large reservoirs and streams or as water flowing from the ground to the surface openings (*Water for the World, RWS 1. M*).

There are four classes of surface water sources that are in common use for rural water supply which include:

- Springs and seeps
- Ponds and lakes
- Streams and rivers
- Rainfall harvesting

### 2.5.1. Springs and seeps

Rural communities often collect water from existing sources close to their homes. In many rural areas this is a spring. A spring or seep is water that reaches the surface from some underground water system, appearing as small water holes or wet spots on hillsides or along river banks (*Water for the World, RWS 1. M*).

Water from a spring is usually preferred because it is cleaner than water from the streams, and usually tastes better than water from other sources. However, even though springs come from an underground source of pure clean water, spring water often becomes contaminated once it comes out of the ground or just before it comes out of the ground.

The *CSIR* (2000) recommends that necessary steps should be taken in the management and protection of the whole system if the spring is to be used for water supply so that any contamination of the spring water does not occur. It is necessary to carry out a sanitary survey and water quality analysis as part of selecting a spring for domestic water supplies to find out if the water will need treatment. Springs can be protected by *(Shaw, 1999):*

- Clearance of vegetation above the eye of the spring
- Constructing a cut off drain to divert surface run off
- Creating a temporary diversion of spring flow in order to keep the working area dry during construction
- Protection of the spring eye by layers of impervious materials above it
- Construction of a spring box

*Pearson et al (2002)* has divided springs into three categories namely:

- Gravity springs
- Artesian springs
- Karst springs.

These are discussed below:

### (a) Gravity Springs

Gravity springs occur where groundwater emerges at the surface because an impervious layer prevents it seeping downwards. This type usually occurs on sloping ground, although it can be found in areas that seem flat to the eye.

Gravity springs can further be subdivided into depression, contact and fracture springs.

- Depression Springs

These types of springs are formed when the land surface dips below the water table and makes contact with the water in permeable material. Any such depression will be filled with water.

According to *Pearson et al (2002)* a typical example is the small to medium wetland seepages that are usually seen in flat to nearly flat areas where shallow permeable soil overlies clay or impermeable bedrock. The seep occurs at the sides of the depression in horseshoe or semi circular fashion.

The yield of depression springs is good if the water table is high, but the amount of water available may fluctuate seasonally. A gravity depression spring may not be suitable for a drinking water source since it can easily dry up.

- Contact Springs

These types of springs are formed when the downward movement of underground water is restricted by an impervious underground layer such as a clay horizon and the water is pushed to the surface. This type of spring usually has a very good flow throughout the year and is a good water source.

- Fracture springs

These are formed when water comes from the ground through fractures or joints in rocks, Often the discharge is at one point and protection is relatively easy. Fracture and tabular springs also offer a good source of water for a community supply.

### (b) Artesian springs

Artesian springs occur when water is trapped between impervious layers and is under pressure. There are two types of artesian springs namely fissure and artesian flow springs.

The yield from artesian springs is uniform and the flow is very nearly constant in spite of seasonal variation in rainfall and evapotranspiration over the catchment.

- Fissure Springs

Fissure springs result from water under pressure reaching the surface through a fissure or joint. Yield of fissure springs is very good. A drop in the water table during dry periods has little impact on the flow of the spring, and this source is excellent for community water supply.

- Flow Springs

Flow springs occur when confined water flows underground and emerges at a lower elevation. This type of spring occurs on the hillsides and is also a good source of water supply.

**(c) Karst springs**

These occur where a surface stream disappears into a sinkhole and flows underground along channels, caves and other cavities produced by the chemical and mechanical action of water on leachable or soluble rocks such as dolomite and limestone. The water finally emerges as a spring at a lower altitude elsewhere.

These types of springs also offer a good source of water supply.

#### 2.5.1.1 Development of springs into drinking water sources

*Shaw (1999)* states that the main objective of spring development and protection is to provide improved water quantity and quality for water supply. Spring development activities include the construction of an intake structure, collection tank, tapstand, and retaining wall, and the provision of drainage, fencing and grassed surround.

The intake structure is located at the source of the spring (called the eye, or the point within the spring where the spring flow is concentrated and follows a stable channel), and collects the water for transfer to the collection tank (*Water for the World, No RWS. 1. M*).

Before a spring can be developed into a drinking water source it is necessary to measure the reliability of the spring in terms of its yield so that the flow can be measured to ascertain whether it is going to be adequate to meet the communities' water demand especially during periods of drought.

The best time to measure the flow rate of a spring is during the driest months of the year like August and September in summer rainfall areas and February and March in winter rainfall areas (*CSIR, 2000*). If the spring yield is very weak other supply options should be considered.

Where the yield of springs is too low to meet the water demand of the people, provision of a storage tank should be made so that the tank can fill with water during periods of no use and thereby be able to supply the demand during periods of use.

For example, *Pearson et al (2002)* reported that based on a demand rate of 25 *l*/c/day, a spring flow of 0.1 *l*/s will provide peak hour demand for only two to three families while a flow of 1 *l*/s will provide a peak hour demand for about 20 to 50 families without the use of storage facilities. However, with the use of storage tanks enough water for up to 35 families and 350 families can be provided at each of the flows respectively.

The methods of developing springs as drinking water sources which act as collection chambers and hence protect the spring from contamination are:

(a) Spring boxes
(b) Simple retaining wall
(c) Seep development

**(a) Spring boxes**

A spring box is built to provide sanitary protection, provide storage capacity and protect the eye of the spring from blockage *(Shaw, 1999.)*

A spring box will collect water during the times that the spring is not in use such as at night and the water from the spring box can be fed to a storage tank or a collection point through an outlet pipe.

A spring box foundation must be installed in the impervious rock below the eye. A seal with the ground must be created to prevent water from seeping under the structure and undermining it.

*Pearson et al (2002)* recommend that a typical spring box should have a back wall built with an un-mortared open stone wall to facilitate inflow of the water and should lie between the water table and the impervious rock. The foundation box should be at least 50 centimetres into the impervious rock below the aquifer, and the top of the box should be higher than the position of high water table.

Stone rap and a gravel filter should be placed between the spring and the inlet. A removable cover should be placed over the box to facilitate cleaning and maintenance. Figure 2.3 illustrates a typical spring box.

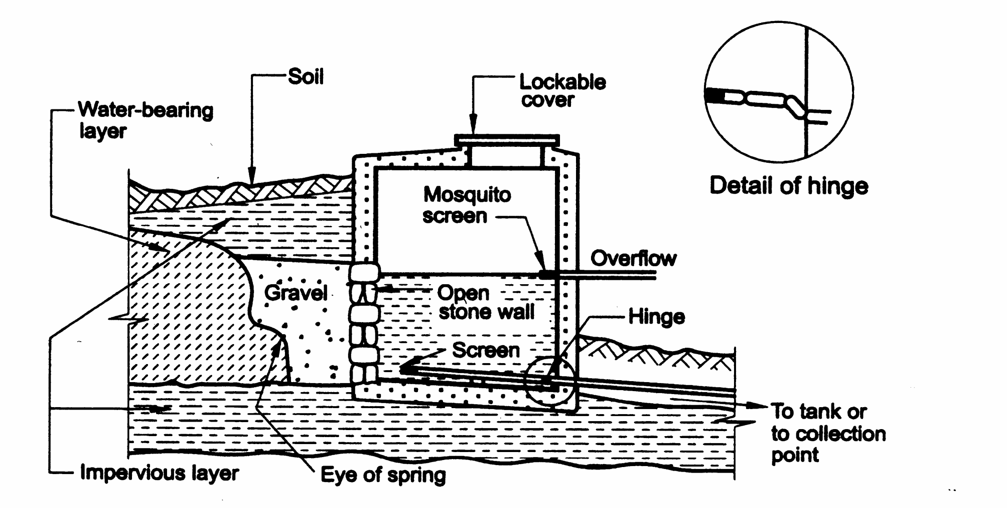

*Figure 2.3: Typical spring box (CSIR, 2000)*

### (b) Simple retaining wall

Spring protection can be carried out by building a retaining wall across the spring outlet where a gravity spring has a steeply sloping water table (steep hydraulic gradient) occurring close to the community such that every household can have easy access to the spring. The flow has to be sufficient to meet the peak demand of the community without need for storage.

This structure should be built in such a way that a small dam is created behind the retaining wall at the spring outlet and a pipe built into the wall to channel the water to a tap where consumers can collect the water.

The retaining wall should be built of rock and cement mortar or reinforced concrete. When designing the wall, it must be that the wall is of sufficient thickness and strength to withstand the pressure of the water, and that the foundation of the wall is built in stable formation below the aquifer.

The end of the pipe on the spring side should be perforated and covered by a filter pack consisting of gravel and sand. *Pearson et al* (2002) has recommended that as an additional option the perforated end of the pipe should be wrapped in a porous geo-fabric and that the space above the filter should be backfilled and sealed against surface contamination by a clay layer or strong plastic sheet. Figure 2.4 is a diagram illustrating a simple retaining wall used to protect a spring.

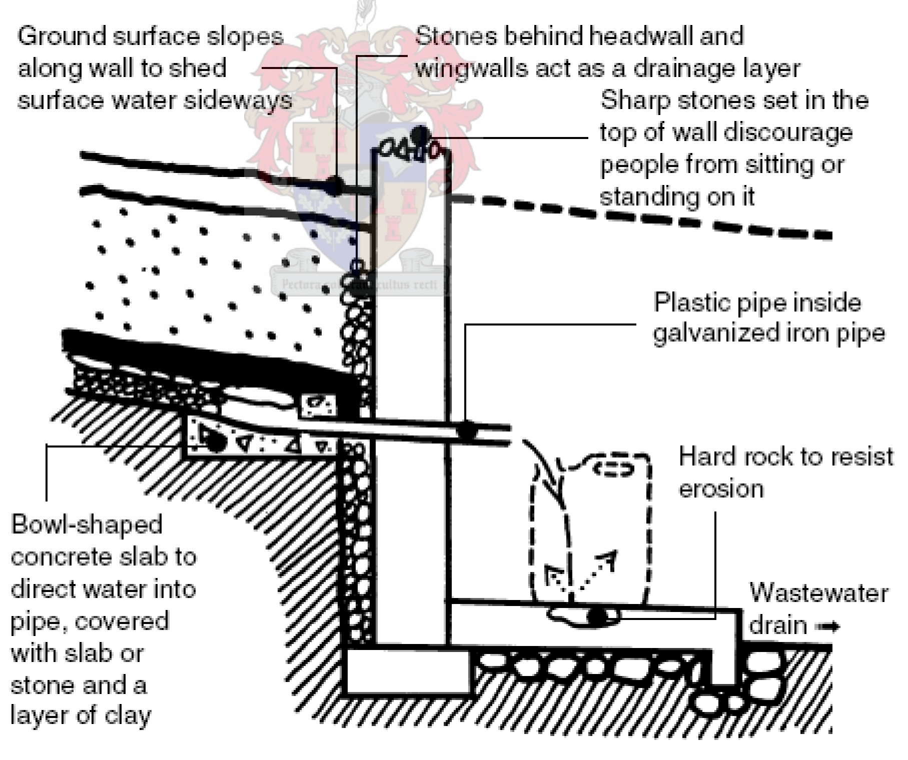

***Figure 2.4: Typical retaining wall structure to protect a spring (Skinner and Shaw, 1992)***

The Advantages of spring box and simple retaining walls are

- Low initial cost
- Operation and maintenance costs are lower
- They require minimum to no treatment if they have adequate sanitary protection
- Since springs are generally located on hills, a simple gravity flow delivery system can be installed
- The local community can be trained to manage the water supply system without any support from external contractors

The main disadvantage of using spring box and simple retaining walls is that the quantity of available water may change seasonally.

**(c) Spring tapping by drains**

If water seeps from the ground and covers an area of several square meters, collector drains may be used in order to provide more convenient and efficient water collection for rural water supply.

The basic structure should consist of pipe trenches, collection pipes, anti-seepage or cut-off walls and a spring box *(Skinner and Shaw, 1992)*

The pipe trenches of appropriate length and one metre wide are dug to the left and the right of the spring outlet point. The trenches should extend in depth to at least 100 mm into the impervious layer below the aquifer.

The collection pipes are perforated and covered with a geo-membrane. The pipes are then laid in the trenches covered by pebbles, gravel and sand in order to provide adequate filtration of the spring water and to transport it to the spring box (*Water for the World, RWS. 1. M*).

The pipe perforations should be made such that they will allow collection of sufficient water and at the same time prevent suspended matter from entering the pipes.

*Pearson et al (2002)* recommend that the pipes should be laid with a sufficient gradient to minimise clogging by sedimentation in spite of the filtration and that the top of the gravel pack should be at least 3 m below the ground surface for sanitary protection, otherwise it should be sealed with clay or plastic sheeting.

The anti-seepage wall can be built of rock and cement mortar, or concrete down slope of the pipes, pipe drains and seep area to trap the water for more efficient collection. The height of the wall should be above the level of the wet season watertable to prevent erosion. Figure 2.5 is an illustration of the seep development structure.

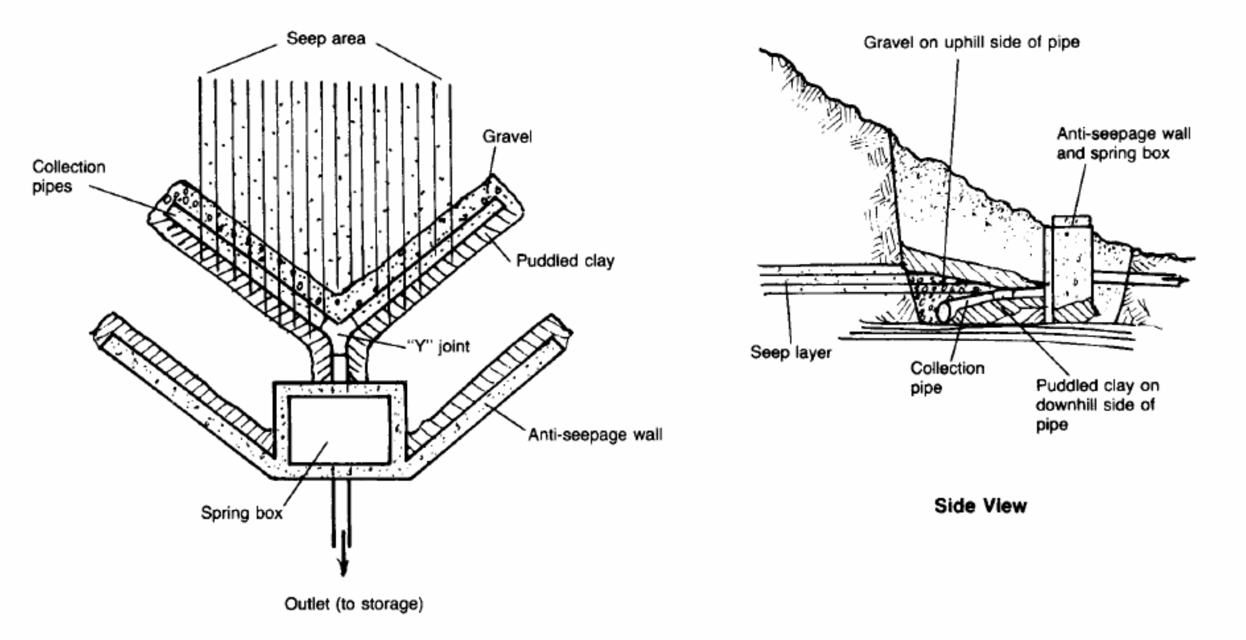

*Figure 2.5: Seep collection system (Water for the World, RWS. 1. M).*

The foundation of the wing walls must be built in the impervious formation below the aquifer. During construction it should be ensured that there is a good seal between the wall and the ground to prevent water seepage so that all the water is trapped to the spring box.

The spring box should be constructed at the centre of the wing walls.

The disadvantages of seep collection system

- Maintenance costs are higher as pipes often clog with soil or rocks.
- The expense and difficulty of construction usually prohibits its use.

Unless the seep supplies abundant quantities of water, this method should not be considered due to its disadvantages.

### 2.5.2 Ponds and lakes

Ponds and lakes exist where surface run-off has accumulated in depressions or where a dam has been built to form a reservoir *(Turneaure et al, 1947)*.

To use water from ponds and lakes, an intake is needed and water is pumped from the source or can flow by gravity into storage. There are two methods used as an intake for the abstraction of water *(Water for the World, RWS 1.C.2)*.

One method that is used is a flexible plastic pipe intake as shown in Figure 2.6. The flexible plastic pipe is attached to a float and anchored so that it rests between 0.5 m and 1.5 m from the surface of the water in order to keep out plants from the surface and sediments from the bottom *(CSIR, 2000)*. The water can then be pumped through the pipe to treatment or storage.

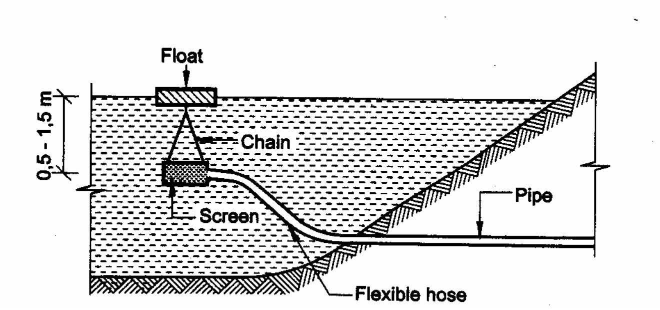

*Figure 2.6: Flexible plastic pipe intake with float (CSIR, 2000)*

Where a dam has been built, the flexible plastic pipe can be attached to a rigid conduit with anti seepage collars. The conduit passes through the pond embankment to the treatment and storage tanks as shown in Figure 2.7.

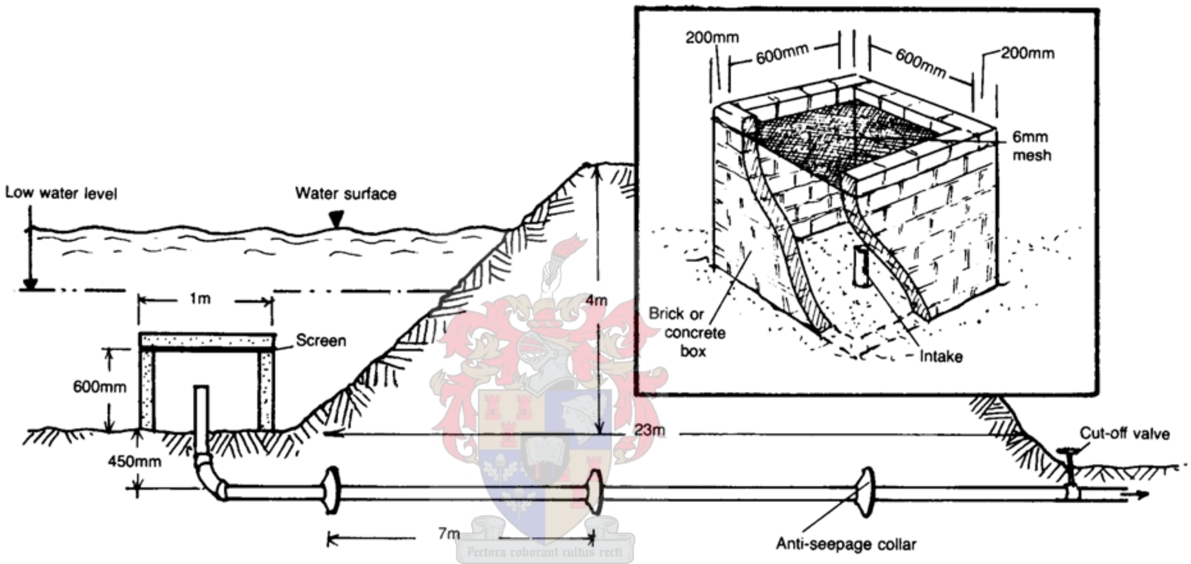

*Figure 2.7: Rigid Pipe Intake at Dam (Water for the World, RWS 1.C.2)*

The quantity of water available from ponds and lakes may not be a problem but the quality needs to be investigated. Generally water from ponds and lakes must receive some treatment. Algae and decaying plants may give the water a taste unacceptable to the user, causing him to seek other water sources. The cost of water treatment should be carefully evaluated.

### 2.5.3 Streams and rivers

Streams and rivers are formed by surface run-off from rainfall. Some rivers and streams have springs as their source. The development of rivers and streams also requires an intake to be built and the intake should be sited at any point where the water can be withdrawn in sufficient quantities *(CSIR, 2000)*.

There are three methods of developing streams and rivers into drinking water supplies:

- Infiltration wells and galleries
- Intakes connected to mechanical pumps
- Gravity flow intakes

### (a) Infiltration wells and galleries

Digging or drilling a well near the banks of a stream or river is the cheapest and simplest method of development.

The well should be close enough to the river channel to collect both the water flowing underground and water seeping in through the channel by filtration as shown in Figure 2.8.

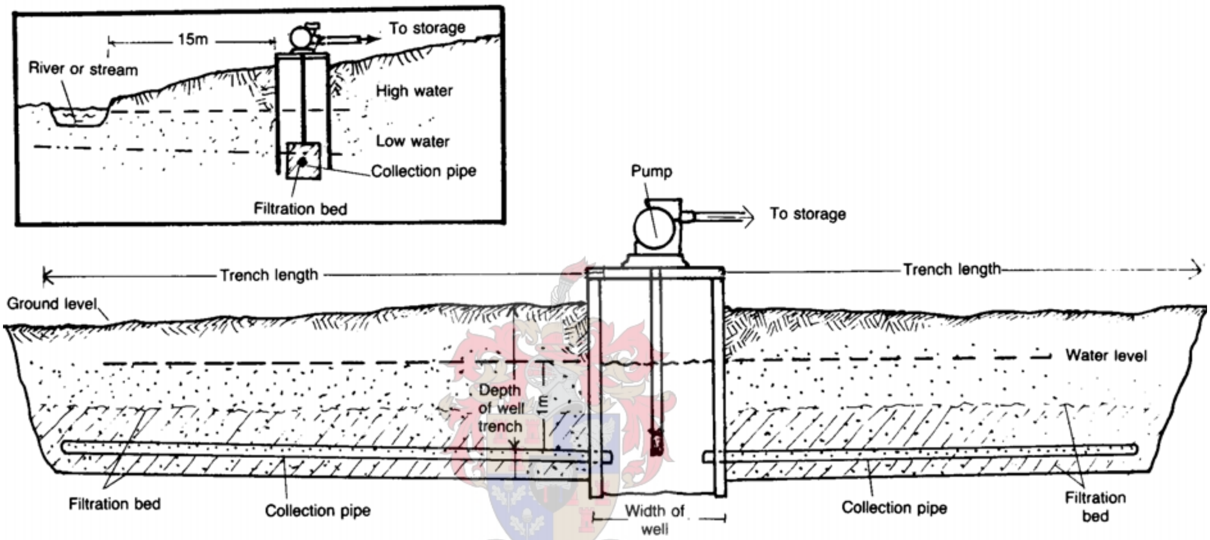

*Figure 2.8: Riverside infiltration well intake (Water for the World, RWS 1.D.3*)

A hand pump, windmill or power pump can be installed to extract the water and pump it through the systems. The pumping method chosen depends on the distribution system.

To increase the amount of water that can be collected by an infiltration well, infiltration galleries are constructed.

Infiltration galleries are trenches dug along the bank parallel to the stream below groundwater level or below the stream-bed itself. Tile, concrete or perforated collecting plastic pipes are placed in gravel lined trenches and connected to storage well. The gravel in the trench filters out sediment and prevents clogging of the pipes. The water is pumped from the storage well into treatment plants and the distribution storage system.

### (b) Intakes with mechanical pump

A surface intake pipe in the channel is another way of drawing the water from a stream or river. Water is pumped from the stream to treatment or storage. Figure 2.9 shows an illustration of intakes with a mechanical pump.

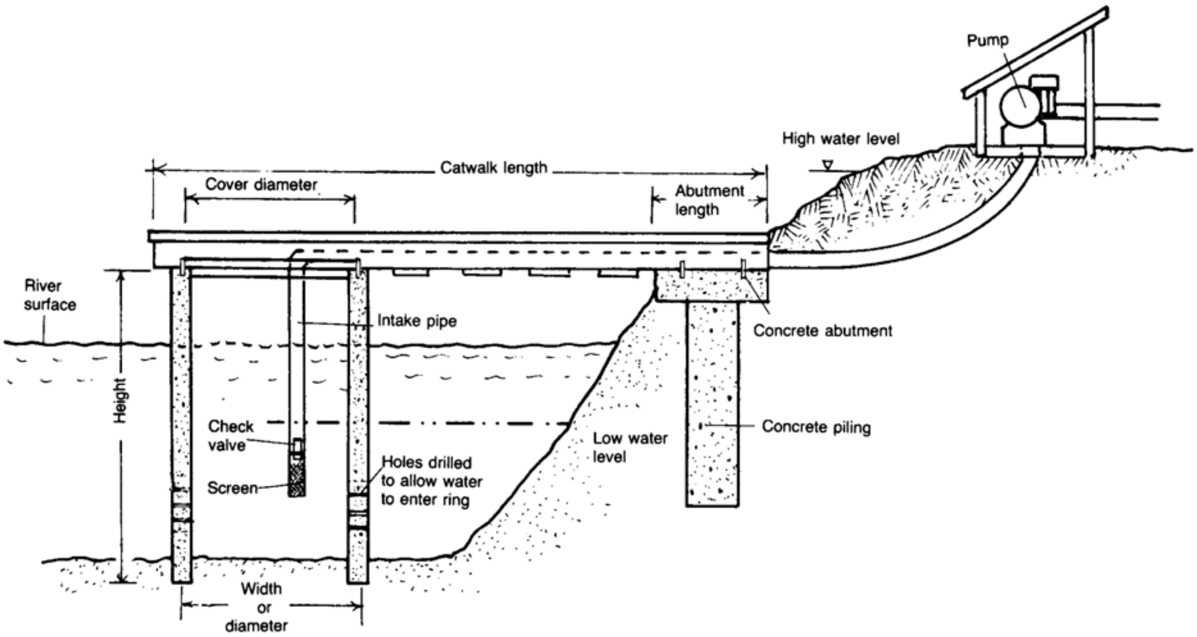

***Figure 2.9: Intakes with mechanical pump (Water for the World, RWS 1.D.3)***

To use this method, a stream with stable banks and a firm bed is needed. Skilled construction workers must also be available as the structure must be sound enough to withstand the stream's current. This method requires more expertise for the laying of the pump accessories and pipes.

**(c) Gravity flow intakes**

Water can be conveyed to the user through a gravity flow system.

This method is suitable for sources with enough changes in elevation to allow gravity to move water from the intake to the storage tank.

The usual components of a gravity scheme are the source, main pipeline, storage and break-pressure tanks, distribution pipelines and tap stands. These components are explained in Section 2.6.

### 2.5.4 Rainwater harvesting

Rainwater harvesting is the immediate collection of rain-water running off surfaces upon which it has fallen directly. This definition excludes run-off from land watersheds, streams, rivers, lakes (*Government of Tanzania, 1997*).

The structures that are used for harvesting rain-water can be installed anywhere where a suitable area is available. In areas of little rain, rainwater catchments can be used in combination with other surface sources. There are two types of catchment systems as described by *Kerr* (1988):

- Roof catchments
- Ground catchments

### (a) Roof catchments

Roof catchment systems offer a simple and fairly inexpensive method of providing water to individual homes.

The catchment is the roof, usually made of an impervious material such as corrugated galvanized iron sheets, asbestos sheeting or tiles. The conveyance is through a gutter and downpipe, the storage is a tank and delivery is through a tap connected to the tank. Storage can range from small containers made especially for rainwater storage purposes or for other purposes, for example oil drums, food cans, etc., up to large tanks of 150 cubic metres or more placed at ground level, or sometimes beneath it.

Because the first water to run off a roof can contain a significant amount of debris and dirt that has accumulated on the roof or gutter, treatment structures should be installed and these include a foul flush system, and a before tank filter system as shown in Figures 2.10 and 2.11.

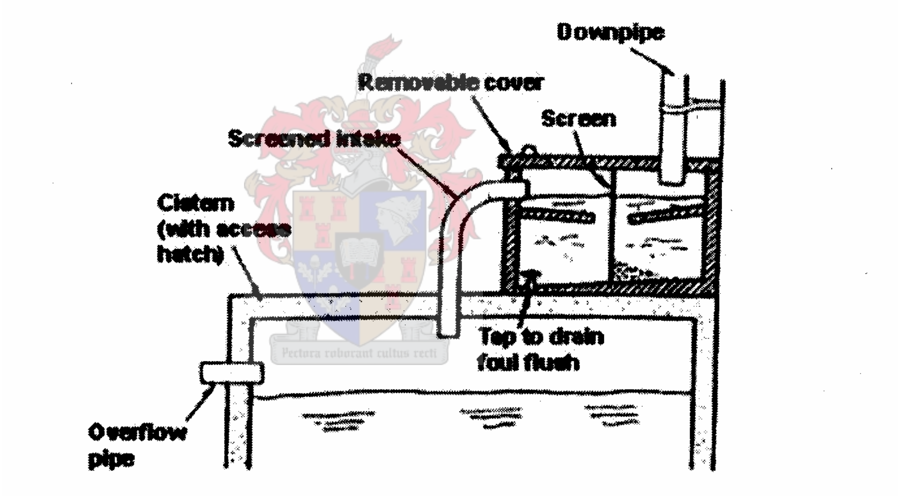

*Figure 2.10: Example of a foul flush box (WaterAid, Rainwater Harvesting)*

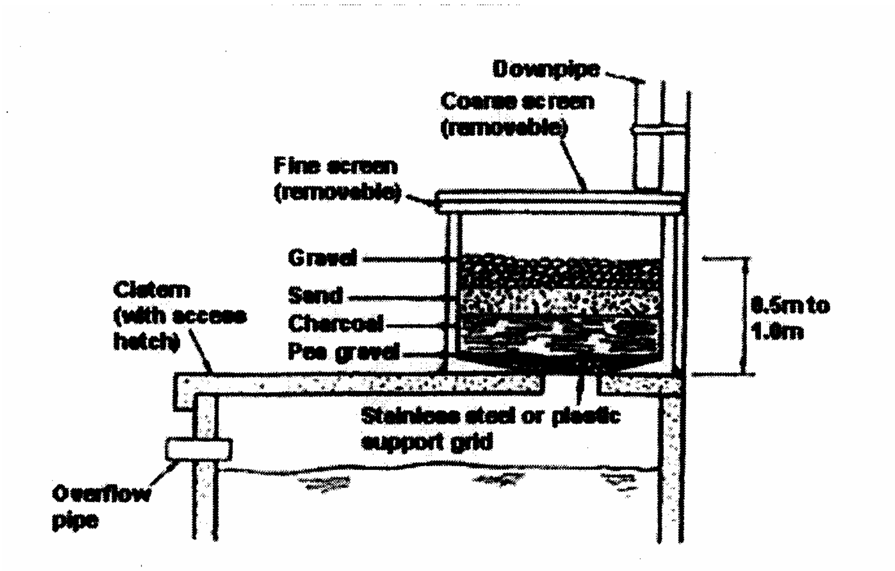

***Figure 2.11**: Example of a filter system (WaterAid, Rainwater Harvesting)*

These structures are used as alternative options in order to ensure that the water that is collected is of good quality. There are also a number of processes that occur in the tank itself such as settlement, floatation and pathogen die off.

The advantages of roof catchments are:

- They can be constructed in the yard of the user if the house has a suitable roof.
- Each individual is responsible for his own system.
- Collective storage from a group of houses can be utilized in order to serve a community

The disadvantages of roof catchments are:

- Water quality is variable with rain catchments and will depend on the users' willingness to clean the roof often and disinfect the cistern occasionally.
- It is based on a finite volume of water that can be depleted if not well managed making it a poor candidate for community supply unless strong measures are taken to prevent overuse.
- It is seasonal in nature; hence there must be another water source available. This source must be able to cope with the demands of households which sometimes use rainwater harvesting, especially as the largest demand will be in dry periods.

**(b) Ground catchments**

This method uses a drain which is placed at the downward end of a slope of a hardened surface to collect water and deliver it to a sedimentation basin and into a storage tank.

Figure 2.12 shows a typical ground catchment system.

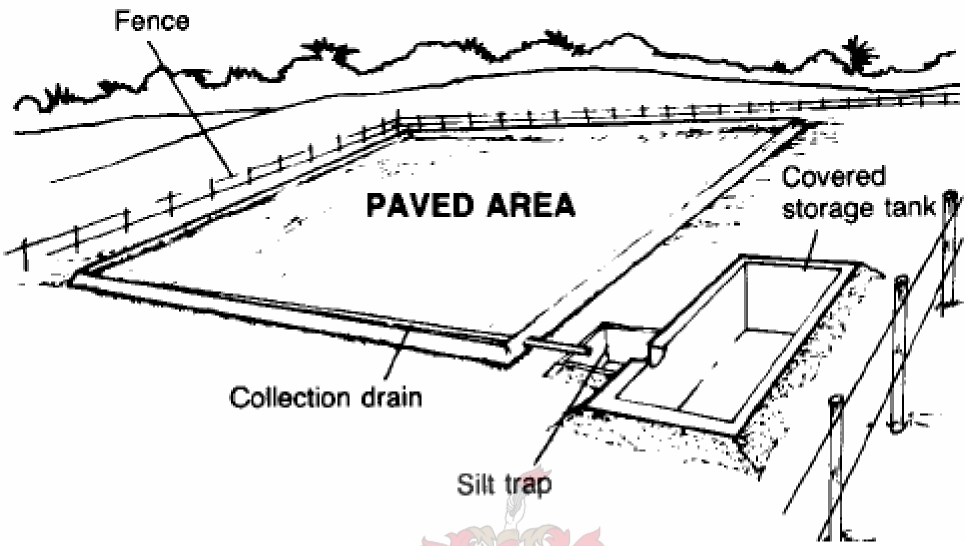

*Figure 2.12: Typical ground catchment structure (Water for the world, RWS 1.P.5)*

An area of sloping ground several hundred meters square must be cleared, graded and preferably paved to form a catchment for precipitation. A paved area is desirable to reduce losses due to evaporation and infiltration, and to reduce erosion. The water from these catchments is usually not of high quality. However, they can be used for secondary purposes such as gardening and livestock drinking.

The advantage of ground catchment is:

- It provides a fairly good quantity of water and with good storage it can meet the needs of the community.

The disadvantages of ground catchment are:

- Costly to install and must be carefully maintained
- Require large tracts of land and that may not be available in a community
- Treatment of the water for human consumption is costly
- Limited to use in areas of high rainfall

Thus, generally, in opting for any particular type of water source, one must ensure as far as practically possible that the source is reliable, that the quantity of water obtainable from it will be sufficient to meet the basic needs of the community and that the quality of the water is of acceptable standards for human consumption.

## *2.6 Water distribution systems*

Once a water source has been identified and the intake developed using the methods described in the preceding sections, a water distribution system has to be selected in order to deliver water to the users.

Different water distribution systems are used for rural water supply. However, in designing and implementing any type of the water distribution system, all water services institutions including water services authorities have to incorporate the minimum standards required for the design of water services set for basic water supply service which are set under the provision of the South African Water Services Act (Act 108 of 1997).

DWAF has produced a booklet on *Guidelines for Compulsory National Standards, and Norms and Standards for Water Services Tariffs* produced in 2002, set under the regulations of the South African Water Act (Act 108, 1997), Sections 9 and 10 which sets out the guidelines for the regulation of water services in the country. The compulsory national minimum standards define the government's minimum desired basic level of water service to every community. The minimum standards are described in the following section.

### 2.6.1 Minimum standards considered in the design of rural water supply systems

The minimum standards are developed and implemented to protect the social and economic interests of all consumers, especially poor and vulnerable households. The objectives in coming up with minimum standards are *(DWAF, 2002)*:

- To provide safe drinking water that will not cause ill health
- To provide a quantity of water that will ensure that the users are able to fulfill their basic water needs
- To ensure that the users spend a minimum of their time on drawing water

The minimum standards which have been determined are defined as follows (*DWAF, 2002*):

**(a) Water demand or quantity**

In South Africa, DWAF's guidelines for compulsory national standards of 2002 stipulate that *(DWAF, 2002)*:

- *The minimum standard for the quantity of water required for basic water supply services should be 25 litres per person per day* (ℓ/c/day)

This is the minimum that is set as the water quantity required for basic water supply service to be delivered to the consumer at the delivery point. This quantity is only considered to be the minimum required by an individual for direct consumption, for the preparation of food and for personal hygiene.

The author notes that in the design of bulk supply lines a minimum capacity of 60 ℓ/c/day is used in order to allow for the expansion of the water supply system to include further communities at a later stage using the same water source. However, this study investigates the effect of increasing the minimum standards at the delivery point required for the basic level of service with respect to cost.

It is one of the South African government priorities to increase the level of standards in the provision of basic water services as is stated in the *White Paper (DWAF, 1997a),* and the approach taken in the water services bill is to allow for a progressive increase in the standards of basic service to be assured by local government.

The document, *Strategic Framework for Water Services (DWAF, 2003a)* states that where sustainable, Water Services Authorities should give consideration to increasing the basic quantity of water from 25 litres per person per day, aiming for the provision of 50 litres per person per day.

*Van Schalkwyk (1996)* found that the range of water consumption for a street standpipe water distribution system at a distance less than 250 m is 25 to 50 ℓ/c/day and it is also indicated by the *CSIR (2000)* that the range of water consumption for areas equipped with standpipes that are often used in rural areas within a distance of 200 m is 10 to 50 ℓ/c/day.

Increasing the minimum water demand to be delivered to the consumer at the delivery point to 50 ℓ/c/day will therefore cater for the full range of water demand in the rural areas where a standpipe is used as the minimum level of service.

It is noted that the range of consumption is different when different water distribution systems and levels of service are considered.

### (b) Distance (cartage)

This standard represents the maximum distance that a person will have to cart water to his dwelling. The general consideration is that of time and effort during the carting.

In determining the minimum standard for the distance the objective is to reduce the amount of time and effort spent by an individual on carrying water to the home.

In South Africa, DWAF's guidelines for compulsory national standards of 2002 stipulate that *(DWAF, 2002)*:

- *The distance of carting water required for basic water supply should be within 200 m of a household.*

In steep terrain this distance may have to be reduced to take into account the extra effort required to cart water up steep slopes. A climb of more than 60 m over a short distance should be considered as being similar to walking a distance of about 1000 m *(CSIR, 2002)*.

An individual should spend a minimum of his time in fetching water so that the remainder of his time is spent on activities that will improve his social and economic livelihood.

### (c) Flow rate (Abstraction rate)

This standard represents the minimum flow rate at which a person will abstract water from the tap. The general consideration is on time spent during the abstraction. In determining the minimum standard for the flow rate the objective is to keep the amount of time that is spent by an individual on abstracting water to a minimum.

The maximum unit of water that can be carried by a person per trip is about 20 ℓ (*Carter et al, 1996*). Therefore if a person has to carry this amount in one trip then the time of abstracting the water has to be kept to a minimum so that enough water required by the household can be collected within a reasonable time.

In South Africa, DWAF's guidelines for compulsory national standards of 2002 stipulate that *(DWAF, 2002)*:

- *The flow rate required for basic water supply services should be not less than 10 litres per minute.*

### (d) Residual pressure

This standard represents the pressure that should be available at the abstraction point where water is drawn by the users.

It represents the pressure that is required to make water flow in the system and for the upgrading of the system to an improved service level. DWAF's guidelines for the development and operation of Community Water Supply Schemes (*DWAF, 1999*) stipulate that:

- *The residual pressure at a standpipe or tap point for community water supply should not be less than 10 m*

It is further stated that a residual pressure of 5 m may be considered in site specific cases where the tap is near a reservoir or on top of a hill *(CSIR, 2000; DWAF, 1999).*

Different heads are known to be able to deliver a specified flow rate depending on the tap size being used as shown in the table below extracted from the *CSIR (2002).*

| TAP DIAMETER | DISCHARGE | | |
|---|---|---|---|
| | 5 m head | 10 m head | 60 m head |
| 15 mm | 16 ℓ/min | 23 ℓ/min | 54 ℓ/min |
| 20 mm | 22 ℓ/min | 31 ℓ/min | 70 ℓ/min |

***Table 2.1: Typical discharge rates for taps (Assumed efficiency rate 80%)***

Since an acceptable standard discharge capacity from a standpipe is 10 ℓ/min per tap, the commonly used taps should be able to deliver the standard discharge rate at the different pressures that can be used in a rural piped water supply system.

For communal standpipes or street taps as is the case used for rural water supply the following criteria should be followed in the provision of standpipes as recommended by *CSIR (2000):*

- One tap required per 25 to 50 dwellings
- Maximum number of people served per water point should be 300

- Maximum number of people served per tap should be 150. Individual kiosks should supply at least 100 dwellings
- Maximum walking distance from a dwelling to a standpipe should be 200 m

**(e) Quality**

The desired quality of water is dependent on the use for which the water is required. The quality of water provided as a basic service should be in accordance with currently accepted minimum standards with respect to health related chemical and microbial contaminants. It should also be acceptable to consumers in terms of its potability (taste, odour and appearance).

DWAF has stipulated standards for drinking water quality that should be adhered to in the provision of drinking water services so as to ensure that the water does not cause health problems which can reduce the consumers' productivity (*DWAF, 1999*).

In cases where the water does not meet these standards, the water needs some form of treatment in order to make it safe for drinking.

Classification of the water quality standards has been divided into four classes: ideal (Class 0), suitable for lifetime use (Class I), suitable for interim use (Class II), and unfit for use without suitable treatment (Class III).

The classification is as shown in Table 2.2: The unit of measurement is mg/l.

| **Constituent** | **Class 0*** | **Class I*** | **Class II*** | **Class III*** |
|---|---|---|---|---|
| Total dissolved salts (TDS) | 0 – 450 | 450 – 1000 | 1000 – 2450 | > 2450 |
| Electrical conductivity (mS/m) | 0 – 70 | 70 – 150 | 150 – 370 | > 370 |
| Nitrate ($NO_3$) plus nitrite ($NO_2$) as N | 0 – 6 | 6 – 10 | 10 – 20 | > 20 |
| Fluoride | 0 – 1.0 | 1.0 – 1.5 | 1.5 – 3.5 | > 3.5 |
| Sulphate | 0 – 200 | 200 – 400 | 400 – 600 | > 600 |
| Magnesium | 0 – 30 | 30 – 70 | 70 – 100 | > 100 |
| Sodium | 0 – 100 | 100 – 200 | 200 – 400 | > 400 |
| Chloride | 0 – 100 | 100 – 200 | 200 – 600 | > 600 |
| pH (pH units) | 6.0 – 9.0 | 5.0 – 6.0<br>9.0 – 9.5 | 4 – 5 or<br>9.5 – 10 | < 4 or > 10 |
| Iron | 0 – 0.1 | 0.1 – 0.2 | 0.2 – 2.0 | > 2.0 |
| Manganese | 0 – 0.05 | 0.05 – 0.1 | 0.1 – 1.0 | > 1.0 |
| Zinc | 0 – 3.0 | 3.0 – 5.0 | 5.0 – 10.0 | > 10.0 |
| Arsenic | 0 – 0.01 | 0.01 – 0.05 | 0.05 – 0.2 | > 0.2 |
| Cadmium | 0 – 0.005 | 0.005 – 0.01 | 0.01 – 0.02 | > 0.02 |
| Faecal coliforms (counts/100ml) | 0 | 0 – 1 | 1 – 10 | > 10 |
| Potassium | 0 – 25 | 25 – 50 slight taste | 50 – 100 slight bitter taste | > 100 |

***Table 2.2: Classification system for the assessment of the suitability of water for potable use (DWAF, 1999)***

*Classification system for drinking water quality, four quality classes have been defined as follows:

Class 0: This is ideal drinking water quality suitable for lifetime use. This class is essentially the same as the target water quality guideline range in the South African Water Quality Guidelines for Domestic Use (2nd Edition).

Class I: In this class the water quality is still safe for lifetime use, but falls short of the ideal of Class 0 where no health effects are permitted. There may be rare instances of health effects in this class, but these are usually mild, and overt health effects are almost always subclinical and difficult to demonstrate. Aesthetic effects may occur in this class.

Class II: In the concentration range defined by this class, health effects are unusual with limited short term use, but may become more common, particularly with use for many years or lifetime use. This class is that of water suitable for short term or emergency use only, but not necessarily suitable for continuous use for a lifetime.

Class III: This is the concentration range where serious health effects may be anticipated, particularly in infants or elderly people with short term use, and even more so with longer term use. The water in this class is not suitable for use as drinking water without adequate treatment to shift the water into a lower (safer) class.

### (f) Assurance of supply

In South Africa, DWAF's guidelines for compulsory national standards of 2002 also recognise that reliability of a water supply also forms part of the basic minimum standard.

Thus the basic minimum standard that has been set in order to ensure an assurance of supply is that:

- *Raw water should be available 98% of the time and no consumer should be denied access to basic water supply for more than seven full days in any year and these seven days must not be consecutive.*

Thus, it is necessary to have an assurance of supply, since in the event of there being no steady supply of water to a rural community the risk is that the people will be forced to resort to using unprotected water sources which are a health hazard and which can amongst other things lead to lowered production in the economic lives of the people.

In order to ensure an assurance of water supply standby facilities need to be provided so that there are no long downtime periods in the event of the operational facility breaking down. A storage period of 48 hours is required in order to ensure the assurance of supply *(DWAF, 1999).*

Technologies in rural water systems need to be selected in such a way that they do not need highly skilled personnel to repair and maintain them when they have broken down.

These minimum standards are compulsory when considering and designing a rural pipe water supply system to satisfy the minimum level of service where a stand pipe is used.

### *2.7 Water distribution systems and factors affecting the choice of selection*

The choice of a distribution system is based on the level of service or system of delivery required *(Twort et al, 1974)*. According to *Skinner (1992)* a rural water supply distribution system should be:

- Acceptable to the community in relation to convenience, traditional beliefs and practices and also acceptable from environmental and health perspectives.
- Feasible in terms of the relevant local social, financial, technological and institutional capacity factors
- Sustainable in terms of being possible to operate reliably and to maintain in the future with the available financial, human, institutional and material resources.

In order to ensure sustainability of rural water supplies *Harvey and Reed (2004)* recommend that selection of the technology for water distribution should be done in consultation with both the water users and the water institutions involved.

Water users should be provided with sufficient information on the merits and demerits regarding the choice of technology. This will assist in establishing the water users' willingness and ability to manage and finance the operation and the maintenance of the distribution system on a long term basis.

Often technology choice is influenced by environmental, technical and financial factors *(Harvey and Reed*, *2004*). Based on these factors information should be sourced on different available technologies and associated costs, operation and maintenance needs in terms of skills required and the availability of spare parts. The benefits of each option and the associated constraints should be considered.

As mentioned, the level of service required by the community also influences the type of water distribution system to be adopted.

There are two levels of service that are considered for water supply in a community *(CSIR, 2000*);

- Communal water systems
- Private water systems

(a) Communal water systems

A communal water system is a level of service whereby the public and the community have access to a water supply terminal installation in form of a street tap or handpump, and users have to walk and collect water in containers or buckets. The basis of the application of the minimum standards defining the basic level of service falls within this category *(CSIR, 2000)*.

The street tap may include a storage tank. The street taps may be the ordinary type or the prepaid type which are equipped with a water meter.

(b) Private water systems

A private water system is a system whereby water is connected to individual homes in the form of house connections and yard connections.

(i) House connections

House connections are of two types:

- Full-pressure conventional house connection

  Water is provided at high pressure in the house and all water use is at full pressure and unregulated flow. Water use is metered conventionally and users pay for water used per month.

- Full pressure, prepaid

  Water is provided at high pressure in the house and all water use is at full pressure, and available with prior payment using prepayment tokens which activate the prepayment meter. No monthly meter reading and billing is required

(ii) Yard connections

Yard connections are also divided into two types:

- Ordinary type

  Water is provided, at pressure, at a tap within the yard. No storage facilities are provided on site and there is no supply to the house.

- Yard tank

  Water is provided to specifically manufactured yard tanks. The tanks can be either ground tanks or elevated roof tanks.

According to the *CSIR (2000)* selection of the level of service to be given to a community should depend on:

- Affordability of the system
- Selected method of cost recovery

- Unit cost to the end user
- Long term maintenance requirements

Thus, the selection criterion of a level of service to be offered to a community should be based on the relative importance of the service level to the users with regard to these factors.

The methods for the distribution of water will also be based on the location of the water source and community to be served. The relative distance between the source and the community will influence on the need for *(Water for the World, RWS.4.M*):

- Distribution of water at the source or near the source.
- Distribution of water away from the source.

### 2.7.1 Distribution of water at the source or near the source

*Water for the World ( RWS.4.M)* have put this category as the type of water distribution which uses wells or boreholes equipped with handpumps, electric pumps or a tap system in case of a spring development which is near the community. Where a handpump is used the water is carried in buckets to the homes. Where an electric pump is used or a spring, the water can be connected to a pipeline system where it can be fed into a storage tank for use in a private water system or communal water systems.

### 2.7.2 Distribution of water away from the source

Under this category, there are two methods that can be used for distribution of water which are hauling and pipeline reticulation system.

#### 2.7.2.1 Hauling

Use of a truck falls in this category. The truck may be used to haul water to the people in the rural communities and the people fetch the water from the truck in buckets.

The advantage of hauling is:

- People do not have to travel long distance to fetch water

The disadvantages of hauling are:

- It provides only minimal quantities of water
- The terrain sometimes makes hauling impossible
- It has high operation and maintenance costs

Therefore hauling should be considered an option where there are minimal quantities of water to be distributed to the users and its cost of provision does not exceed that of other options available for rural water supply.

### 2.7.2.2 Pipeline reticulation system

With distribution of water away from the source, a pipeline reticulation system can be used. This method uses a reticulated transmission pipeline network installed to the distribution points within the supply area and the water is abstracted at service points which have taps serving a group of people or may serve individual homes *(Steel, 1960)*.

A source of pressure is required to move the water from the source to the point of use. This is accomplished by the use of a gravity system or a pumping main to pump the water.

There are several components that make up the distribution network of a piped water supply system as described by *Twort et al (1974)* these include:

- Source and intake
- Treatment works
- Main or transmission pipeline
- Storage reservoirs
- Distribution pipelines and tap stands

(a) The source and intake

The intake structure is constructed nearest to the source in order to collect water from the source and supply to a storage facility or community through a water transmission system. The selection of an appropriate intake depends on the type of source. The system to use can be a gravity flow system or a pumping system. It should be ensured that the intake has an all weather access road and is well-protected from theft and vandalism (*Babbit et al, 1962*)

Gravity flow and pumping systems can be used in combination in order to improve on efficiency and reduce costs

The source at the intake can be any one of the water sources that have already been discussed.

(i) Gravity flow intake

If the intake at the water source is at a higher elevation than the supply area, then a gravity flow system can be used whereby the water will flow into the distribution network under the pressure of gravity.

Design considerations for a gravity flow intake include:

I. Quantity of water required

When designing for a gravity system and all other water supply systems it should be ascertained that the yield of the source will be able to meet the total daily demand of the water users now and in the future during the economic life of the system. According to *Webster (1999)* the following factors should be considered in determining total daily demand required from a water source:

- Annual average daily demand.
- Population and population growth

- Water losses to be incurred in transmitting the water to the users
- Peak factors to account for the peak daily and seasonal variation in water demand
- Increase in water demand if anticipated due to change in the level of service over the project life (upgrading), e.g. upgrading from standpipe to yard connection.

The total daily water demand of the users is used to determine if the yield of the water source is sufficient to supply water safely over long periods of time and to determine the storage capacity needed to ensure that an adequate supply is available during peak demands and critical periods of water shortage.

The following equation can be used to calculate the total daily water demand required by the users:

Total daily water demand (ℓ/day) = $P * GAADD * PF * DF$ (2.2)

And $GAADD = (1 + L_F)\ AADD$ (2.3)

where

$P$ = Population of water users inclusive of population growth considerations
GAADD = Gross average annual daily demand in ℓitres per capita per day (ℓ/c/day)
AADD = Average annual daily demand in ℓitres per capita per day (ℓ/c/day)
$L_F$ = Design loss factor due to unacconted-for-water loss. 10% is recommended *(DWAF, 1999)*
$PF$ = Peak daily factor
DF = design factor to take into account upgrading of system to a bulk supply level

The gross average daily demand takes into account the unaccounted-for-water loss in the system that will occur in transmitting the total daily demand based on the annual average daily demand.

The design factor takes into account the increase in the rate of water use when the system is upgraded. DWAF recommends a design factor of 2 to 3 to be used depending on the anticipated increase *(DWAF, 1999)*.

The *CSIR (2000)* recommends that demographers and town planners who are best equipped with knowledge on town planning should be consulted to determine the future population of an area.

For rural water supplies DWAF recommends that a 0% population growth rate be used or as otherwise approved, due to the influence of Human Immunodeficiency Virus and Acquired Immune Deficiency Syndrome (HIV/AIDS) (*DWAF, 1999*). This implies that where the influence of HIV/AIDS is not present, a growth rate based on the factors that can influence population growth in the area should be used.

Therefore the total daily water demand required from the source will be determined based on the future total daily water demand if growth in the population is considered, and on the service level to be provided to the community.

II. Required Source Production (design discharge)

From the total daily water demand of the community the required source production rate or discharge in litres per second is calculated from the formula

$$\text{Required daily production rate } (\ell/\text{s}) = \frac{P * GAADD * PF * DF}{t} \qquad (2.4)$$

Where $t$ = Period of production in seconds

DWAF recommends the period of production to be 24 hours for a continuous flow for a gravity system (*DWAF, 1999*). As mentioned previously, the required daily production rate is the minimum discharge that the source has to produce in order to meet the total daily demand of the water users.

The advantages of a gravity flow intake are:

- It is efficient
- It requires no additional energy where the source is located at a higher elevation than the supply area
- It is economical to operate and maintain

The disadvantages of gravity flow intake are:

- It is initially expensive to construct
- Its use is restricted to water sources at a higher elevation

Thus, the use of gravity flow systems eliminates the costs that are incurred when using a pumping system since there are no pumping costs that have to be met, the system relying solely on gravity.

(ii) Pumped water intake

If the supply area is higher than the water source, the water has to be pumped from the intake to the supply area using motorized pumps. It is necessary to ensure that the pump selected is appropriate to the head and flow capacity required.

The method of selecting an appropriate pump is to determine the system design flow and the system head (including system losses) required. From this data the pipe system curve can be plotted. The pipe system curve can then be plotted together with a pump performance curve either in series or in parallel as required, in order to establish an optimum operating point for a particular pump.

The intersection of the pump performance curve and the system curve will give the operating point of the pump. The operating point will indicate the flow output and head that the selected pump can produce. The corresponding flow output and head at the operating point can then be compared with the required pumping conditions to determine if the pump chosen will be able to operate efficiently at the pumping conditions that are required. An ideal pump selection will result in the pump operating point falling at or very near to the pump best efficiency point. The procedure is as described below.

The primary requirement is to determine a suitable pump and pipe combination for the required design discharge or water quantity. In designing for the pumping requirements the following should be considered (*Twort et al, 1974*):

I. Quantity of water required

This is the total daily water demand required by the users. The procedure for determining the total daily water demand is similar to that discussed under gravity flow intake and equation (2.2) can be used. However, consideration of population growth and increase in water demand should be up to the economic design life of the pump to be selected.

II. Daily pump production rate requirements (design discharge)

The daily pump production rate to be determined for the pump to be chosen is the pumping rate or discharge required to supply the total daily water demand of the users. Equation (2.4) is used for determining the daily pump production rate requirements.

However, the period of production is considered as the pumping period under which the pump will be operating. This is the period the pump will be used to supply a storage reservoir. *DWAF (1999)* recommend a pumping period of 20 hours per day. Pumping to supply reservoirs should be done when the electricity tariffs are low to minimise pumping costs.

III. Pumping head

The pumping head is the head to be imparted by a pump in order to deliver the required design discharge (Q) through a specific pipeline, from the water source to the highest point in the system which is usually a reservoir.

In order to move the required design discharge, the total pumping head ($H_p$) provided by the pump must be able to overcome the static head (H) as a result of elevation differences and the headloss due to pipe friction to be incurred in the pipeline selected to deliver the water.

Pipe head losses are due to friction head loss ($h_f$) due to the hydraulic roughness of the pipe material, and local head losses ($h_L$) due to eddy formations generated in the fluid at pipeline bends, junctions and valves. Pipe friction head loss varies with discharge for different pipes used *(Chadwick & Morfett, 1985)*.

$$\text{Total pumping head } (H_p) = H + h_f + h_L \tag{2.5}$$

And

$$\text{Local headloss } (h_L) = \frac{K_L V^2}{2g} \tag{2.6}$$

where
V = Velocity of flow in the pipeline
$K_L$ = Constant for a particular fitting with values available from literature e.g. *Chadwick & Morfett (1985)*
$g$ = 9.81 m/s$^2$

For a long pipeline the local headlosses can be neglected *(Chadwick & Morfett, 1985)*.

The selection of a pipe size is influenced by the pumping rate required to meet the total daily volume of water needed to supply the users, and the distance between the source and the storage facility *(Water for the World, RWS 1.D.2)*

For the pump daily production discharge determined using equation (2.4), and any pipe diameter that can be selected to transmit this discharge, the friction headloss ($h_f$) to be incurred through the pipeline can be determined using the Hazen-Williams or the Darcy-Weisbach equations described under subsection (c) on Transmission Pipelines.

In order to select an optimum pump for a specific pipeline diameter, the Hazen-Williams or the Darcy-Weisbach equations are used to determine the pipeline characteristics at different discharges by relating the discharge against the associated pumping head as a sum of the friction headloss and the static head. Pump and pipeline combinations, however, affect the cost of pumping *(Twort et al, 1974)*.

The larger the pipe size the lower the pumping costs. This is because frictional losses decrease with increasing pipe size and therefore less energy is lost due to friction and the available energy is used to drive water in the system.

In order to reduce pumping costs, *Chadwick & Morfett (1985)* recommend that various pipe sizes and pump alternatives should be investigated to compare power consumption requirements before an optimum pump and pipe combination that suits the given conditions can be selected.

With the total required daily discharge and the total design head determined, the optimum pump that can fit the required parameters of operation can be selected using pump characteristics which can be obtained from pump catalogues and the pipeline characteristics that have been determined for a specific pipe diameter as has been described.

The pump characteristics are described in terms of values of discharge against the associated head and efficiency at which the pump can perform. From this information a head-discharge and efficiency-discharge pump characteristics can be expressed.

For a given system (pump and pipeline size) the head-discharge and efficiency-discharge pump characteristics can be superimposed on that of the pipeline characteristics. A typical graphical representation of this representation is shown in Figure 2.13.

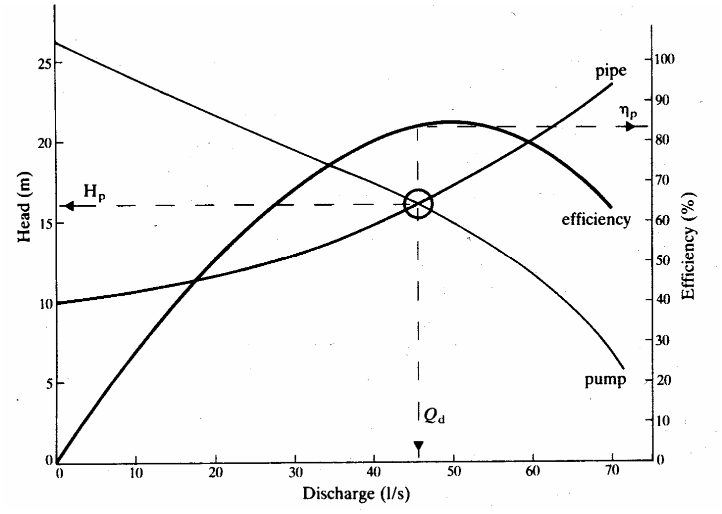

***Figure 2.13: Typical superimposed characteristic curves for pump and pipeline systems (Chadwick and Morfett, 1985)***

The point where the pipe curve and the pump curve intersect is the operating point. At this point the corresponding head and discharge can be compared with the required design discharge $Q_d$ and total head $H_p$ to see if the pump performance can meet the specified requirements to deliver water to a system reservoir.

The power consumption for the system at the operating point can be calculated from the equation:

$$P = \frac{\rho g Q_d H_p}{\eta_p} \qquad (2.7)$$

where $P$ = Power consumption requirements for the system

$Q_d$ = Total required design discharge (ℓ/s)

$H_p$ = Total pumping head (m)

$\eta_p$ = Efficiency (%)

The selected pump should be equipped with pump controls. *Section H* of the *Guidelines for the Development and Operation of Community Water supply Schemes (DWAF, 1999)* stipulates that a pump station should be complete with switch gear, pump sets, valves, and pipework housed in a specially constructed civil structure in order to ensure pump control and protection.

The advantages of pumping are:

- It provides flexibility on the location of the water source
- It is efficient

The disadvantage of pumping is:

- It is expensive as it requires a large amount of energy to run the pumps and, operation and maintenance costs are high.

It is important that pumps be equipped with pump controls to protect the pumps from damage due to surge pressures during pump start ups, pump stops and valve closures.

The flexibility in the location of the water source enables the pump system to be applicable in all situations.

### (b) Water treatment works

The selection of an appropriate water treatment process is essentially determined by (*DWAF, 1999*):

- The raw water quality (physical and chemical).
- The prescribed final quality

The *Guidelines for the Development and Operation of Community Water Supply Schemes (DWAF, 1999)* recommend that the design of a water treatment process should be carried out by a suitably trained professional engineer as it is a specialist expertise. The recommended loading rates and design parameters for water treatment process units are given in Section G in the guidelines.

In circumstances where the quality of water is generally good, two simple methods of treatment are considered viable for the treatment of water for a rural water supply (*Harvey and Reed, 2004*): settlement and slow sand filtration. Settlement will improve the appearance of the water, but slow sand filtration, particularly when used with settlement, should give clear and bacteriologically pure water. The *CSIR* (2000) also recommends the use of package water treatment plants

### 1. Settlement

The quality of water from streams, etc, can often be significantly improved by the removal of suspended matter by simple settlement.

Most suspended particles are heavier than water (although a few may float) and will settle in quiescent conditions; very fine clay particles may not settle out at all. Most structures that hold water will function as a settlement basin. Natural or manmade ponds or lakes will suffice, but purpose-made structures which incorporate efficient inlet and outlet arrangements and facilities for silt removal are generally more effective.

*Morgan (1990)* recommends that the length of the settlement structures should be made about three times the width, with a practical depth of about 2 m. A capacity of 2 to 4 hours retention at maximum flow should be sufficient to remove most sand and silt. On small installations it may be better to fill the basin with stone or gravel to prevent the incoming flow from disturbing the settled solids. The sediment can then be washed out with a hose pipe.

2. Slow sand filters

According to *Morgan (1990)* slow sand filters consist of an open tank about 3 m deep and a filter media 1 m deep with clean sand of one size, between 0.15 mm and 0.35 mm. The filter media is supported on gravel, varying between 2 mm and 10 mm.

An under floor drainage system is required, which can be constructed of bricks, blocks or pre-cast slabs. The baffled inlet should be about 1 m above the sand and the outlet flow needs to be controlled by a weir and outlet valve.

Slow sand filters function by forming a film of bacteria and algae on the surface of the sand as the water passes through it. The rate of flow must be controlled to 2.5 $m^3$ per $m^2$ per day, or a vertical flow rate of 0.1 m per hour.

The filter must be cleaned periodically as the flow rate drops, by removing a skin of sand of 20 mm thickness at the top.

The incoming water must be of a reasonable quality, or must receive pre-treatment, to prevent the slow sand filter from blocking too quickly. It is usually necessary to have two units in parallel, so that some supply can be maintained when one unit is out of commission for cleaning.

The *CSIR* (2000) have reported slow sand filtration to be an economical and successful option for water treatment plants in developing areas of South Africa.

3. Package water treatment plants

These are prefabricated purification plants that are assembled on site. They may or may not require small civil construction works and piping for complete functioning. They can be used for smaller communities in rural areas and have the potential to fulfill the need for potable water.

However, attention should be given to operation and maintenance requirements as well as backup services from suppliers (*CSIR, 2000*).

A publication entitled *Package Water Treatment Plant Selection* gives guidelines on the appropriate plant type to choose for a particular size of a community *(CSIR, 2000)*.

### (c) Main or transmission pipeline

This constitutes the transmission of the water from the source or treatment works depending on the need of a treatment plant, to the supply area storage. In rocky areas the pipeline will probably be laid above ground and will be of galvanized mild steel tubing, anchored on saddles. Elsewhere the pipeline will be laid in trenches, to protect it from damage and will usually be made of uPVC or HDPE pipes.

The main or transmission pipeline design involves selecting the pipe size that will deliver the required discharge, enough to provide the storage volume that is required at the storage reservoir for a specified period of drawing in order to meet the total daily demand of the system and the instantaneous water demand.

The size of the transmission pipeline required to deliver the required discharge can be calculated using the Hazen-Williams equation (*Streeter et al, 1997*)

$$h_f = \frac{10.675 * L * Q^{1.85}}{C^{1.85} * d^{4.87}} \qquad (2.8)$$

where

$h_f$ = Head loss due to friction (m)

L = Length (m) of pipeline between the intake and storage reservoir including the length of fittings

Q = Required discharge rate ($m^3/s$). The required discharge rate used is the result obtained for the required production rate (equation 2.4) for pumping or gravity system, depending on the system used.

C = Hazen-Williams roughness coefficient

d = Diameter of pipe (m)

Consideration of the pipeline design should also include:

- Pipeline materials
- Cover of pipes in trenches
- Slope of the pipeline. A slope of steeper than 3% is required to avoid air pockets (DWAF, 1999)

Valves along the pipeline should be provided in order to:

- Enable the air trapped in the mainline to be released (air valves).
- Enable the main transmission line to be maintained at any point along the length of the pipeline when there is need for maintenance (isolating and scour valves).
- To protect the system from transient pressures (pressure relief valves, surge tanks and air chambers)

(d) Storage reservoirs

Storage reservoirs may be either at ground level or elevated. In a water distribution system storage reservoirs serve three main functions (*Twort et al, 1974*):

- To balance peaks in the water demand
- To provide emergency storage
- To ensure specified residual pressures throughout the network at all times
- Eliminate continuous pumping

Storage reservoirs are designed within the system to provide a total volume of storage equivalent to the total water demand of the area to be served.

The first step in determining storage capacity of a storage reservoir is to determine the total water demand. The procedure is the same as explained on determining the total water demand for intake requirements of a gravity flow or pumping system.

From determining the daily total water demand, the reservoir storage capacity converted into $m^3$ per day can be calculated as follows:

$$\text{Reservoir capacity } (m^3) = \frac{P * GAADD * PF * DF}{1000} \qquad (2.9)$$

The final sizing of the storage capacity depends on the period of storage required. According to the *Guidelines for the Development and Operation of Community Water Supply Schemes (DWAF, 1999)* storage reservoirs should be designed for a storage of 48 hours at the annual average daily demand for pumping mains pumped from one source and for 36 hours at the annual average daily demand for pumping from multiple sources.

If a gravity system with a continuous supply is used the storage reservoir should be designed for a storage of 24 hours at the annual average daily demand.

The period of storage is considered in order to make sure that there is enough storage in the reservoir so that there is an uninterrupted water supply between the reservoir and the users when there is a breakdown of the system between the source and the reservoir and the system is being repaired.

The design of storage reservoirs should also include a balancing storage that is required to balance instantaneous peak periods in water demand so that there are no periods of imbalance when the reservoir is being drawn.

*Twort et al (1974)* has state that where a feeder pipe from the source to the storage reservoir is the only pipe that influences the required balancing storage of the tank and is situated upstream of the consumer area, the following consideration should apply:

If the feeder pipe is a large pipe with an inflow capacity (Q) which exceeds the instantaneous peak in the downstream demand, no balancing storage is required. If the feeder pipe inflow capacity is marginally lower than the instantaneous peak demand, or if the capacity of the feeder pipe is so low that it only equals the annual average daily demand rate, a balancing storage is required to supplement the feeder pipe during short periods of imbalance.

However, if the storage reservoir is situated inside or downstream of the consumer area, all the pipes in the network, and not only the feeder pipe, influence the balancing capacity of the reservoir and a balancing volume should be provided.

The balancing volume required for a storage reservoir to meet the instantaneous demand at peak periods of a given duration is calculated based on the equation:

$$\text{Balancing Volume } (V_x) = \text{GAADD} * \text{PF} * X - Q*X \qquad (2.10)$$

where

$Q$ = the supply inflow into the reservoir (ℓ/day)
$X$ = peak period (days)

GAADD and PF are as previously defined.

The peak daily factors are used since the demand for water does not stay constant at all times but varies from the average demand rate at different times of the day and season. To account for the variation in demand from the annual average demand rate at daily peak periods, the peak daily factors are used.

As previously mentioned peak factors are used in sizing of storage reservoirs and other reticulation components to account for the magnitude of fluctuations in demand around the annual average daily demand rate during peak periods. *Van Schalkwyk (1996)* found that two distinct peaks occur in the daily distribution of water use. The peaks occur at about 7 to 8 am and 4 to 7 pm. Figure 2.14 shows the typical daily water demand use distribution at peak periods for a rural water supply system using a street tap adapted from *Van Schalkwyk (1996)*.

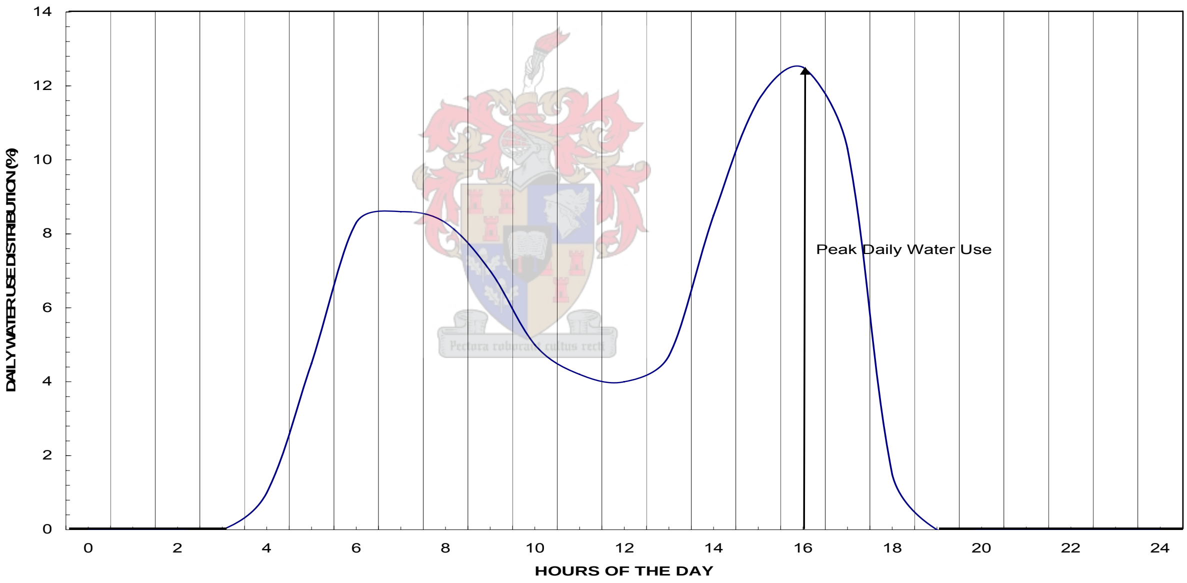

***Figure 2.14 Distribution of daily water use, percentage of total daily use (Van Schalkwyk, 1996)***

Peak factors can be calculated from the equation

$$\text{Peak daily factor (PF)} = \frac{\textit{Peak or Maximum Daily Demand}}{\textit{Annual Average Daily Demand}} \qquad (2.11)$$

For rural pipe water supplies where a standpipe is used, a daily peak factor of 3 is recommended for reticulations in rural areas *(DWAF, 1999; Van Schalkwyk, 1996)*. However, it is suggested that the designer should apply considerable thought in making the actual choice of peak factors to use as the ones recommended are only a guideline and are conservative. The peak factors are used in the design of all the components of the water supply system.

On site storage tanks can be used in a situation where the peak flows cannot be satisfied at the furthest point in the system, in order to meet the required flow.

If possible storage reservoirs should be located close to the supply area in order to ensure a more even distribution of pressure and to reduce distribution pipe costs. The *CSIR (2000)* recommends that where a storage reservoir also serves as a service reservoir and is required to supply water at the required residual pressure to the furthest point in an area, the reservoir should be located near the centre of the supply area.

To reduce operating pressures, it is sometimes necessary to introduce intermediate storage reservoirs in the form of break pressure tanks, which are usually made of concrete or ferrocement.

If suitably sized, the intermediate storage tanks can also be used within the system for the following:

- A reduction in the size of the main storage reservoir, in terms of both balancing storage and emergency storage
- A division of the supply into smaller subsections which can be more easily managed by community organizations
- A reduction of the impact of supply breakdowns
- To ensure the economic sizing of the pipeline system where the pipeline will be sized to carry the total average daily demand. The intermediate storage tank will be sized to meet the total daily water demand including peak demands at peak periods and the balancing storage if the inflow capacity into the tank cannot meet the instantaneous demand from the consumers

**(e) Distribution pipelines and tap stands**

A distribution system of pipes laid in trenches, is used to distribute the water around a community. For a rural water supply system tap stands are used to serve the communities and they should be placed at positions aimed to reduce the maximum distance people have to carry water, as discussed in Section 2.6.1(b).

The transmission line is responsible of delivering water to the consumers who might be at different locations in the profile of the system. It is sized based on the instantaneous water demand at any point in time at the abstraction point rather than on a constant flow as would be used in the main transmission line.

The distribution pipeline should be designed to be able to carry the total water demand for the population to be served taking into account the average annual demand and the demand at peak periods. Therefore peak factors are used to account for the demand at peak periods.

The total water demand can therefore be determined using the equation:

Total water demand = P x AADD x PF (2.12)

Other considerations of design for distribution pipelines are the same as those mentioned for a main or transmission pipeline in sub-section (c).

A distribution pipeline system consists of a network of interconnected pipes or loops which deliver water to consumers at different nodes as shown in Figure 2.15.

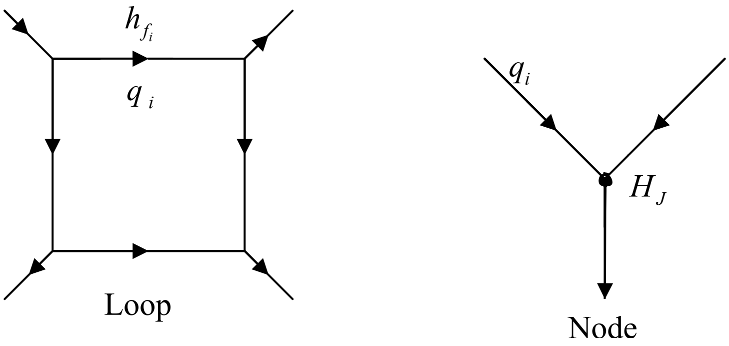

***Figure 2.15 Diagramatic representation of a loop and node***

The abstraction nodes are usually at different elevations. At each node, water demand is highly variable depending on the season and the population to be served at each node. However, supply must be constant (*Chadwick and Morfett, 1985).*

A hydraulic relationship exists in the network system amongst the elements of the distribution network. Every element is influenced by its neighbour and the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements

In order to calculate the flow characteristics required in the system at each node in terms of the flow and the required residual head, taking into account the head losses throughout the pipeline system, two concepts are used *(Streeter et al, 1998).*

- Conservation of mass
- Conservation of energy

Referring to the node junction shown in Figure 2.15 the principle of conservation of mass dictates that the fluid mass entering the node will be equal to the mass leaving the node. Therefore the continuity equation is applied to a node (Figure 2.15) in the network using the equation:

$$\sum (q_{in} - q_{out}) = 0 \qquad (2.13)$$

where

$q_{in}$ = Flow entering a node (ℓ/s)

$q_{out}$ = Flow leaving a node junction (ℓ/s)

To ensure continuity in a network system, the following condition must be satisfied at each node junction:

$$\sum_{i=1}^{n} q_i = 0 \qquad (2.14)$$

where $n$ = is the number of pipes joined at the node.

$q_i$ = the discharge from each loop or pipe joining a node

In Figure 2.15 the sign convention used here sets flows into a node junction as positive and out of a junction as negative.

Referring to the loop shown in Figure 2.15 the principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken by the water. Thus, the energy equation is applied to a loop (Figure 2.15) based on the equation:

$$\frac{p_1}{\rho g} + \frac{u_1^2}{2g} + z_1 + H_E = \frac{p_2}{\rho g} + \frac{u^2{}_2}{2g} + z_2 + H_f \qquad (2.15)$$

where

$p$ = Pressure head

$u$ = Velocity

$\rho$ = Density of water

g = Gravity acceleration constant

z = Elevation head

$H_E$ = Energy head gained (e.g. pumping head)

$H_f$ = Total energy head losses

Subscripts 1 and 2 refer to any two points along the pipeline.

Within each loop the following condition must be satisfied:

$$\sum_{i=1}^{m} h_{f_i} = 0 \tag{2.16}$$

Where $m$ = number of pipes in a loop

$h_{f_i}$ = energy loss per unit length around a loop

The equation implies that the algebraic sum of energy losses around each loop must be equal to the difference in total hydraulic grade between fixed nodes. From Figure 2.13 the sign convention sets flow and head loss as positive in the clockwise direction.

In order to balance the flow conditions and check that the proper relation is satisfied and maintained between the head loss and discharge for each pipe, an equation in pipe head loss as a function of flow is expressed as follows:

$$h_{f_1} = f(q_i) \tag{2.17}$$

where $f(q_i)$ represents the Darcy-Weisbach or the Hazen-Williams pipe friction equations. The Hazen-Williams equation is as previously defined in equation (2.8) and the Darcy-Weisbach equation is expressed as follows (*Illemobade and Stephenson, 2003*):

$$D = \left( \frac{8\lambda L Q^2}{\pi^2 g h_f} \right)^{0.20} \tag{2.18}$$

where $\lambda$ = Darcy-Weisbach pipe friction factor

The other parameters are as defined under the Hazen-Williams equation.

Since there is a complex network system of pipes in water distribution systems, one continuity equation must be developed for each node in the system and one energy equation must be developed for each pipe. Therefore, for a complex system the result is a set of simultaneous non-linear equations in head and discharge which cannot be solved directly.

For a network of pipes in a water distribution system a systematic approach is employed using the *Hardy-Cross* and *Nodal* methods to solve these equations and to calculate the flow and head characteristics required at different abstraction nodes.

The *Hardy-Cross* and *Nodal* methods involve the application of correction factors to the non-linear simultaneous equations to linearise them through iterative means by assuming trial values of flow or head until the system is in hydraulic balance (*Chadwick and Morfett, 1985)*. The Newton-Raphson iterative procedure is used to determine the unknown variables at the node (head or discharge).

- Hardy-Cross method

This method essentially consists of eliminating the head losses from the energy equation and the head loss equations (Hazen-Williams or Darcy-Weisbach) to give a set of equations in discharge only. It may be applied to loops where the external discharges are known and the flows within the loop are required. Steps in the method of procedure are as follows:

(1) Assume the best distribution of flows $q_i$ that satisfies continuity at the nodes by careful examination of the network in an elementary loop selected such that $\sum q_i = 0$. An elementary loop is a basic loop that forms part of the whole network system.
(2) For each pipe in the elementary loop selected, calculate the head loss $h_{f_i}$ from $q_i$ using the Darcy-Weisbach or the Hazen-Williams and sum the net head loss such that $\sum h_{f_i} = 0$
(3) If $\sum h_{f_i} = 0$, then the solution is correct
(4) If $\sum h_{f_i} \neq 0$, then apply a correction factor $\partial q$ to all $q_i$ in the loop assumed in step (1) and return to step (2)

$$\partial q = - \frac{\sum h_{f_i}}{2\sum \frac{h_{f_i}}{q_i}} \tag{2.19}$$

(5) Proceed to another elementary loop within the network and repeat the correction process of step (2). Continue for all elementary loops in the network.
(6) Repeat steps (2) – (4) as many times as needed until the corrections $\partial q$ are arbitrarily small.

- Nodal Method

This method consists of eliminating the discharges from the continuity equation and the head loss equations (Hazen-Williams or Darcy-Weisbach) to give a set of equations in head losses only. It may be applied to loops or branches where the external heads are known and the heads within the networks are required. Steps in the method of procedure are as follows:

(1) Assume values for the head ($H_j$) at each junction in an elementary loop selected.
(2) Calculate $q_i$ from $H_j$. For each pipe in the elementary loop selected, calculate the flow $q_i$ using the Darcy-Weisbach or the Hazen-Williams and sum the net flow to satisfy the continuity equation such that $\sum q_i = 0$
(3) If $\sum q_i = 0$, then the solution is correct
(4) If $\sum q_i \neq 0$, then apply a correction factor $\partial H$ to $H_j$ and repeat the process from step (2)

$$\partial H = \frac{2\sum q_i}{\sum \frac{q_i}{h_{f_i}}} \tag{2.20}$$

(5) Proceed to another elementary loop and repeat the correction process of step (2). Continue for all elementary loops in the network.

(6) Repeat steps (2) – (4) as many times as needed until the corrections $\partial q$ are arbitrarily small for each elementary loop selected.

Therefore in using the Nodal and Hardy-Cross methods, flow characteristics in complex networks systems can be calculated as required.

There are many computer programs that have been developed for the planning, optimization and modelling of water distribution systems. These programs incorporate either the *Hardy-Cross* or the *Nodal* methods in order to perform the fundamental pipe network analysis computations in order to determine the required flow characteristics in a complex pipe network system.

Some of the programs that are used include *Wadiso (Water Distribution Simulation and Optimisation), Wadessy (Water Decision Support System*), *Epanet, WaterCad, Cybernet,* $H_2$*ONET, SynerGEE Water, AquaCad and KYPIPE 2*. The list is not exhaustive and selection of the program to use depends on specific applications for which the program is used for and the availability of funds to purchase the program.

In this study *Wadiso SA* is used and the program was selected because it was the same program that was used in the original design of the *Nooightgedacht rural water supply project* used as a case study. The computer program and how the *Nodal method* is used by the program to compute  flow characteristics in a water distribution system are presented in Chapter 3.

# 3.0 Methodology

## *3.1 Investigation of rural water supply relating to minimum design standards of reticulation systems and the feasibility of different supply methods*

This chapter discusses the design and methodology employed in order to achieve the objectives of this study. A case study project has been designed using a computer software program titled *Wadiso SA Version 4.0 (GLS Engineering Software, 2003)*. The case study project design is based on data from a water supply project called the *Nooightgedacht rural water supply project*.

The strategy employed in this study in order to achieve the objectives is:

a) The use of *Wadiso SA, version 4.0 (GLS Engineering Software, 2003)* as a design tool to design the case study project and to evaluate minimum standards with respect to their effect on cost.

   The *Wadiso SA* computer program is a computerised hydraulic network model for evaluating the hydraulic adequacy of water distribution systems. It is used for planning, analysis and designing of water distribution network systems consisting of pipes, nodes (pipe junctions and abstraction points), pumps, valves and storage reservoirs. The hydraulic model tracks the flow of water in each pipe, the pressure at each node, and the flow of water into or out of each reservoir.

   *Wadiso SA* relies upon the EPANet or Wadiso network solvers to determine if pipe network systems are in hydraulic balance. The network solvers are hydraulic analysis engines which employ the Nodal method as described in section 2.7.2.2 (e), to carry out the hydraulic analysis to compute the pressure and flow distributions by calculating friction head losses in pipe systems based on the Hazen-Williams or Darcy-Weisbach equations.

   The *Wadiso SA* program allows for steady state analysis, optimisation, extended time simulation and water quality simulation of water distribution systems.

   In this study evaluation of the minimum standards (residual pressure, demand rate and abstraction rate) as defined in section 2.6.1, was done using the steady state analysis tool of the program. The steady state is the condition whereby all specified demands and pressures are met at the same time and at all delivery points.

   In *Wadiso SA,* the steady state analysis tool allows the user to calculate the pressure and flow distribution in pipe networks and from the calculations, systems can be analysed to determine hydraulic adequacy and reasons of bad system performance.

   It was therefore possible to design a water supply system and evaluate the minimum standards with respect to cost using the steady state analysis tool by ensuring that the system is in hydraulic balance and the steady state conditions are met each time a set of minimum standards were specified.

   The effect on cost was evaluated by using different pre-selected pipe network configurations for each set of standards specified during the analysis.

The minimum standards evaluated in this study are defined as follows (*DWAF, 1999*)

- Minimum residual pressure of 10m at the point of delivery to consumers
- Minimum demand rate of 25 ℓ/c/day to be available at the delivery point
- Minimum abstraction rate of 10 ℓ/min at the point of delivery to consumers

The *Wadiso SA's* tools were not fully utilised as pipe size configurations were pre-selected and all the conditions defined for the design of the water supply project could be met using the steady state analysis tool. The optimisation, extended time simulation and water quality simulation tools were therefore not used.

A description of *Wadiso SA* model components and how it is used in the designing and balancing of water distribution systems is described in Appendix B (*GLS Engineering Software, 2003*). The methodology for the evaluation of the minimum standards using *Wadiso SA* is discussed in Section 3.3.

b) *Microsoft Excel* discounting cash flow techniques which are economic analysis tools, were used to compare different rural water supply systems with respect to capital, operation and maintenance costs.

The economic tools that were used are the Net Present Value technique and the sensitivity analysis. The Net Present Value technique allows to convert the sum of money required for the implementation and support of the systems in terms of capital and operation and maintenance costs during the project's economic life to a net present day cost.

The sensitivity analysis is used to obtain an indication of the influence of economic factors on the net present cost of the different water supply systems.

The economic analysis was done based on the *Nooightgedacht water supply project*. The rural water systems that have been analysed are:

- Reticulated pipe water system
- Borehole system
- Hauling system

The consideration was that each of the rural water systems would be used in the project as a method of water supply and a comparison of each systems life cycle cost would be made. The methodology for the economic analysis is discussed in Section 3.4.

Thus, a case study on a rural water supply project is used on which the strategies of this study are employed. The case study is based on data from part of the existing Nooightgedacht *rural water supply project* which was considered to be representative of the whole scheme.

### 3.2 Description of project (Nooightgedacht water supply project) used in the analysis

The *Nooightgedacht water supply project* is a rural water supply scheme which benefits 33 farms situated to the north of the R311 road between *Hopefield* and *Moorreesburg* in the west coast region as shown in Appendix C. The project starts 3 km west of *Moorreesburg*, continuing for a further 13 km along this road, and then stretches northward towards the bulk supply line from *Withoogte* for another 15 km to cover an area of 195 km$^2$.

The project will provide adequate and potable water from an existing 1000 mm diameter bulk supply line through a network of pipelines to the households on the farms. The bulk supply line runs between the *Withoogte Water Treatment Works*, where the water from the source i.e. the *Berg* river is treated, and the town of *Hopefield*.

The bulk supply pipeline is adequate to handle the design capacity of the *Withoogte Water Treatment Works* which has a capacity of 72 Mℓ/day. The present operating capacity of the *Withoogte Water Treatment Works* is about 50 Mℓ/day. Water is drawn from a connection point on the existing bulk supply pipeline and is fed into the *Nooightgedacht water supply network.* The connection point to the *Nooightgedacht* water supply network is at a higher elevation than the rest of the *Nooightgedacht* water supply network and is able to supply the network through gravity flow.

A network of pipelines is used to distribute the water at different nodes which are connected to on-site storage tanks, with standpipes, at all farming settlements within the project area.

The full design of the project serves a population of 514 people resulting into a total water demand of 12.85 kℓ/day, based on basic water needs of 25 ℓ/c/day. This required water demand represents only a very small fraction of the surplus bulk pipeline capacity of about 22 Mℓ/day, and therefore, will be able to meet the demand of *Nooightgedacht water supply project*. A population growth of 2.45% per annum is predicted and HIV/AIDS has no influence on the current growth rate. However the growth in the population will not have any impact on the demand capacity required from the bulk supply pipeline

The present water situation in these communities is that most farms receive water from boreholes as the main water source. However, the water is not suitable for long term consumption because of deteriorating water quality due to the very high salt and chlorine levels. During the dry periods the boreholes also frequently dry up.

The farm settlements on-site storage tanks are filled from the boreholes when the water quality permits. More often, in the dry periods the tanks are filled by a tanker, which carts the water from the town of *Moorreesburg* which is between 3 km and 18 km away.

The water situation in the *Nooightgedacht* communities therefore, called for a sustainable solution which can provide their basic water need.

As mentioned, this study focused only on a part of the existing design of the *Nooightgedacht water supply project* which has been considered to be representative of the whole scheme, as a case study.

In this case study the following assumptions have been made:

I. Source

- The source of water for the *Nooightgedacht* water *supply project* area is a bulk supply pipeline from the *Withoogte Water Treatment Works*. The *Withoogte* source has adequate water available for 98% of the time as required by DWAF (*DWAF, 2002*). The part of the water project used in this case study has 17 farm settlements and a population of 236 people.

- The source of the *Nooightgedacht water supply project* has been considered to be located at the connection point to the bulk supply line. Since the water source has more than enough capacity to meet the total demand of the water users it has been modelled in *Wadiso SA* as a reservoir that will maintain at a fixed water level.

- A constant water level is maintained at the source at an elevation of 160 m with an elevation difference of 60 m between the source and the highest elevation node in the system. The pipe network is below this elevation and the reservoir is able to discharge by gravity.

- The source has been designed for a 24 hour continuous constant outflow since the system is a gravity flow system *(DWAF, 1999).*

II. Storage

- At the delivery nodes on-site storage tanks will be used to provide enough capacity to meet the demand of the users. Storage capacity of the tanks is for 48 hours storage to ensure an assurance of supply (*DWAF, 1999*) and will be designed to meet the peak daily demand and the instantaneous demand requirements.

  The on-site storage tanks will be able to begin filling once the water level begins to drop in the tank and will continue to fill during the day when there is use and during the night when there is little or no use.

  A peak daily factor of 3 has been used to account for peak demand at peak periods as required by *DWAF (1999).*

- The present population (236 people) has been used in the design. It has been assumed that the behaviour of the effect of varying the standards with respect to cost will be same irrespective of whether population growth is taken into account or not.

- Water demand is based on an average daily demand per capita for the entire network which gives the total amount of storage required per day.

  For example, at an average daily demand rate of 25 ℓ/c/day a total storage capacity of 5.9m$^3$/day would be required to supply a population of 236 people.

- The demand rate is distributed among the nodes in proportions based on the populations at each delivery node.

### III. Distribution

- For each evaluation, the pipe network has been designed for the present population.
- The evaluation is based on average daily demand rate, for the demand rate that is desired for each analysis

  The daily average demand has been used so that the effect of increasing the demand rate can be directly observed with respect to cost as the pipe configuration changes. This will assist to determine if increasing the demand rate can create a constraint in cost if the minimum standards are to be adjusted

- The pipeline system will provide the total required capacity required over a one day period.
- The pipeline route runs parallel to the existing roadways.

### IV. Connections

The project uses communal standpipes at the storage tanks at a maximum cartage of 200 m for every household. The criteria for the allocation of the communal standpipes is based on the requirement of one tap required per 25 to 50 dwelling or 150 people to be served per tap *CSIR* (2000). Therefore considering the populations at each centre, a single tap is provided.

Table 3.1 Pipe and node data used in the project *(Nooightgedacht water supply project)*

| Pipe Ref# | Pipe Length (m) | Diameter* (mm) | Node Ref# | Population | Elevation ( m ) | Description | Demand* (ℓ/s) | Minimum Residual Pressure head* (m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 210 | variable | 1 | | 160 | Source | variable | variable |
| 2 | 85 | variable | 2 | | 60 | | variable | variable |
| 5 | 175 | variable | 3 | | 60 | | variable | variable |
| 6 | 1350 | variable | 6 | | 60 | | variable | variable |
| 10 | 1085 | variable | 10 | | 60 | | variable | variable |
| 11 | 2790 | variable | 11 | 7 | 70 | Bo-Klipgat | variable | variable |
| 14 | 195 | variable | 14 | | 100 | | variable | variable |
| 15 | 1955 | variable | 15 | 28 | 95 | Vlakvlei | variable | variable |
| 18 | 1140 | variable | 18 | | 95 | | variable | variable |
| 22 | 640 | variable | 22 | | 100 | | variable | variable |
| 23 | 380 | variable | 23 | | 97 | | variable | variable |
| 24 | 805 | variable | 24 | 14 | 100 | Bakensvlei | variable | variable |
| 26 | 565 | variable | 26 | | 87 | | variable | variable |
| 27 | 340 | variable | 27 | 18 | 95 | Houmoed | variable | variable |
| 28 | 455 | variable | 28 | | 90 | | variable | variable |
| 29 | 1695 | variable | 29 | 4 | 85 | Louwsbron | variable | variable |
| 32 | 425 | variable | 32 | | 60 | | variable | variable |
| 33 | 1065 | variable | 33 | | 60 | | variable | variable |
| 34 | 1560 | variable | 34 | 4 | 90 | Uitsig | variable | variable |
| 36 | 2590 | variable | 36 | 4 | 65 | Nelskop | variable | variable |
| 40 | 2950 | variable | 40 | | 95 | | variable | variable |
| 42 | 770 | variable | 42 | 14 | 83 | Langkuil | variable | variable |
| 43 | 765 | variable | 43 | 11 | 90 | Cradock | variable | variable |
| 44 | 2270 | variable | 45 | 11 | 103 | Klipheuwel | variable | variable |
| 45 | 205 | variable | 46 | | 80 | | variable | variable |
| 47 | 1900 | variable | 49 | 25 | 100 | Driehoopsvlei | variable | variable |
| 50 | 1175 | variable | 50 | | 102 | | variable | variable |
| 51 | 340 | variable | 51 | 11 | 105 | Nooitgedacht | variable | variable |
| 52 | 2815 | variable | 52 | | 120 | | variable | variable |
| 53 | 305 | variable | 53 | 25 | 120 | Donkerskloof | variable | variable |
| 54 | 750 | variable | 54 | | 135 | | variable | variable |
| 55 | 855 | variable | 57 | 7 | 115 | Patrysvlei | variable | variable |
| 58 | 2250 | variable | 59 | | 110 | | variable | variable |
| 60 | 865 | variable | 60 | 4 | 135 | Degunst | variable | variable |
| 61 | 1030 | variable | 63 | 35 | 120 | Anyskop | variable | variable |
| 64 | 1935 | variable | 67 | 14 | 103 | Middelburg | variable | variable |
| 68 | 645 | variable | 68 | | 110 | | variable | variable |
| 69 | 440 | variable | 69 | | 100 | | variable | variable |
| 70 | 625 | variable | 70 | | 105 | | variable | variable |
| 71 | 245 | variable | 71 | | 83 | | variable | variable |
| **Total** | 42 640 | | | 236 | | | | |

***Table 3.1: Pipe and node data used for the Nooightgedacht water supply project***

* Diameter, Demand and Minimum residual pressure are indicated as variables because different values of each parameter were selected in the evaluation of the minimum standads.

\# Pipe and Node reference numbers were used based on the reference numbers on the part of the project used in this study.

The location of the project area is shown in Appendix C. The schematic layout of the water supply network used in this evaluation not drawn to scale is shown in Figure 3.1.

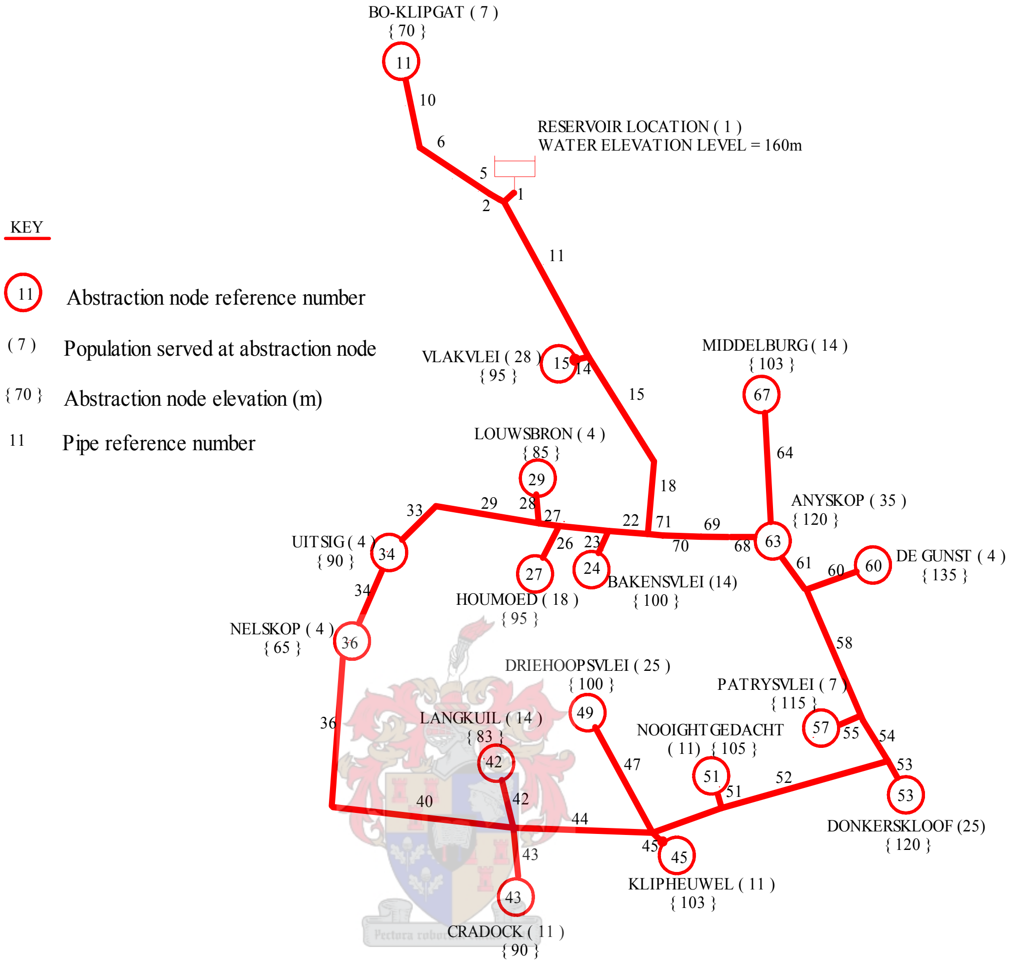

*Figure 3.1: Schematic layout of Nooightgedacht rural water supply project*

Based on the program procedure for designing water distribution systems as described in Appendix B, the design of *Nooightgedacht* water supply system involved the input of pipe characteristics (the topology, i.e. how pipes and nodes are linked together) as well as pipe sizes and water demand characteristics at the nodes. The input data required to define the pipe characteristics was:

- Size of each pipe used in the network
- Number of each pipe assigned in the network system
- Number of nodes to which each pipe is connected on each side

The input data required to define the node characteristics was:

- Type of node
- Number assigned to each node
- Elevation of each node
- Coordinates of each node

The basic input data spreadsheets used for designing the case study project defining the pipe and node characteristics for the pipe layout as shown in Figure 3.1 and characteristics of the pipes and nodes shown in Table 3.1 are provided in Appendix D.

However, in addition to the data entered in Appendix D used to define the scheme layout, data on pipe diameter and demand rate were entered separately for different scenarios used in the study, since these were variables (as has been indicated in Table 3.1) and had to be changed for each analysis carried out. The procedure on how data on pipe diameter and demand rate were entered as variables is explained under Section 3.3.

Once the design of *Nooightgedacht* system was done to define the project layout using the software, it was used as a case study to evaluate the standards.

### *3.3 Methodology for the evaluation of minimum standards of a pipe water supply system using Wadiso SA Version 4.0*

The reason for conducting this investigation is to evaluate the feasibility of the minimum standards established as a criteria to achieve the minimum level of service as set by the South African Department of Water Affairs and Forestry (DWAF) and to investigate if the minimum standards can be increased to a certain value without having significant effect on the cost of provision of a water supply service in the rural areas particularly where a gravity flow system is used.

As previously mentioned the minimum standards being evaluated in this study are defined as follows *(DWAF, 1999)*:

- Minimum Residual Pressure of 10m to be available at the delivery point
- Minimum Demand rate of 25 ℓ/c/day to be provided at the delivery point
- Minimum abstraction rate of 10 ℓ/min to be available at the delivery point

The theory that was used in this investigation was that the pressure in a pipe network changes if the diameter of the pipes in the network is changed while the head available at the reservoir is constant.

If a large pipe diameter configuration is used in a pipe network system, the node that will have the minimum residual pressure available in the system will have higher residual pressure available than if a pipe network system with a small pipe diameter configuration is used.

Another theory is that, at any pressure value that can be assigned and set as a minimum residual pressure that has to be available at any abstraction node in a water supply system, there is a maximum output or demand of water that can be abstracted from the nodes before the residual pressure falls below the set value at any of the abstraction nodes.

If the output exceeds the maximum value the residual pressure at least at one of the abstraction nodes will drop below the minimum pressure that is set.

The variations in the minimum residual pressure, and the maximum output available in a system due to the use of using different pipe configurations, result because of pipe friction head losses, change in pipe cross-sectional area, and change in the elevations of the nodes and the velocities in the pipes that are encountered for each particular case.

Small diameter pipes will have a high head loss as opposed to large diameter pipes due to increased head losses in small diameter pipes for a given discharge.

It follows that the minimum standards can be evaluated with respect to cost by fixing the minimum standards at different values and observing the hydraulic adequacy in a steady state condition as different pipe network configurations are used.

Thus, to determine the pressure and the demand and flow variations with respect to cost, *Wadiso SA* steady state analysis tool was employed. *Wadiso SA* uses the Epanet or Wadiso network solvers which are hydraulic analysis engines to determine if a system is in hydraulic balance by calculating head losses in a system and determining pressure, demand and flow distributions using the *Nodal method* technique.

Selection of the network solvers depends on the components of the system. Epanet analysis engine is selected when pressure sustaining valves, pressure breaker valves, throttle control valves and general purpose valves as well as pumps with multi-point curves are used in a system since the Wadiso engine does not incorporate such components, otherwise selection of the solvers is optional.

As previously mentioned, prior to simulation and balancing of the system, parameters such as pipe sizes and other pipe characteristics, consumer demands, network layout configurations, pump characteristics  and node elevations must be known and are required as input data.

When the data specifying the parameters and minimum standards required is entered, the system is balanced

When the system is balanced, output from the simulation include: pipe flows, pipe headlosses, node residual pressure heads, abstraction rate at each node and velocities from pipes.

For the designed pipe system layout of *Nooightgedacht* water supply system, a set of different pre-selected pipe configurations was tested at different values set for the minimum standards. The pipe configurations were entered based on the pipe links defined in the design as shown in Table 3.1.

For each of the pre-selected pipe size configuration used, the standards were varied one at a time, holding the other standards constant and then investigating if the system is balanced at the specified minimum standards. The corresponding cost involved in meeting this standard was also investigated.

The cost used in the evaluation of the standards is based on the pipe sizes used in the pipe network. The candidate pipe sizes that were used were uPVC pipes. The pipes are expressed in terms of diameter size and their corresponding costs as shown in Table 3.2.

| Pipe Diameter (mm) | Cost ( R/m ) |
|---|---|
| 25 | 8.78 |
| 50 | 17.73 |
| 63 | 27.48 |
| 75 | 38.14 |
| 100 | 64.93 |
| 150 | 139.43 |

***Table 3.2: Pipe sizes and their related costs***

The unit costs represent only the capital pipe cost for each pipe size and do not include excavation and installation costs, therefore where costs are indicated for pipes it must be realised that it is relative cost. To determine the total relative cost of pipes for the entire network of pipes in the system, involve multiplying the total length over which a particular pipe size is used by its cost per metre.

The pipes in Table 3.2 were used in different combinations to come up with candidate pipe configurations that were pre-selected and used in the analysis.

The pipe sizes that were used in combination in the design were used such that the main supply line from the reservoir source to the network connection (i.e. pipe numbers 1,11,14,15 and 18) were fitted with a larger diameter size and the rest of the pipes in the distribution network to the abstraction nodes were fitted with a smaller diameter size.

The lengths of the main supply line and those of the distribution line are summarised as shown in Table 3.3:

| Pipeline | Number of pipes | Total length ( m ) |
|---|---|---|
| Main supply line | 5 | 6 290 |
| Distribution line | 35 | 36 350 |
| Total | 40 | 42 640 |

***Table 3 .3**: **Summary of pipeline lengths***

The pipe configurations used as a system of pipes to make up the whole network system together with their related costs are shown in table 3.4:

The author notes that there are many pipe network configurations that could be used for the project in order to evaluate the standards, however this study has limited the combinations as shown in Table 3.4 since the behaviour of results to be obtained is the same.

| *Pipe network configuration (mm) | Pipe size ( mm ) | | Total Cost ( R ) |
|---|---|---|---|
| | Main supply Line | Distribution line | |
| 25 | 25 | 25 | 374 379 |
| 50 x 25 | 50 | 25 | 430 675 |
| 63 x 25 | 63 | 25 | 492 002 |
| 50 | 50 | 50 | 756 007 |
| 63 x 50 | 63 | 50 | 817 335 |
| 75 x 50 | 75 | 50 | 884 386 |
| 63 | 63 | 63 | 1 171 747 |
| 75 x 63 | 75 | 63 | 1 238 799 |
| 75 | 75 | 75 | 1 626 290 |
| 100 | 100 | 100 | 2 768 615 |
| 150 | 150 | 150 | 5 945 295 |

***Table 3.4: Pipeline size configuration used in the network and their related costs***

The pipe configuration 50 x 25 refers to a pipe network with the main supply line being 50 mm and the distribution line 25 mm in diameter.

The variables used in the analysis are summarised below:

- Pipe network configurations with different diameter sizes (Table 3.4)

- Range of minimum residual head (pressure) at the critical node

The minimum residual head is the minimum head that should be available at any node of delivery in the system. The range of head values pre-selected is 5, 7, 10 and 15 m and was selected arbitrarily but to include the current DWAF required minimum standard for residual pressure (10 m).

- Range of water demand rates.

A range of different demand rates was also arbitrarily pre-selected but to include the current minimum DWAF standard (25 ℓ/c/day) as well as the desired water demand target (50 ℓ/c/day). The range of values pre-selected expressed in litres per capita per day is 20, 25, 30, 35, 40, 45 and 50.

It should be mentioned that in order to evaluate the standards using the *Wadiso SA* program using the steady state analysis module, the program allows the user to enter the demand rate as an output required from the system at each node in order to meet the total daily water demand of the population to be served by the node.

Therefore it should be noted that throughout this study where the demand rate was entered, it was first converted to an output required at each node, based on the population at the node.

The following equation was used to convert the demand rate in litres per capita per day (ℓ/c/day) to an output in litres per second (ℓ/s).

$$Output\ (l\ /\ s) = \frac{Demand\ rate\ (l\ /\ c\ /\ day) \times Population\ at\ a\ node}{86400\ \mathrm{(sec)}} \qquad (3.1)$$

The range of standards was selected in order to obtain a general indication of the effect of the variation on standards with increasing cost. However selected values on the standards will be used to describe the findings of the study in order to describe how the objectives have been achieved.

After designing the water supply system the minimum standards being analysed were evaluated one at a time to observe the effect on each standard with varying costs.

### 3.3.1 Evaluating pressure with respect to cost

For the designed *Nooightgedacht* water supply system, in order to evaluate the effect on residual pressure with cost, the procedure that was followed involved fixing the demand rate at different pre-selected values. For each pre-selected demand rate, different pipe size network configurations as shown in Table 3.4 were analysed and upon balancing the system, an observation of the residual pressure that is available at the critical node in the system was made.

The critical node in the system is the abstraction node which has the lowest residual pressure available upon balancing the system.

The observed minimum residual pressure is compared with the cost of each pipe configuration used. The pipe cost increases as the size of the pipe configuration used increases.

The pre-selected demand rates were selected one at a time as the desired demand rate. For each selected demand rate the candidate pipe configurations were analysed to observe the minimum residual pressure available at the critical node for the chosen demand rate. The cost of each pipe configuration used at each analysis was calculated. Thus, the demand rate was fixed and the residual pressure was allowed to vary by changing the pipe configuration.

The interpretation of this procedure is that an observation is made on the effect that various pipe costs, as a result of using different pipe size configurations, have on residual pressure. The effect on pressure is interpreted by the amount of increase or decrease in the minimum residual pressure that is available at the critical node as the pipe cost changes at each demand rate assigned.

The procedure followed in order to achieve the evaluation is explained below and illustrated in Figure 3.2:

1. Set the demand rate at pre-selected values.

   The pre-selected values for the demand rate are 20, 25, 30, 35, 40, 45, 50 ℓ/c/day. These values were arbitrarily selected.

2. Select and log one of the pre-selected demand rates in the “Node Table” as an output in litres per second. The “Node table” is used to specify the flow conditions required at each node. At each node the output required for each demand rate was logged one at a time.

3. Select and log the candidate pipe network configurations in the “Pipe/Check Valve Table” for each pre-selected demand rate. The Pipe/Check Valve table is a table which is used to specify the system data (properties) associated with each pipe.

   The candidate pipe configurations were logged one at a time at each demand rate selected in step (2).

4. With the demand rate and pipe network selected, calculate the residual pressure at the nodes by balancing the system using *Wadiso SA* network solver.

5. View results and record the minimum residual pressure available at the critical abstraction node.

6. Calculate the cost of the pipe network configuration which results in the minimum residual pressure recorded.

7. Repeat the procedure from (3) to (6) for the next candidate pipe configuration until all the configurations have been analysed at the demand rate selected in (2).

8. Log the next demand rate and repeat the procedure from (2) to (7).

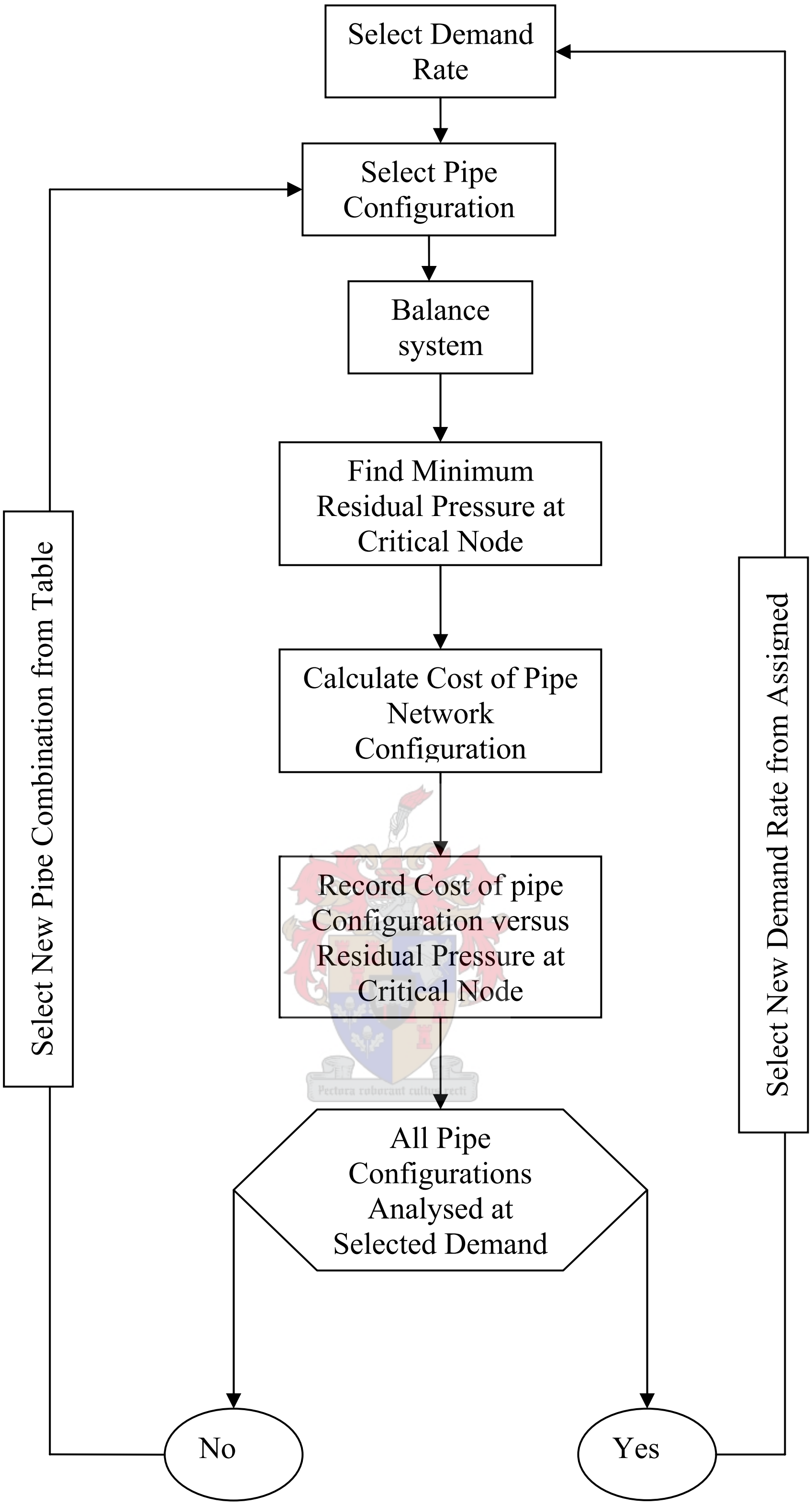

***Figure 3.2: Flow chart for the procedure of evaluation of residual pressure***

Appendix E shows the input data spreadsheets of the pipe characteristics of the different pipe size configurations used for each demand rate used in the analysis, to determine the lowest residual pressure available to the system when each pipe size is used. Appendix F shows the input data for node characteristics at the nodes corresponding to the demand rates used in the evaluation.

### 3.3.2 Evaluating demand with respect to cost

The evaluation of the effect of demand on cost involved setting pressure at different pre-selected values considered as values that can be used as minimum pressure and, using different pipe size configurations from Table 3.4 with each of the pre-selected values of pressure, to analyse the maximum demand that can be abstracted from the system for each arrangement. The total pipe cost for each arrangement was recorded.

The pre-selected pressure values expressed in metres, were set arbitrarily at 5, 7, 10 and 15 m. The procedure followed was that the respective pre-selected pressures would be assigned as a minimum pressure to be available in the system at the critical node.

The critical node in the system is any abstraction node which will have the lowest residual pressure available. At the critical node, the residual pressure must be equal or just above the assigned minimum pressure.

If the residual pressure is below the assigned minimum residual pressure, the system is considered to have failed to meet the standards.

The minimum pressure standards that were assigned in the investigation were used in such a way that, for each pipe size combination used and minimum pressure assigned, the residual pressure at the critical node should not fall below, but should be equal or just above, the minimum pressure assigned when the maximum demand rate is logged. Thus, the residual pressure was fixed and the demand rate was allowed to vary for each of the pipe configurations used.

The maximum demand was investigated by imposing different target demand rates as an output in the “Node table” as described in Appendix B. This was a trial-and-error procedure until the maximum demand rate which causes the residual pressure to be equal or just above the assigned pressure was reached.

The effect of the variation of demand rate on cost is translated by comparing the difference in cost and the gain in demand that can be achieved moving from one pipe cost to the next as the pipe size configuration increases.

The steps followed in order to achieve the evaluation are explained below and illustrated in Figure 3.3:

1. Set minimum pressure at different pre-selected values.

   The pre-selected values were 5, 7, 10 and 15 m, selected arbitrarily.

2. Assign one-by-one, the pre-selected minimum pressures for analysis.

3. Select one of the candidate pipe network configurations from Table 3.4 and log the pipe data in the “Link Table”.

4. With the minimum pressure and pipe configuration selected in steps (2) and (3) respectively, assign a demand rate perceived to be the most likely maximum demand rate that can be abstracted from the system in the “Node Table”.

5. With the parameters as defined in step (4), balance the system.

6. View results and investigate the residual pressure at the critical node.

   The critical node is the abstraction node that will have the lowest residual pressure. The maximum demand at the critical node is the demand that causes the residual pressure to be equal or just above the assigned minimum pressure.

7. If the minimum residual pressure at the critical node is equal to the assigned minimum pressure, record the corresponding maximum demand rate.

   If the minimum pressure is above or below the assigned minimum pressure, try another demand rate by repeating steps (4) to (6) until the maximum demand rate that causes the residual pressure at the critical node to be equal or just above the assigned minimum pressure is reached. Record the corresponding maximum demand rate.

8. Calculate the cost of the pipe network configuration used.

9. Select the next pipe network configuration from Table 3.4 and repeat steps (3) to (8) until all the candidate pipe configurations have been analysed for the specific minimum pressure assigned in step (2).

10. Assign the next minimum pressure and repeat steps (2) to (9) until all the assigned minimum pressures have been analysed.

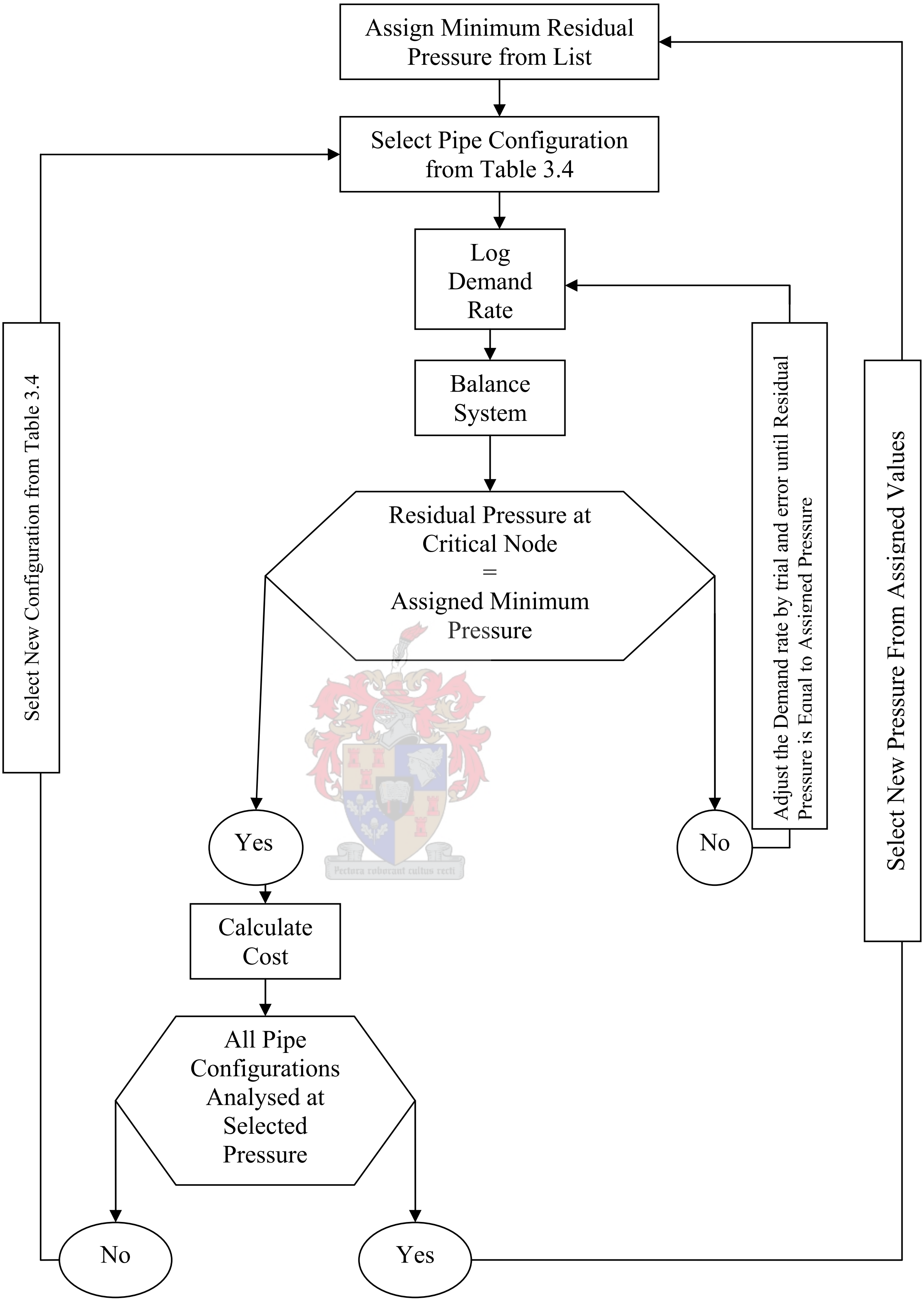

***Figure 3.3: Flow chart for the procedure of evaluation of demand rate***

Appendix E shows the input data spreadsheets for the candidate pipe size configurations for the variation of demand for the different pressure standards that were used in the investigation. The input data spreadsheets for the maximum demand rates used in the analysis at different pressure standards and pipe combinations is shown in appendix F.

### 3.3.3 Evaluating abstraction rate with respect to cost

The evaluation of the effect of abstraction rate on cost involved fixing residual pressure at different pre-selected values and using different pipe size configurations from Table 3.4 with each of the pre-selected values of pressure to analyse the maximum abstraction rate that can be abstracted from the system for each arrangement. The total pipe cost for each arrangement was recorded.

The pre-selected values of pressure expressed in metres were set at 5, 7, 10 and 15 m.

In *Wadiso SA* the abstraction rate at a node is governed by the demand rate which is expressed as an output required to satisfy the demand of the users based on the population to be served at a particular node. For the demand rate entered as an output, the abstraction rate is viewed in the "result table" as an abstraction rate that will satisfy the specified output.

Therefore in evaluating the abstraction rate, it is the demand rate that has been varied and the resulting abstraction rate that can satisfy the desired demand rate is compared with the pipe cost for each fixed pressure.

The procedure followed was that the respective pre-selected pressures were assigned one by one as minimum residual pressure to be available at the critical node in the system. At each of the assigned pressure the maximum demand rate that can be extracted from the system was investigated and the corresponding maximum abstraction rate at the critical node was observed. This procedure was carried out for all the candidate pipe configurations.

The critical node in the system is any abstraction node which will have the lowest residual pressure available. At the critical node, the residual pressure must be equal or just above the assigned minimum pressure.

If the residual pressure is below the assigned minimum residual pressure, the system is considered to have failed to meet the standards.

Therefore the minimum pressure standards that were assigned in the investigation were used such that for each pipe size combination used and minimum pressure assigned, the residual pressure at the critical node should not fall below but should be equal or just above the minimum pressure assigned when the maximum demand rate is logged.

The comparison of the effect of abstraction rate with cost is made by comparing the gain or loss in the maximum abstraction rate and the corresponding difference in cost that has to be incurred as the pipe cost increases.

The input data is the same as that used in Section 3.3.2, "evaluation of demand rate with respect to cost".

The steps followed in order to achieve the evaluation of abstraction rate are explained below and illustrated in Figure 3.4.

1. Set minimum pressure at different pre-selected values.

   The pre-selected values were 5, 7, 10 and 15 m and were selected arbitrarily.

2. Assign one by one the pre-selected minimum pressures for analysis.

3. Select one of the candidate pipe network configurations from Table 3.4 and log in the “Pipe/Check valve table”.

4. With the minimum pressure and pipe configuration selected in steps (2) and (3) respectively, assign a demand rate perceived to be the most likely maximum demand rate that can be abstracted from the system in the “Node Table”.

5. With the parameters as defined in step (4), balance the system.

6. View results and investigate the maximum demand at the critical node.

   The critical node is the abstraction node that will have the lowest residual pressure. The maximum demand at the critical node is the demand that causes the residual pressure to be equal or just above the assigned minimum pressure.

7. If the minimum residual pressure at the critical node is equal to the assigned minimum pressure, record the corresponding maximum demand rate.

   If the minimum pressure is above or below the assigned minimum pressure, try another demand rate by repeating steps (4) to (6) until the maximum demand rate that causes the residual pressure at the critical node to be equal or just above the assigned minimum pressure is reached.

8. Find and record the corresponding maximum abstraction rate at the maximum demand rate.

9. Calculate the cost of the pipe network configuration used.

10. Select the next pipe network configuration from table 3.4 and repeat steps (3) to (9) until all the candidate pipe configurations have been analysed for the specific minimum pressure assigned in step (2).

11. Assign the next minimum pressure and repeat steps (2) to (10) until all the assigned minimum pressures have been analysed.

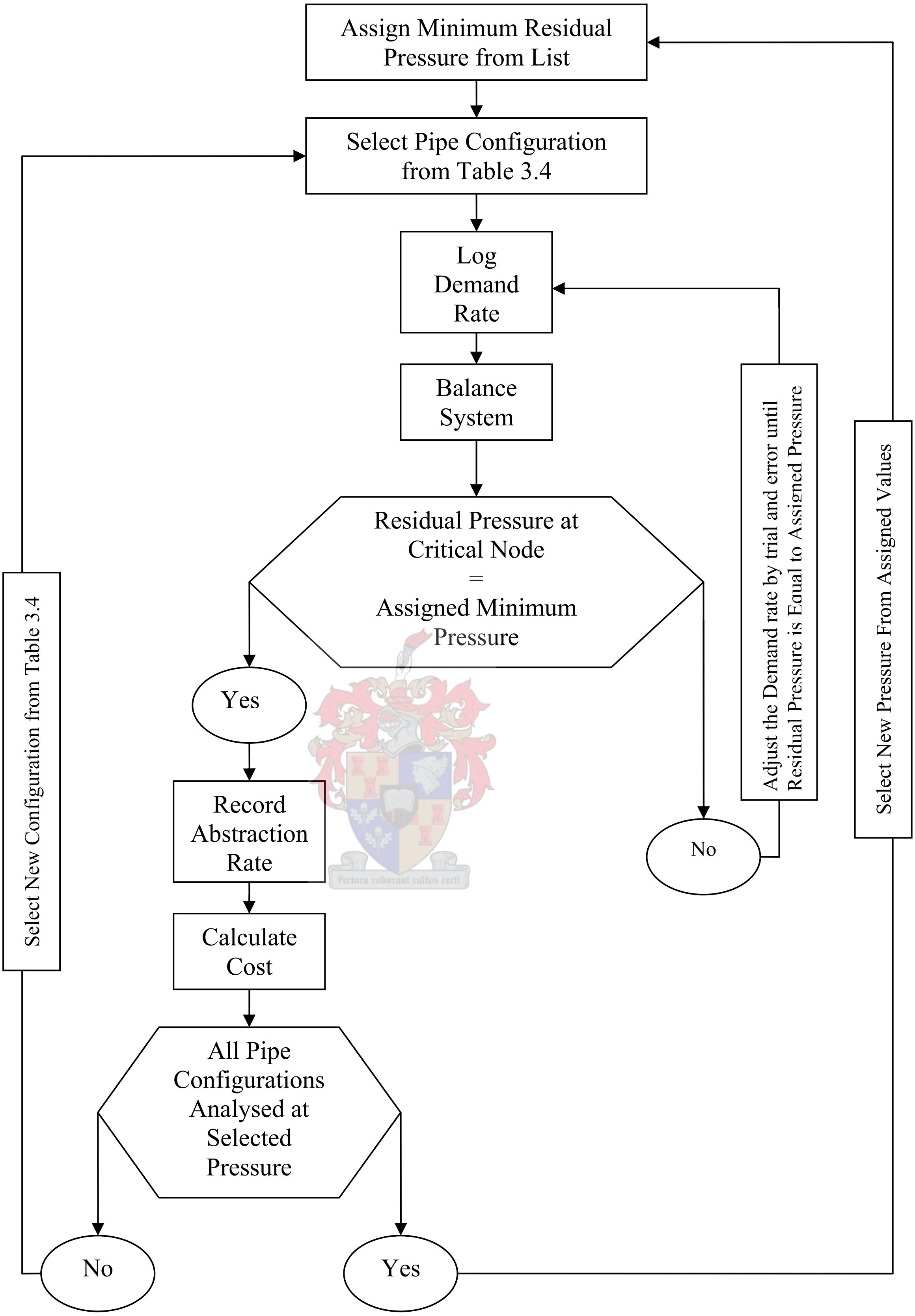

*Figure 3.4: Flow chart of the procedure for the evaluation of abstraction rate*

The input parameter in the “Pipe/Check valve table” of the program was the candidate pipe sizes as shown in Appendix E and the input for maximum demand rate is shown in Appendix F.

### 3.4 Methodology for the economic analysis of different methods of rural water supply

Economic analysis was performed using two methodologies. The methodologies were used to carry out a cost comparison of rural water supply systems and a sensitivity analysis in order to find out the economic factors that most affect the cost of the water systems.

Costs used in the analysis were calculated inclusive of labour, materials, plant and professional expenses, as close to predicted costs as possible.

The costs rely on guidelines from *Cost Benchmark Guidelines (DWAF, 2003b)*, capital costs incurred in constructing *Nooightgedacht pipe water supply project*, Internet (*Automobile Association of South Africa: May,* 2005), personal communications and the experience of professionals in the field of rural water supply.

#### 3.4.1 Methodology of cost comparison of different rural water supply systems

As a secondary objective, it was considered necessary to investigate which water supply system can be implemented in the rural areas in the most cost effective manner in terms of capital and operation and maintenance costs when minimum standards are adhered to.

The minimum standards that were used for the systems are the current DWAF delivery standards (*DWAF, 1999*):

- The minimum water demand rate designed for all the schemes is 25 ℓ/c/day.
- The maximum distance of cartage of water within 200m of a household.
- The minimum residual head designed for the conventional piped water supply system is 10m.

The methodology that was employed in order to achieve this investigation is the use of economic tools that enable different projects to be compared in terms of investment over their economic life. The *Nooightgedacht* water supply scheme was used as a case study in order to carry out the analysis for each system.

In rural water supply, different systems are used as discussed in Chapter 2. The systems investigated in this study are:

- Conventional piped water supply system using gravity feed
- Supply of water using wells and boreholes
- Hauling

The analysis is based on a life cycle costing technique, comparing the methods by looking at the costs to be incurred if the systems were to be used in the *Nooightgedacht* water supply project.

The capital cost is based on the total construction cost of each system required for the project.

The capital cost of the pipeline in this case is the total construction cost of laying the pipes including labour and excavation that was calculated for the *Nooightgedacht* piped water supply project.

In analysing these systems, capital budgeting decision rules, or discounting cash flow techniques are used to assist in determining which system is an economical system to employ. Capital budgeting involves comparing the amount of cash spent today on an investment with the cash flows expected from it, or to be spent on it, in the future.

Capital budgeting decision rules are used to rank projects and to decide whether they should be accepted or rejected when investment decisions are being made.

However, future cash flows are spread over time and cannot be compared directly because money received earlier is worth more than money received later. Time value of money is an important consideration when using these economic tools and therefore discounting techniques are used to overcome this. Discounting is the mechanism used to convert future cash flows into the present equivalent value or discounted value.

The methodology that was employed in this study to carry out the cost comparison regarding different systems of rural water supply is:

1) Identifying the capital costs to be employed for each project

   In identifying the capital costs for each alternative, the cost that is used in this analysis is the total sum of money required to put the system into operation at the stage when it is commissioned.

2) Evaluation and estimation of each project's relevant cash flow stream and appropriate interest rate on capital.

   The cash flow stream was determined on an annual basis. This is the sum of money required annually for the maintenance and operation of each system's economic life. It was assumed that the cash flow stream will increase at the rate of 7% annually, which is equivalent to the inflation rate.

   It is also assumed that the finances used to fund the projects will be borrowed funds and that the interest rate on capital redemption expected from the loan is at 10%. This is the rate at which the future cash flow must be discounted in order to find its net present value.

   The basis of estimating the capital budgets and relevant cash flows for each of the systems is described below:

   - **Conventional Piped Water Supply System (Gravity System)**

   The budget and cash flow forecasts are based on the cost incurred in the construction of *Nooightgedacht pipe water supply project* and on the information provided in the *Cost Benchmarks Guide for Water Services Development Projects* and its *Cost Model* prepared by the Department of Water Affairs and Forestry *(DWAF, 2003b)*.

Therefore based on the construction cost and the guidelines provided in the *Cost Benchmarks Guide* the following assumptions have been made in order to determine the cash flow:

- Pipe and reservoir operation and maintenance costs are estimated at 2% of the capital costs of each structure during the first year and in the succeeding years they will increase at an inflation rate of 7% *(DWAF, 2003b)*.
- Total capital costs include the total cost of the pipeline and reservoir incurred in the construction of Nooightgedacht project. This includes professional fees, labour and excavation costs. Total capital cost is R 1 534 299.
- The economic life of a conventional piped water supply system is assumed to be 10 years *(DWAF, 2003b)*.

  This economic life used was adopted based on the DWAF guidelines used in the *Cost Benchmarks Model* as the economic design horizon. However, the author takes note that practically the economic life of a conventional piped water supply system can be more than 10 years.

- **Hauling**

For a hauling project, a truck has to be purchased to supply water to the consumers. The truck has to make round trips to supply the consumers by moving around the area which the designed project covers.

The budget and cash flow forecasts are based on the information provided in the *Automobile Association of South Africa Rates for Vehicle Operating Cost Tables*, prepared by the *Automobile Association of South Africa* (May, 2005) and the interviews the researcher carried out with contractors to find the purchasing cost of a hauling truck and the related costs of upgrading the trucks.

The *Automobile Association Vehicle Operating Cost Tables* have been devised to provide users with a fair and equitable rate against which to asses vehicle performance or alternatively to enable the user to determine or exercise a fair claim for vehicle usage.

Based on the *Vehicle Operating Cost Rate Tables*, the following assumptions have been made for the hauling alternative:

- The truck's economic life was assumed to be 5 years. Therefore, in order to compare with the economic life of the other systems at 10 years, the replacement method was used, whereby the truck would have to be replaced after 5 years.
- Two trucks are required, one operational and one on standby in order to ensure an assurance of supply. After 5 years the operational truck will be replaced with a new one and it is assumed the previous standby truck will be in usable condition and will become the operational truck. The new truck will be on standby.
- After 5 years the cost of the truck will also have increased at 7% per annum.
- It was assumed that the cost of employing a truck driver is R60 000 per annum and will increase by 7% per annum.

- It was assumed that the truck will run on diesel, and the cost of diesel is estimated at R5.53 per litre as of August, 2005 and will also increase by 7% per annum

Capital costs were determined by looking at the cost of purchasing a truck for hauling.

The capacity of the truck is 6000 ℓ. For the designed population of 236 people and fixing the demand rate at 25 ℓ/c/day, 5900 ℓ/day of water would be required to supply the consumers in the area.

From the schematic layout of the proposed water supply network shown in Appendix C at a scale of 1:60 000, it was calculated that the total distance around the network is 60 km and the truck would have to cover a total distance of 120 km a day, to supply the total water demand. The water supply points are situated alongside the roadway but close to the households.

From the total distance of 120 km to be covered by the truck in a day, the total distance to be covered per annum was calculated by multiplying 365 days in a year by the total distance to be covered per day. Therefore the total distance per year to be covered by the truck is 43 800 km.

Total maintenance and operation costs were determined from the sum of running and fixed costs of the vehicle. Running and fixed costs were calculated using unit rates provided in the *Automobile Association Rate Tables* in cents per kilometre travelled.

Fixed costs include insurance, depreciation and licensing costs that are incurred by the vehicle owner irrespective of the number of kilometres travelled. Running costs are those costs that vary directly with the kilometres travelled. These are fuel, service and repairs, and tyre costs.

The unit rates for fixed costs in the *Automobile Association Tables* are selected based on the purchase price of the truck and the annual total distance travelled by the truck. The purchase price of the truck is R350 000. From the annual total distance to be covered of 43 800 km and using the Automobile Association tables, the unit fixed cost of running the truck is R2.07 per kilometre. The rating table for fixed costs is as shown in table G1 of Appendix G

The unit rates for the running costs are selected based on the average real costs that would be incurred to maintain a vehicle with the particular engine capacity and fuel type. The average unit running cost is derived from the costs of tyres, fuel, and service and repair costs.

Table G2 in Appendix G shows the factors used to derive the unit rates of running costs. The factors are divided into columns A, B and C for: fuel, service and repairs and tyre cost factors respectively, as shown in the table. The formula used to calculate the unit rate is as shown below:

Running Cost Calculation (cents/km) = (A * Diesel Price in R/Litre) + B + C

The engine capacity of the truck is 3000 cc. and from table G2 in Appendix G, this falls under the engine capacity in the category 2501- 3000 cc and under this service and repair, tyre and diesel fuel factors, are 11.52, 21.75 and 18.32 respectively. Diesel cost is at R5.53 per litre (as of 3rd August, 2005).

Thus, running cost rate (cents/km) = (11.52 * 5.53) + 21.72 + 18.32

= R1.03/km

Technically it was assumed that the truck will run 50% of the time with a full load of water. The rating tables recommend that for a loaded vehicle, running costs should be adjusted by 25% of the result calculated from the tables. The running cost rate of R1.03/km obtained from the calculation was adjusted upwards by 25% to obtain a running cost rate of R1.28/km which was used in the analysis.

The total vehicle operating and maintenance cost per kilometre is found from the sum of the fixed and running cost unit rates. From the calculated unit fixed cost of R2.07/km and unit running cost of R1.28/km, the total vehicle unit operating cost is assumed to be R3.35/km

From the total annual distance of 43 800 km to be covered by the truck and a total unit operation and maintenance cost of R3.35/km, the total operation and maintenance cost of the truck per annum is R 146 730.

- **Borehole**

The budget and cash flow forecasts are also based on the information provided in the C*ost Benchmarks' Guide for Water Services Development Projects* and its *Cost Model* prepared by the Department of Water Affairs and Forestry *(DWAF 2003b)*.

Based on the guidelines provided in the cost benchmark's guide the following assumptions were made in order to determine the cash flow:

- A borehole will have to be drilled at every farm settlement; this is where there is a cluster of houses within the project area. There are 17 farm settlements within the project area and therefore 17 boreholes will have to be drilled.
- Each borehole will be equipped with an electric pump and will also have a standby electric pump in order to ensure an assurance of supply.
- Electricity is available throughout the year.
- Each borehole will have a storage tank in which the pumped water will be stored and water from the storage tank will be distributed by a pipe supply system to the tap point where water will be abstracted.
- Total capital costs for each borehole will include the costs of the following items required during the development of a borehole:

    - Cost of the establishment of the drilling team
    - Cost of the construction of the headworks
    - Consulting fees
    - Drilling costs
    - Cost of borehole tests

  - Reservoir cost
  - Water distribution cost
  - Electric pump cost
  - Electricity distribution cost

- Maintenance costs for electric pump, reservoir and borehole are estimated at 4%, 1% and 7% of the cost of each item respectively during the first year, and in the succeeding years they will increase at the inflation rate.
- The depth to the water table is assumed to be at 50m.
- Operation costs include electricity costs of pumps.
- It is assumed that the boreholes yield enough water to satisfy the demand of each community.

3. Selecting a decision making rule

The decision rule that was used in this evaluation is the Net Present Value (NPV).

The Net Present Value rule is used to evaluate the cost effectiveness of the alternatives for rural water supply. The procedure that was followed to determine the best alternative using the net present value was:

- Find the present value of each year's cash flow, discounted at the project's interest on redemption cost.

- Sum the discounted cash flows calculated over each year; this sum is defined as the project's net present value.

- If the net present value is positive, the project is an economical project, while if the net present value is negative, it is not economical. If the projects all yield a positive net present value, the one with the highest net present value is chosen as the one that is the most economical, as compared to the other projects whose values are lower.

However in this study, total investment costs required during the life of a system are being considered in terms of capital, operation and maintenance costs and the intention is to establish the system that would require the least cost of investment when the water supply systems are compared

The Net Present value technique was used to bring the total sum of money required to invest in a particular project during its economic life to the present cost, and therefore the system with the lowest Net Present Value was considered as the most economical one to implement.

The equation for the calculation for the Net Present Value is based on the formula shown below, however a *Microsoft excel* spreadsheet was used to determine the Net Present Value based on the same formula:

$$NPV = CF_0 + \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2} + .............. + \frac{CF_n}{(1+k)^n}$$

$$= \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}$$

Where:

NPV = Net Present Value

$CF_t$ = expected cash flow at end of year $t$

$t$ = period in years

$n$ = maximum period of years

$k$ = interest rate on capital redemption

In applying the Net Present Value the replacement chain method was used to compare the different projects. Consideration was given to the fact that the projects do not have equal economic lives and in analysing such projects it is assumed that the project with a shorter economic life will be replaced in order to compare the projects over an equal period of time.

The inputs that were used for the financial evaluation of each option include the estimation of the useful life of each type of option, the cash flows each option can generate over that period, and the appropriate interest rate on capital required to calculate the present value of the project's expected cash-flow stream.

### 3.4.2 Methodology on sensitivity analysis of economic factors on present value cost of different water supply systems

Further to evaluating piped water supply, borehole and hauling water supply systems based on Net Present Value cost, a sensitivity analysis was performed on the Net Present Value cost of the systems to analyse the economic factors to find out which one has a big investment influence on each of the systems.

The economic factors are considered as variables since they change according to how the economic climate dictates at the time when an investment is being considered and during the life of the system. The economic factors that are considered as variables in this study are:

- Maintenance and Operation (M & O) costs
- Interest rate on capital redemption
- Inflation rate

The sensitivity analysis was therefore carried out based on the budgets that were calculated for the borehole, hauling and piped water supply systems used in the cost comparison of the water systems as explained in Section 3.4.1.

Sensitivity analysis is a technique that indicates how much Net Present Value (NPV) will change in response to a given change in an input variable while other variables are held constant.

Sensitivity analysis begins with a base-case situation which is developed using the expected values for each variable. The base-case situation is where the values used in determining the budget and cash flow are the most likely values expected to be used to draw up a budget based on the existing scenario of cost rates. The resulting Net Present Value is the base-case NPV.

In sensitivity analysis each variable is changed by several percentage points above and below the expected value, holding all other variables constant. Then a new NPV is calculated using each of these values. Finally the set of NPVs is plotted to show how sensitive the NPV is to changes in each variable.

The sensitivity of each variable to the NPV is determined from the slope of the graph. Thus the steeper the slope, the more sensitive the NPV is to changes in the variable

In this analysis the base case was considered to be the situation under which the initial budgets used in the evaluation of the water systems were determined. From the base case situation the sensitivity analysis was performed by changing the variables which were used to determine the budget and cash flow in the base-case scenario, by several percentage points.

It was assumed that these variables can increase or decrease by percentages of 10%, 20% and 30% in each case. In the analysis a negative percentage indicates that the value of the variable decreases by that percentage and vice-versa when the percentage is positive.

In sensitivity analysis, percentage values of the variables were used one at a time to calculate the NPV of each changed variable with other variables held constant. The calculated NPVs' are then compared to analyse their sensitivity to the changes in the variables.

# 4.0 Results and analysis of findings

As previously mentioned, the main purpose of evaluating the minimum standards is to determine the feasibility of adopting the current minimum standards as required by DWAF, and to investigate the effect of increasing the standards with respect to capital pipe cost, particularly where gravity fed systems are used as the case study project used is a gravity fed system. Therefore the results obtained are applicable to a situation where a gravity system is applicable.

Considering that different options are used for rural water supply systems it was also considered necessary to carry out an economic analysis on the systems to investigate which one is cost effective to use in the rural areas.

In evaluating the minimum standards with respect to pipe cost, it was possible to use *Wadiso SA (GLS Engineering Software, 2003)* to assign the standards at different pre-selected values and to vary one standard at a time while holding the other standards constant.

For each standard being varied, a value was selected from a pre-selected list and an observation was made to check if the set standards can always be satisfied at all the water abstraction nodes by balancing the system in the steady state condition each time the pipe cost is changed using pre-selected pipe configurations as shown in Table 3.4.

In the case of investigating the cost effectiveness of the water supply options, it was possible to carry out an economic analysis using *Microsoft excel* net present value technique to determine net present cost on budgeted cash flows over the economic life of the systems and also to carry out a sensitivity analysis on the net present cost to economic factors.

The results of this study based on the methodology explained in chapter three are presented as follows.

## *4.1 Results of the evaluation of minimum standards of piped water supply systems*

The results of the evaluation of the minimum standards required for the design of rural pipe water supply projects are presented in this section.

### 4.1.1 Results of the effect of pressure on cost

In order to investigate the variation of pressure with cost, the methodology that was followed is as discussed in Section 3.3.1. The consideration was that for any pipe size configuration that can be used in the design of a water supply system, there is a minimum residual pressure up to which the system can provide without the system failing for any required output specified.

The minimum residual pressure is the lowest pressure that is available at any one of the abstraction nodes in the pipe network system and the node is described as a critical node.

The effect of the gain in pressure in relation to the pipe cost is defined by the difference in the minimum residual pressure that can be gained at the critical node by increasing the cost of the pipe. Refer to Table 3.4 under Section 3.2 for pipe size configurations used.

The difference in increase in pressure is compared with the cost that will be incurred if an increase in pressure is desired.

The input data for these results were the different types of pipe configurations and different pre-selected demand rates converted into an output required at each node in order to meet the total daily water demand of the population to be served at the node.

For each pipe network configuration used in the designed system, a demand, per capita per day, was assigned and an investigation was done to identify the minimum residual pressure that can be available in the system at the critical node. The cost to be incurred by this system to meet the set standards was recorded.

During the analysis of all the different scenarios, node 60 proved to be the critical abstraction node. Figure 3.1 is reproduced to indicate the location of node 60.

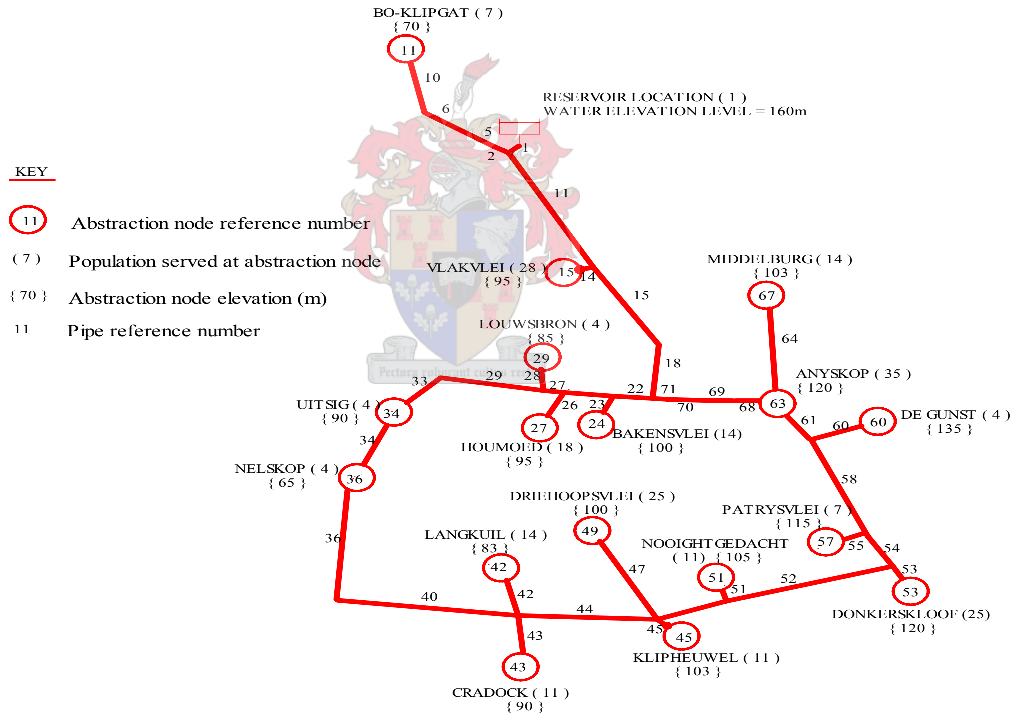

*Figure 3.1: Schematic layout of Nooightgedacht rural water supply project*

The minimum pressure available at the critical node for each pipe configuration used, expressed in terms of pipe cost, are shown in Table 4.1 and also presented graphically for all the demand rates analysed.

Examples of the spreadsheet results calculated by the program for the whole system showing the available residual pressures at the nodes for the demand rate fixed at 25 ℓ/c/day are shown in Appendix H.

| | Demand ( l/c/day ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 | 45 | 50 | |
| Pipe Size ( mm ) | Pressure ( m ) | Pressure ( m ) | Pressure ( m ) | Pressure ( m ) | Pressure ( m ) | Pressure ( m ) | Pressure ( m ) | Pipe Cost ( R ) |
| 25 | 18.942 | 15.853 | 12.194 | 8.127 | 2.977 | 1.166 | 0.872 | 374 379 |
| 50 x 25 | 23.990 | 23.485 | 22.887 | 22.194 | 21.363 | 20.486 | 19.532 | 430 675 |
| 63 x 25 | 24.264 | 23.899 | 23.467 | 22.957 | 22.361 | 21.716 | 21.026 | 492 002 |
| 50 | 24.548 | 24.318 | 24.045 | 23.742 | 23.357 | 22.917 | 22.538 | 756 007 |
| 63 X 50 | 24.822 | 24.732 | 24.625 | 24.505 | 24.355 | 24.203 | 24.003 | 817 335 |
| 75 x 50 | 24.852 | 24.777 | 24.625 | 24.589 | 24.464 | 24.338 | 24.196 | 884 386 |
| 63 | 24.929 | 24.894 | 24.852 | 24.803 | 24.748 | 24.684 | 24.617 | 1 171 747 |
| 75 x 63 | 24.959 | 24.939 | 24.915 | 24.887 | 24.853 | 24.818 | 24.780 | 1 238 799 |
| 75 | 24.971 | 24.957 | 24.939 | 24.920 | 24.896 | 24.871 | 24.843 | 1 626 290 |
| 100 | 24.993 | 24.989 | 24.985 | 24.980 | 24.974 | 24.968 | 24.961 | 2 768 615 |
| 150 | 24.999 | 24.999 | 24.998 | 24.997 | 24.996 | 24.996 | 24.995 | 5 945 295 |

***Table 4.1: Results of variation of minimum residual pressure with pipe cost at node 60***

From the results in Table 4.1, a superimposed graphical presentation of the minimum residual pressure available at the critical node in the system at different demand rates is shown in Figure 4.1.

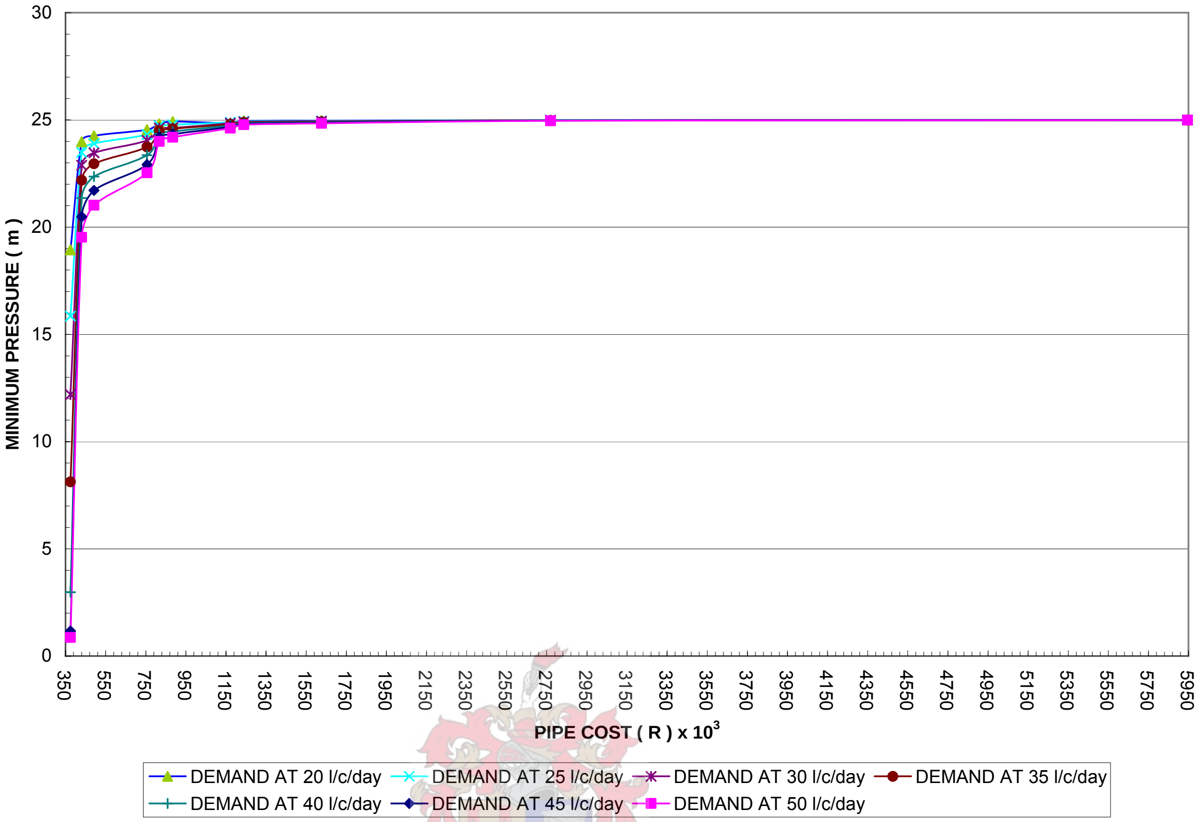

***Figure 4.1**: Relationship of minimum residual pressure with pipe cost at different demand rates*

From results in Table 4.1 and Figure 4.1 it can be seen that as the pipe cost increases due to large diameter pipes used, the minimum residual pressure at the critical node also increases up to a certain point and after that, any further increase in the cost does not result in any increase in pressure. This is evident from Figure`4.1 where the graphs are converging into a straight line approaching a limit of pressure of 25 m for all the demand rates analysed.

The increase in residual pressure is due to the reduction in friction losses each time the pipe capacity increases due to the increase in pipe size configuration. Friction losses reduce because there is less pipe friction resistance between the fluid particles and the pipe walls due to shear forces, as pipe capacity increases.

Since the residual pressure is the available pressure that remains at a node from the difference of the total energy available at a node and the total friction head loss incurred by the water in moving through the pipeline system in order to reach a node. Therefore as the friction losses decrease due to the increase in the capacity of the pipes, less work is required to move the water in the system and the difference in the available pressure increases, hence the increase in residual pressure.

However, the increase in pressure appears to approach a limit. The limit is reached because the friction head loss reduces until there is no substantial decrease in the losses in increasing the capacity for the range of the pipe configurations used, therefore the difference in the total energy available at the node and the friction losses to be incurred remains constant and this results in the limit in residual pressure being approached.

Figure 4.2 is a graph representing a portion of the graph in Figure 4.1, showing the variation of minimum residual pressure when the pipe cost is increased at different assigned demand rates. This graph shows the first part of Figure 4.1 up to a value of R1350000.

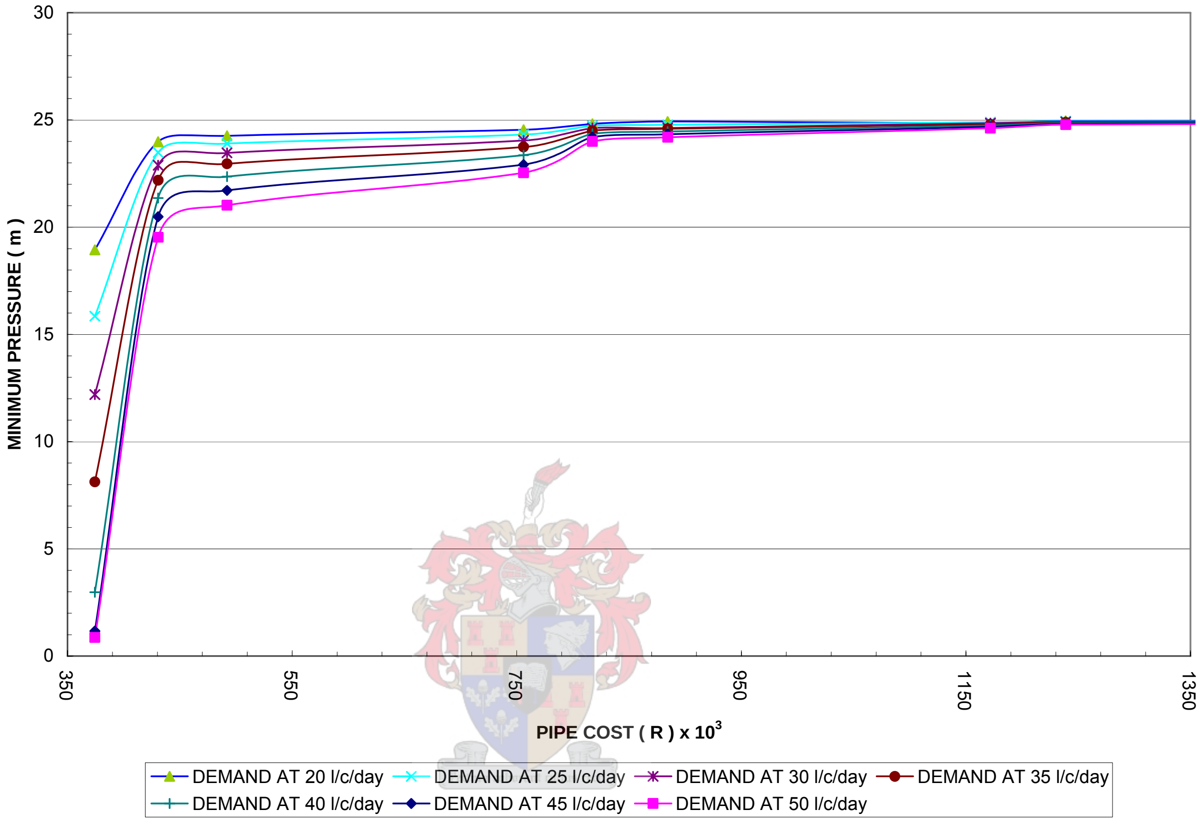

*Figure 4.2: Portion of Relationship of minimum residual pressure with pipe cost at different demand rates*

From Figure 4.2, it can be seen that there is a substantial gain in pressure up to a certain value of cost and any further increase does not result in a significant gain in pressure.

It can be seen that there is significant gain in residual pressure with increasing pipe cost up to a cost of R 430 675 and thereafter increasing the pipe cost and hence the pipe capacity will not result in significant gain in pressure as the pressure stays within 20 and 25 m for the demand rates and pipe configurations analysed.

Analysing the residual pressure over the range of pipe cost where we observe significant increase in residual pressure (R 350 378 to R 430 675) at the current minimum standard of demand of 25 ℓ/c/day as required by DWAF (*DWAF, 1999; Redbook 2000*) and at the demand rate of 50 ℓ/c/day which is the upper limit allowed by DWAF in terms of the minimum basic level of service (DWAF, 2003a).

It can be seen from Figure 4.2 that without dropping the current demand rate below 25 ℓ/c/day we can be able to achieve a minimum residual pressure of 10 m at the abstraction point as set by DWAF at the lowest cost analysed of R 374 379. At this cost the residual pressure achieved is 15 m. If we increase the pipe cost to R 430 675 a residual pressure above 20 m can be achieved.

If a demand rate of 50 ℓ/c/day is desired to satisfy the increase in demand rate as allowed by DWAF, it can be seen from Figure 4.2 that at the lowest cost of R 374 379 it is not possible to achieve a minimum residual pressure of 10 m as required by DWAF, as the pressure achieved at this cost is less than 10 m.

However, the graph also shows that with a small increase in pipe cost (R 430 675) it is possible to increase the demand rate to 50 ℓ/c/day and to achieve a residual pressure above 15m, which is above 10m as required by DWAF.

Table 4.2 shows the percentage increase in pressure that can be gained for a corresponding percentage increase in pipe cost at different demand rates in order to show the general relationship of the increase in residual pressure with pipe cost.

The percentages reflected in the table represent the capital pipe cost and residual pressure as a percentage of the lowest capital cost option of R 374 379 and the associated pressure respectively.

| Demand Rate (ℓ/c/day) | | | | | | | Percentage Increase in Pipe Cost (%) |
|---|---|---|---|---|---|---|---|
| 20 | 25 | 30 | 35 | 40 | 45 | 50 | |
| Percentage Increase in Pressure (%) | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 48 | 88 | 173 | 618 | 1657 | 2140 | 15 |
| 28 | 51 | 92 | 182 | 651 | 1762 | 2311 | 31 |
| 30 | 53 | 97 | 192 | 685 | 1865 | 2485 | 102 |
| 31 | 56 | 102 | 202 | 718 | 1976 | 2653 | 118 |
| 31 | 56 | 102 | 203 | 722 | 1987 | 2675 | 136 |
| 32 | 57 | 104 | 205 | 731 | 2017 | 2723 | 213 |
| 32 | 57 | 104 | 206 | 735 | 2028 | 2742 | 231 |
| 32 | 57 | 105 | 207 | 736 | 2033 | 2749 | 334 |
| 32 | 58 | 105 | 207 | 739 | 2041 | 2763 | 640 |
| 32 | 58 | 105 | 208 | 740 | 2044 | 2766 | 1488 |

***Table 4.2: Corresponding percentage increases in pressure and pipe cost***

Figure 4.3 shows the relationship of the percentage increases in pressure and pipe cost at a demand rate of 25 ℓ/c/day as shown in Table 4.2.

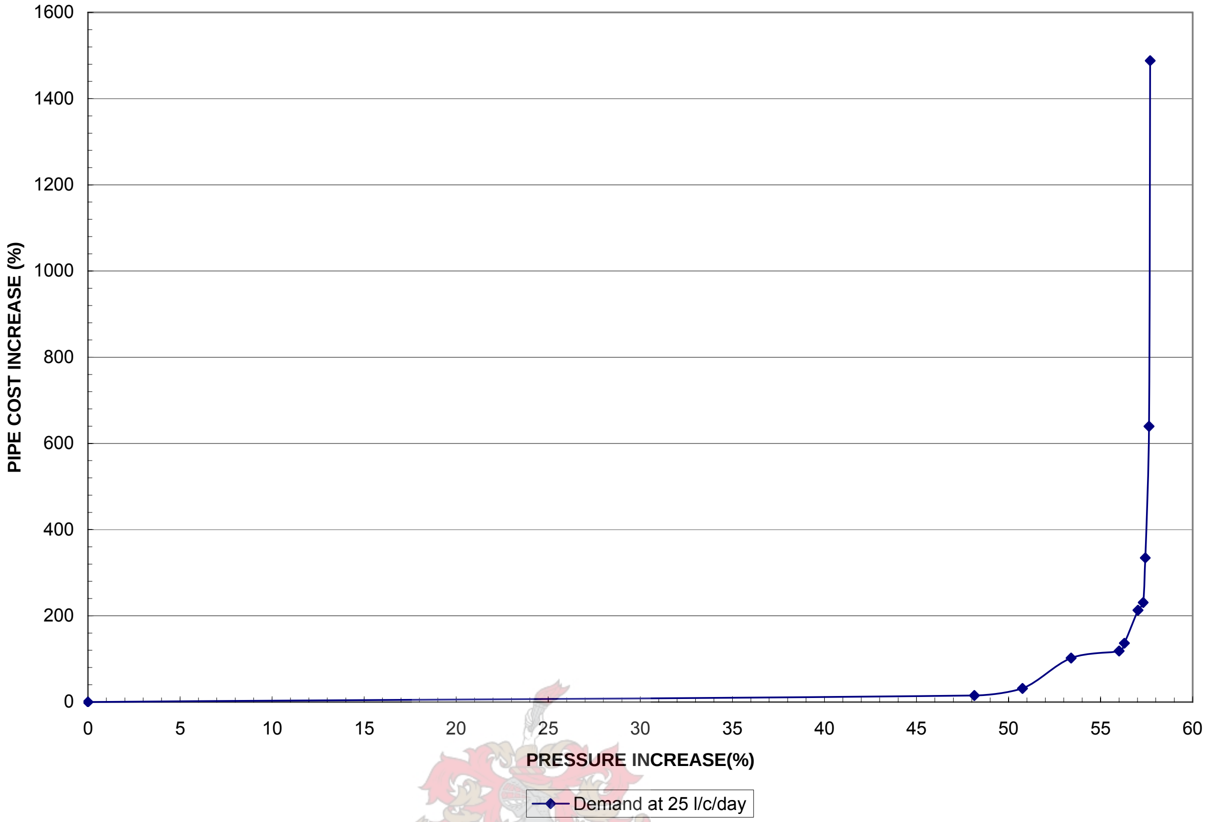

*Figure 4.3: Relationship of corresponding percentage increases in pipe cost and pressure at 25 ℓ/c/day*

Figure 4.3 also shows that there is a significant percentage gain in residual pressure up to a certain percentage increase in pipe cost. Any further increase in the cost does not result in any significant percentage increase in residual pressure.

Figure 4.4 shows a portion of Figure 4.3 with pipe cost plotted up to 120 % and the pressure increase plotted up to 55% to indicate the behaviour in the region where significant pressure increase is observed at a demand rate of 25 ℓ/c/day.

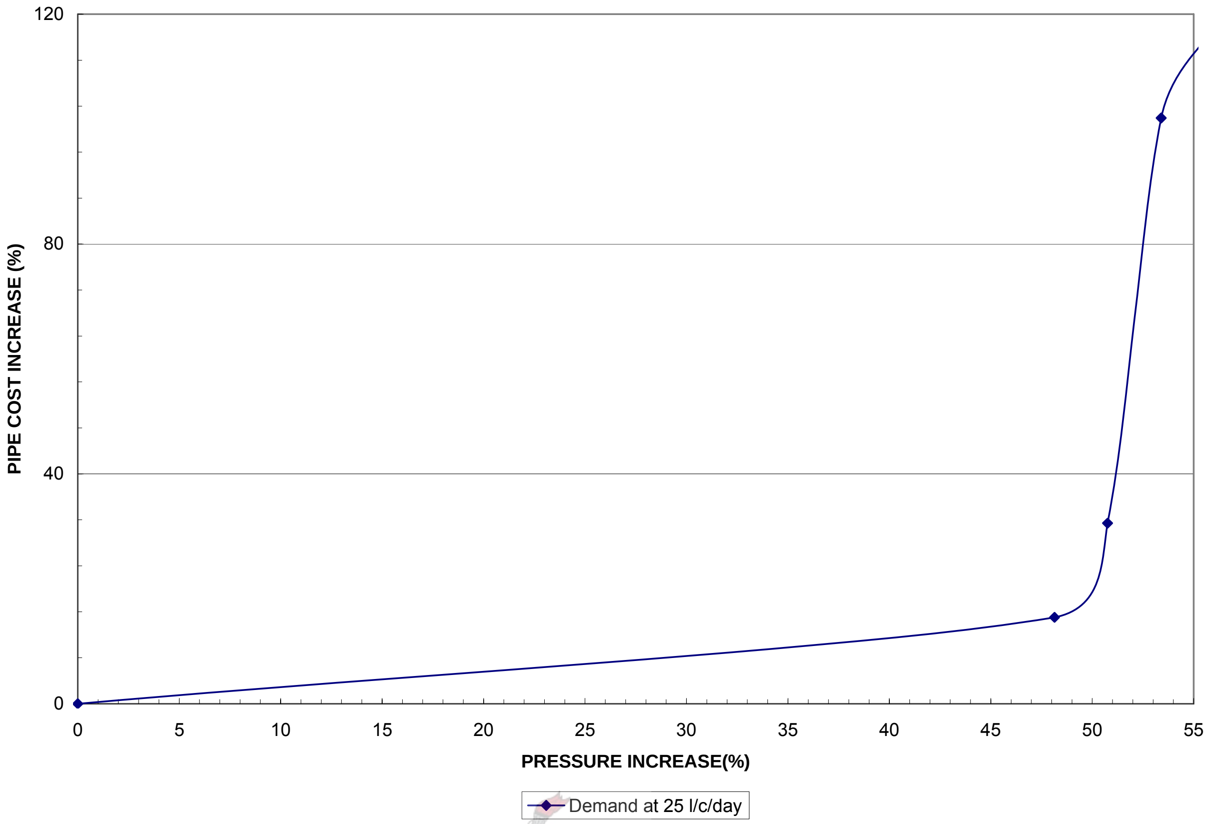

***Figure 4.4: Portion of Relationship of corresponding percentage increases in pipe cost and pressure at a demand rate of 25 ℓ/c/day***

Figure 4.4 indicates that a significant increase in pressure is observed up to an increase in pipe cost of 15% where a gain in residual pressure of 48% is achieved for a demand rate of 25 ℓ/c/day. Thereafter the pressure increase is not significant and is more or less constant (between 48% and 58%).

For a 15% increase in pipe cost the cost increases from R 374 379 to R 430 679 indicating an increase of R 56 300 and the pressure increases from approximately 15 m to 23 m indicating a 48% increase in residual pressure.

The percentage increase in pipe cost is small compared to the associated benefit realised in increasing the pipe cost.

Similarly, it can be deduced from the results in Table 4.2 that at a demand rate of 50 ℓ/c/day a significant increase in residual pressure is observed up to an increase in pipe cost of 15%.

Although this study did not focus on evaluating the minimum velocity required in the systems, it was however noted during the analysis, that although the residual pressure was increasing with increasing pipe configurations, the velocity of flow was decreasing as the pipe configuration was increasing for a specified demand and was increasing with increasing demand rate. However the velocity achieved was below the required minimum of 0.3 m/s as required by DWAF *(DWAF, 1999)*.

Thus, based on the results it can be said that where a gravity fed system is used for rural pipe water supply then:

- At a demand rate of 25 ℓ/c/day it is feasible to achieve a minimum residual pressure of 10m at the abstraction point as required by DWAF, at a low cost.
- It is also possible to achieve higher residual pressure at a low cost without dropping the demand rate below 25 ℓ/c/day. It has been shown that at a demand rate of 25ℓ/c/day a residual pressure of 16m was achieved at a relative low cost.
- At a demand rate of 25 ℓ/c/day as set by DWAF, if an increase in residual pressure is desired, then at 15% increase in pipe cost, a significant increase in residual pressure can be achieved (up to 23 m). Thus, at a small percentage increase in cost, higher residual pressures than set as minimum, can be achieved without dropping the demand rate below the minimum of 25 ℓ/c/day.
- If an increase in the demand rate of 50 ℓ/c/day is desired as aimed by DWAF then it is also possible to increase the residual pressure above the required 10 m with a small percentage increase in pipe cost. At 50 ℓ/c/day it was possible to achieve a residual pressure of above 15 m with a 15% increase in pipe cost.

### 4.1.2 Results on effect of demand rate on cost

The investigation on demand rate involved assigning the minimum pressure at different pre-selected values of 5,7,10 and 15 m one by one. When the pressure was fixed, an investigation of the maximum demand that can be abstracted from the system before the pressure falls below the minimum fixed pressure at the critical node in the system was evaluated.

The procedure for this evaluation is as described in Section 3.3.2. The input data in the program was the different pipe combinations from Table 3.4 and the demand rate. It should be noted that for the selected pressure and pipe configuration, the maximum demand rate was investigated by trial-and-error as described in Section 3.3.2.

When the pressure is fixed, and the maximum demand that can be abstracted from the system at different pipe configurations is determined, then it is possible to determine the effect of demand rate on cost as a result of increasing the pipe size configuration.

The relationship is determined by comparing the difference in gain in demand and the related costs in order to achieve this gain.

Table 4.3 shows the maximum demand rate that can be abstracted from the system at the critical node, at the assigned minimum pressures for each of the pipe size configurations used. The related costs are also shown in the table.

An example of the spreadsheet results calculated by the program, showing the residual pressure available at different nodes in the system at the maximum demand rate with the minimum residual pressure fixed at 10 m is shown in Appendix I.

| Pipe Size (mm) | Pressure (m) 5 Maximum Demand ( l/c/day ) | Pressure (m) 7 Maximum Demand ( l/c/day ) | Pressure (m) 10 Maximum Demand ( l/c/day ) | Pressure (m) 15 Maximum Demand ( l/c/day ) | Pipe Cost ( R ) |
|---|---|---|---|---|---|
| 25 | 38 | 38 | 33 | 26 | 374 379 |
| 50 x 25 | 101 | 95 | 87 | 69 | 430 675 |
| 63 x 25 | 119 | 112 | 103 | 83 | 492 002 |
| 50 | 155 | 145 | 130 | 106 | 756 007 |
| 63 X 50 | 256 | 241 | 219 | 177 | 817 335 |
| 75 x 50 | 284 | 267 | 242 | 195 | 884 386 |
| 63 | 421 | 398 | 362 | 290 | 1 171 747 |
| 75 x 63 | 570 | 537 | 486 | 391 | 1 238 799 |
| 75 | 687 | 647 | 587 | 471 | 1 626 290 |
| 100 | 1462 | 1381 | 1253 | 1005 | 2 768 615 |
| 150 | 4246 | 4002 | 3637 | 2921 | 5 945 295 |

***Table 4.3**: Results of maximum demand at different minimum pressure values*

The results shown in Table 4.3 are illustrated graphically for the variation of demand rate with cost, at each fixed minimum pressure as shown in Figure 4.5.

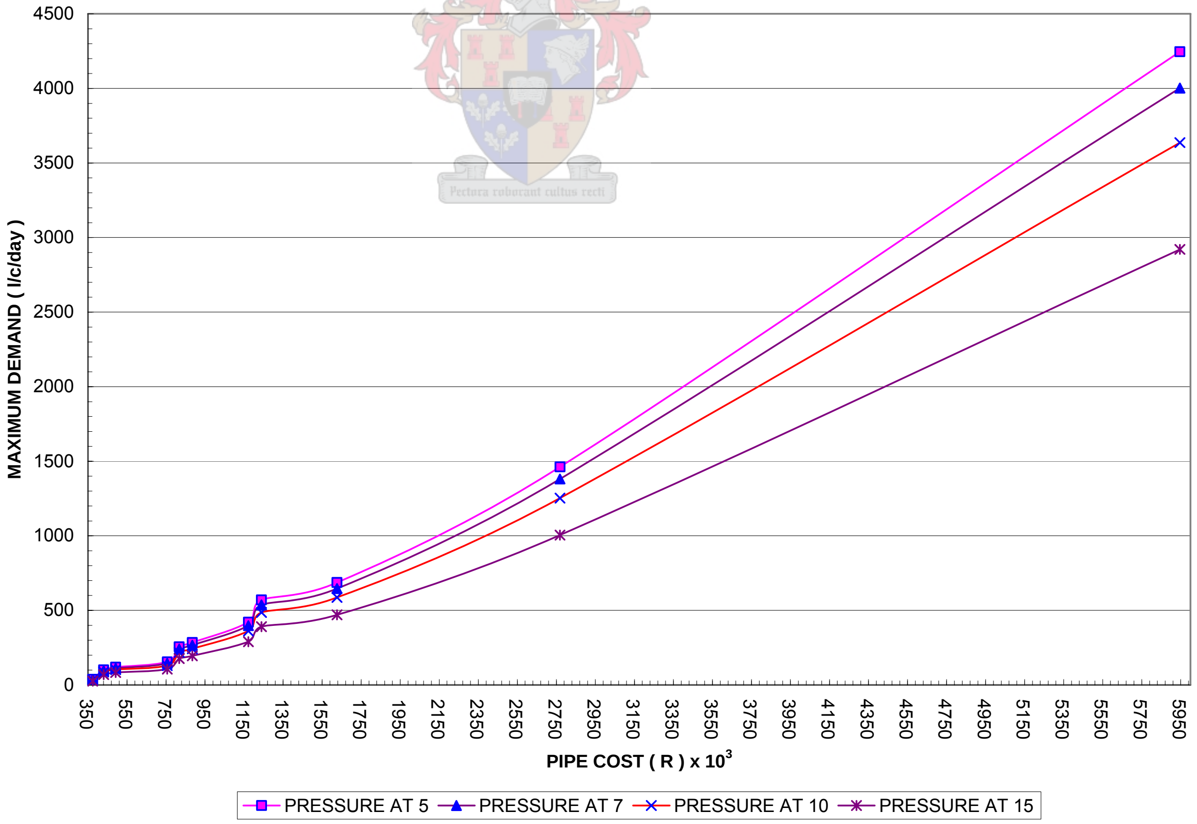

***Figure 4.5**: Relationship of maximum demand with pipe cost at different Pressure Values*

The graph shows that as the pipe system cost increases the demand that can be abstracted from the system also increases and at higher pipe cost significantly higher demand rates are achieved.
The variability in the steepness of the slopes of the graphs is due to the sudden increase in the capacity of the different pipe configurations used. As the pipe capacity increases the maximum output that can be discharged from the pipeline system increases. Therefore for a sudden increase in the pipe capacity, there is a drastic increase in the output from the pipeline system, which is evident from the steep slopes seen in the graph.

It is predicted that a gradual increase in the pipe configuration will indicate a smooth transition in the increase in demand rate and hence produce a smooth curve. However, the relationship of varying the demand rate by increasing the cost would be the same.

Figure 4.6 is a graph representing a portion of the graph in Figure 4.5, showing the behaviour of the relationship of maximum demand and pipe cost. This graph shows the first part of Figure 4.5 for the maximum demand up to 200ℓ/c/day and the pipe cost up to a value of R 800 000 considering DWAF's aim of increasing the demand rate to 50 ℓ/c/day *(DWAF, 2003a)*

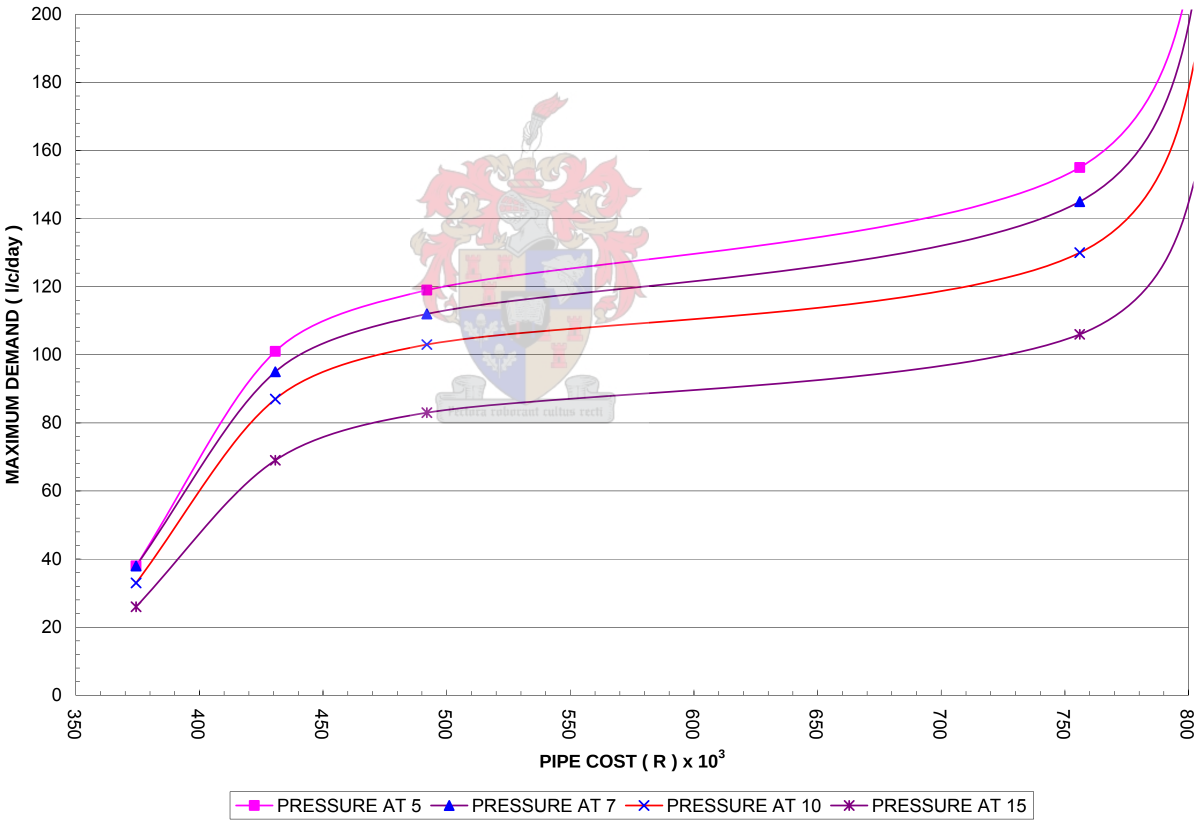

***Figure 4.6: Portion of Relationship of maximum demand with pipe cost at different pressure values***

Even though Figure 4.5 indicates that demand rate increases as the pipe cost increases, if we consider the part shown in Figure 4.6 it can be seen that there is a significant gain in demand with the initial increase in cost as the pipe cost increases up to R 430 675, and as the cost increases further up to R 750 000, there is no significant increase in demand.

This can be seen from the slope of the graph in that up to a pipe cost of R 430 675, the slope of the graph is steep indicating that for a small change in the pipe cost there is a big change in the maximum demand and increasing further up to R 750 000, the graph is rather flat indicating that for a big change in pipe cost there is a small change in maximum demand that can be abstracted from the system.

It can be seen that it is possible to deliver 25 ℓ/c/day without dropping the residual pressure below 10m as set by DWAF at the lowest cost analysed. It can be seen from Table 4.3 and Figure 4.6 that at 10m a demand rate of 33 ℓ/c/day, higher than required is achieved at a cost of R 374 379.

As proved in Section 4.1.1, Figure 4.2, it can also be proved from Figure 4.6 that it is possible to deliver a demand rate of 25 ℓ/c/day as set by DWAF at a residual pressure of 15 m at the lowest cost analysed.

From Table 4.3 it is observed that at 15 m residual pressure a demand rate of 26 ℓ/c/day can be achieved.

Considering Government’s aim to increase the water quantity to 50 ℓ/c/day on condition of an assurance of water supply (DWAF,2003a):

It is shown in Table 4.3 and Figure 4.6 that without a very high increase in capital cost it is possible to achieve a demand rate of 50 ℓ/c/day, without dropping the residual pressure at 10 m as set by DWAF. Increasing the pipe cost from R 374 379 to R 430 675 a demand rate of 87 ℓ/c/day, which is above 50 ℓ/c/day, is achieved.

It can also be seen that if the residual pressure was increased to 15 m it would still be possible to deliver 50 ℓ/c/day with a small increase in pipe cost. With residual pressure fixed at 15 m a demand rate of 69 ℓ/c/day was achieved.

Table 4.4 shows percentage increases in demand rate that can be gained for a corresponding percentage increase in pipe cost at different values fixed as minimum residual pressure.

The percentages reflected in the table represent the capital pipe cost and demand rate shown in Table 4.3 as a percentage of the lowest capital cost option of R 374 379 and the associated maximum demand rate that can be achieved respectively.

| Pressure | | | | Percentage Increase in Pipe Cost (%) |
|---|---|---|---|---|
| 5m | 7m | 10m | 15m | |
| Percentage Increase in Demand Rate (%) | | | | |
| 0 | 0 | 0 | 0 | 0 |
| 166 | 150 | 164 | 165 | 15 |
| 213 | 195 | 212 | 219 | 31 |
| 308 | 282 | 294 | 308 | 102 |
| 574 | 534 | 564 | 581 | 118 |
| 647 | 603 | 633 | 650 | 136 |
| 1008 | 947 | 997 | 1015 | 213 |
| 1400 | 1313 | 1373 | 1404 | 231 |
| 1708 | 1603 | 1679 | 1712 | 334 |
| 3747 | 3534 | 3697 | 3765 | 640 |
| 11074 | 10432 | 10921 | 11135 | 1488 |

***Table 4.4: Corresponding percentage increase in demand rate and pipe cost***

Figure 4.7 shows the relationship of the percentage increases in the maximum demand rate and pipe cost at a residual pressure of 10 m as shown in Table 4.4.

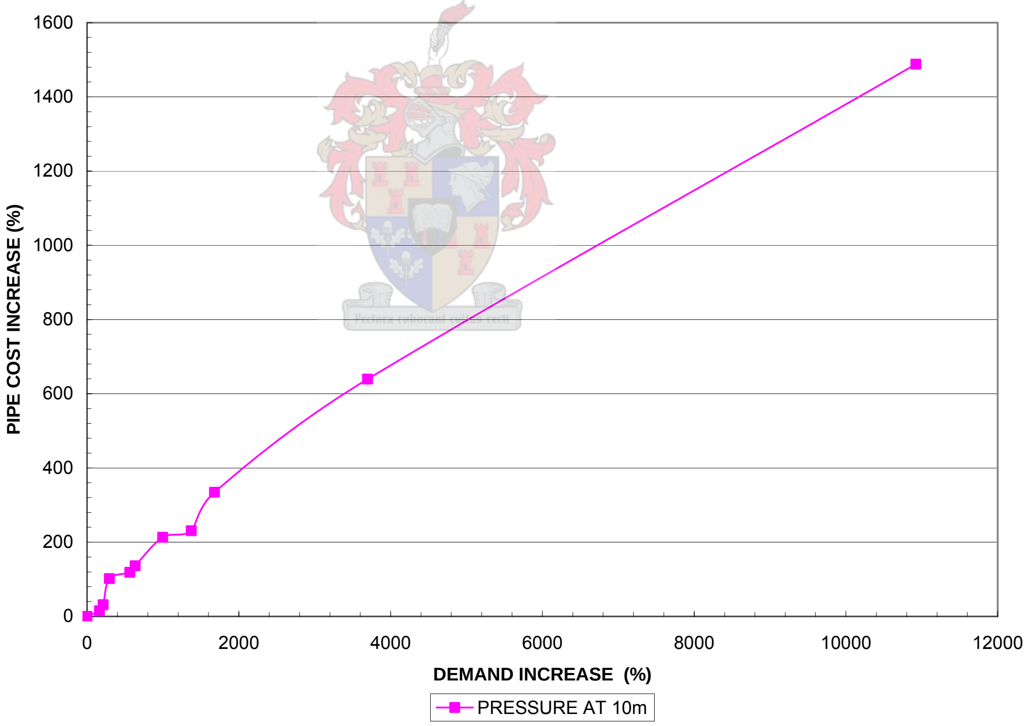

***Figure 4.7: Relationship of corresponding percentage increases in pipe cost and demand rate at 10m***

Figure 4.7 shows that as the percentage in pipe cost increases there is also a related percentage increase in demand rate that can be achieved.

Figure 4.8 shows a portion of figure 4.7 with percentage increase in pipe cost plotted up to 100% and demand rate increase plotted between 0% and 300%.

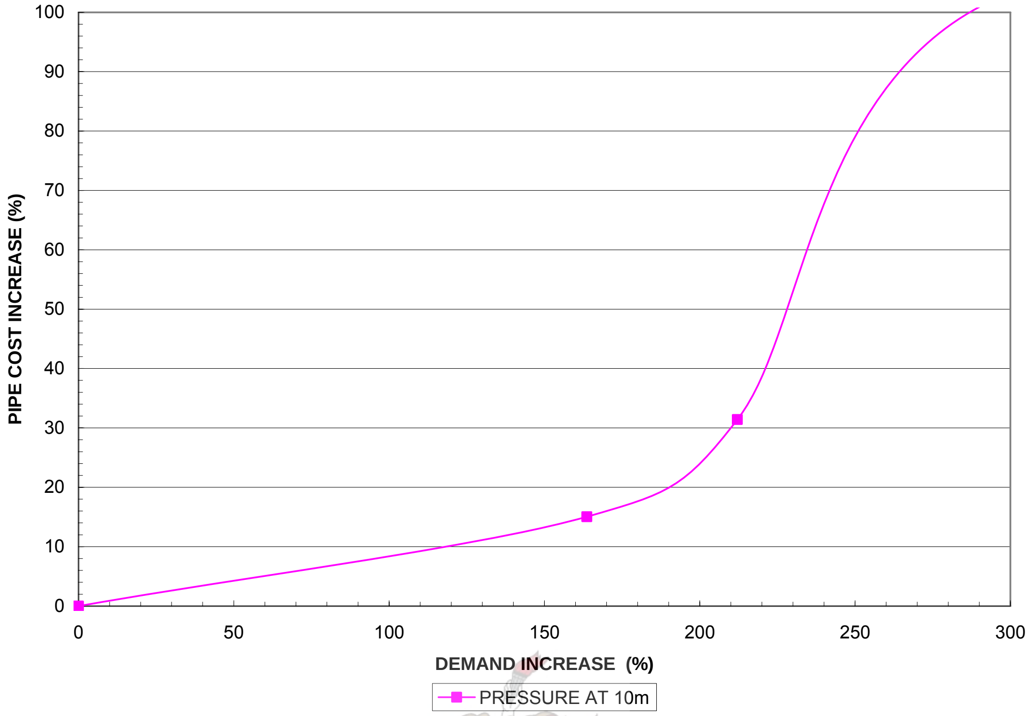

***Figure 4.8: Portion of Relationship of corresponding percentage increases in pipe cost and demand rate at 10 m***

Figure 4.8 indicates that a substantial increase in the demand rate can be achieved up to a certain point, and thereafter, an increase in pipe cost does not result into any significant increase in demand.

It can be seen that a substantial percentage increase in demand rate is observed when the pipe cost increases up to 15% and thereafter the margin of percentage gain in demand starts to diminish with increasing pipe cost when successive increments are considered. This indicates that the benefit in demand rate is not much as we keep increasing the cost over this range, even though the demand rate keeps increasing.

The graph shows that the lowest cost pipe configuration already achieves a demand rate of 33 ℓ/c/day. A 15% increase in cost results in a demand rate of 87 ℓ/c/day, which is above the maximum possible future demand of 50 ℓ/c/day as suggested by DWAF.

The cost to be incurred in order to achieve 50 ℓ/c/day is small compared with the associated benefit that can be realised from this increment when the percentages are considered.

Thus it can be said that a high percentage increase in demand rate can be achieved with a small percentage increase in pipe cost up to a certain cost which can be considered to be reasonable but once this cost is reached, although there are significant gains in the demand rate, increasing the pipe cost much further results in the cost to be incurred to achieve the gain in demand rate being too high.

For the velocity of flow, it was also noted that as the maximum demand was increasing with increasing pipe configuration at a specific pressure, the velocity of flow at the critical node was also increasing. The velocity was however decreasing with increasing residual pressure at a specific pipe configuration. In both scenarios the velocity achieved was below the required 0.3 m/s as required by DWAF *(DWAF, 1999).* The results indicate that in order to achieve high velocities at a specific residual pressure significant investment costs have to be incurred

Therefore the results indicate that for a gravity main system used for rural pipe water supply using a stand pipe:

- It is feasible to deliver 25 ℓ/c/day at a relatively low cost without dropping the minimum residual pressure below 10 m as set by DWAF.

- At low cost, higher pressures than set as minimum, can be achieved without dropping the demand rate below the minimum of 25 ℓ/c/day. It has been shown that at low cost, without dropping the demand rate below 25 ℓ/c/day as set by DWAF, it is possible to increase the residual pressure up to 15 m.

- At a fairly small increase in pipe cost it is possible to achieve a demand rate of 50 ℓ/c/day without dropping the residual pressure below 10 m as set by DWAF. However at this demand rate it is also possible to increase the residual pressure to 15 m.

  It has been proved that with a 15% increase in pipe cost from R 374 379 to R 430 675 high demand rates above 50 ℓ/c/day were achieved.

### 4.1.3 Results of effect of abstraction rate on cost

Investigation into the effect of abstraction rate on cost was done by observing the maximum abstraction rate that can be achieved at the critical node, at a particular assigned pressure as the pipe cost increases. The procedure followed is as discussed in Section 3.3.3. The input data was the candidate pipe configurations and demand rates.

Results of the maximum abstraction rate at different nodes in the system, computed by the program with the residual pressure fixed at 10 m, are shown in Appendix J. The results are expressed in litres per second.

During the analysis of all the different scenarios, node 60 proved to be the critical abstraction node. The results at the critical node i.e. node 60, are presented in Table 4.5 and the abstraction rate in litres per second was converted to litres per minute (ℓ/min) as shown in the tables.

| Node 60 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe Size ( mm ) | Pressure 5 m | | Pressure 7 m | | Pressure 10 m | | Pressure 15 m | | Pipe Cost ( R ) |
| | Flow rate | | Flow rate | | Flow rate | | Flow rate | | |
| | l/s | l/min | l/s | l/min | l/s | l/min | l/s | l/min | |
| 25 | 0.001 | 0.06 | 0.001 | 0.06 | 0.001 | 0.06 | 0.001 | 0.06 | 374379 |
| 50 x 25 | 0.004 | 0.24 | 0.004 | 0.24 | 0.003 | 0.18 | 0.003 | 0.18 | 430675 |
| 63 x 25 | 0.005 | 0.30 | 0.004 | 0.24 | 0.004 | 0.24 | 0.003 | 0.18 | 492002 |
| 50 | 0.006 | 0.36 | 0.006 | 0.36 | 0.005 | 0.3 | 0.004 | 0.24 | 756007 |
| 63 X 50 | 0.010 | 0.60 | 0.010 | 0.60 | 0.009 | 0.54 | 0.007 | 0.42 | 817335 |
| 75 x 50 | 0.011 | 0.66 | 0.011 | 0.66 | 0.010 | 0.60 | 0.008 | 0.48 | 884386 |
| 63 | 0.017 | 1.02 | 0.016 | 0.96 | 0.014 | 0.84 | 0.012 | 0.72 | 1171747 |
| 75 x 63 | 0.023 | 1.38 | 0.021 | 1.26 | 0.019 | 1.14 | 0.016 | 0.96 | 1238799 |
| 75 | 0.027 | 1.62 | 0.026 | 1.56 | 0.023 | 1.38 | 0.019 | 1.14 | 1626290 |
| 100 | 0.058 | 3.48 | 0.055 | 3.30 | 0.050 | 3.00 | 0.040 | 2.40 | 2768615 |
| 150 | 0.170 | 10.20 | 0.160 | 9.60 | 0.145 | 8.7 | 0.117 | 7.02 | 5945295 |

***Table 4.5: Results of maximum abstraction rate at different minimum pressure values, at node 60***

The graph shown in Figure 4.9 illustrates the results shown in Table 4.5 for the variation of abstraction rate at node 60 in litres per minute as the pipe cost is increased and the pressure fixed at different standards.

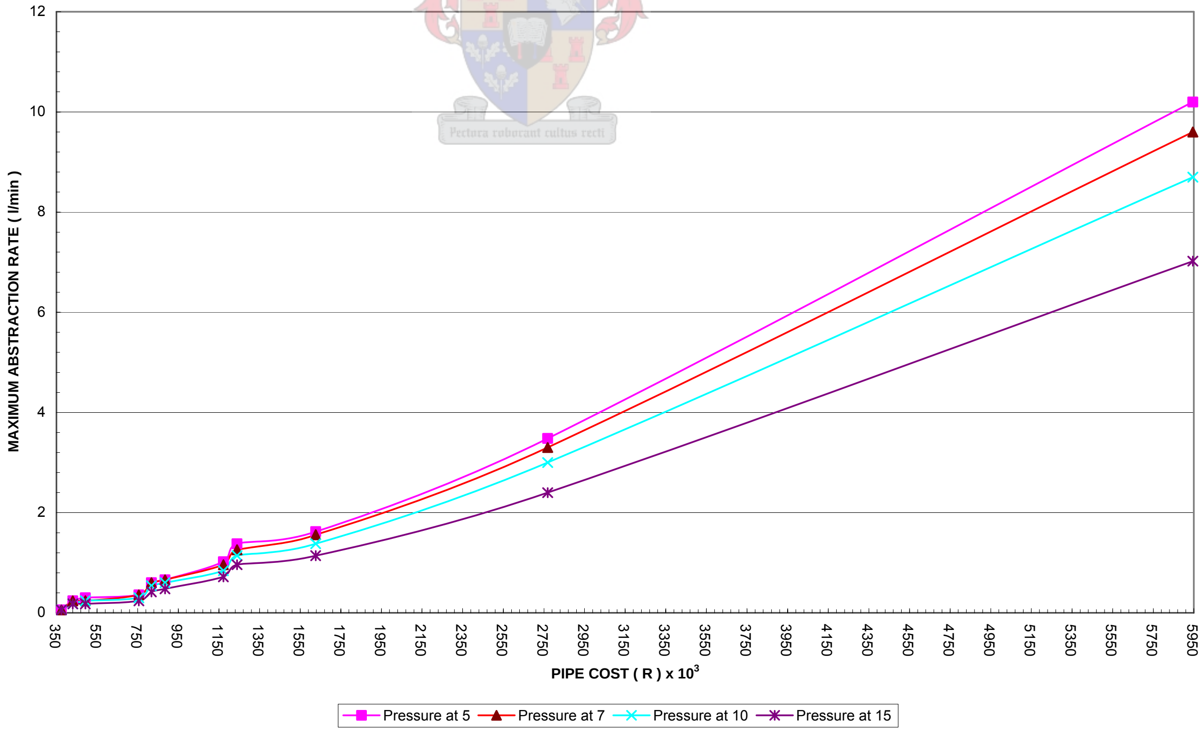

***Figure 4.9**: Relationship of maximum abstraction rate with pipe cost at different pressure values for node 60*

The graph in Figure 4.9 indicates that, as the pipe cost increases as a result of increasing the pipe size, the abstraction rate from the system also increases, but significant abstraction rates are achieved only at a very high cost.

Figure 4.10 is a graph showing a portion of the graph in Figure 4.9, showing the behaviour of the relationship of the maximum abstraction rate and pipe cost. This graph shows the first part of Figure 4.9 up to R 850 000.

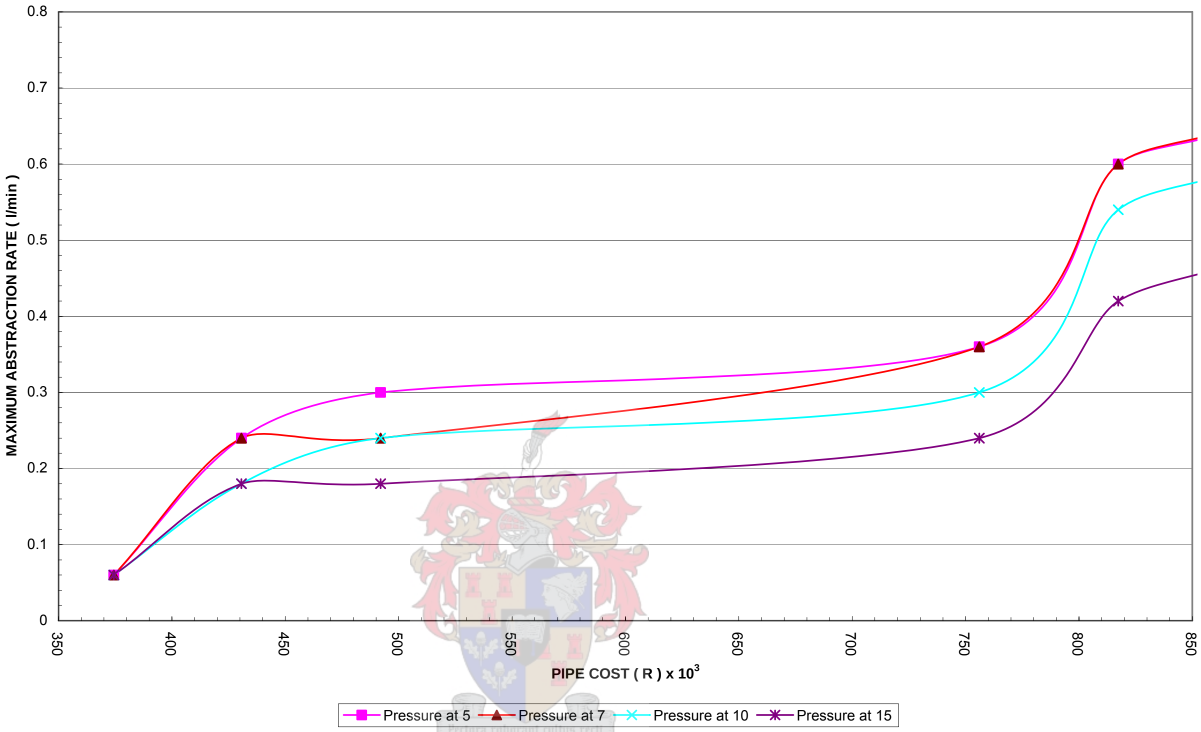

*Figure 4.10: Relationship of maximum abstraction rate with pipe cost at different pressure values at node 60*

It can be seen in Figure 4.10 that significant benefit in abstraction rate can be realised up to a certain point in pipe cost and thereafter increasing the pipe cost does not result in any significant benefit of the abstraction rate compared with the pipe cost invested.

It is shown that benefits in abstraction rate can be realised up to a pipe cost of R 430 675 as the slope of the graph in this region is steep indicating that for a small proportional increase in pipe cost we can get a relatively large increase in abstraction rate.

However if we look at the margins of increase in Table 4.5 for the region where we observe an indication of huge increase, it can be seen that the margins of increase that are achieved are very small if it was desired to achieve a high abstraction rate.

As the pipe cost increases further from R 430 675 to R 750 000 it can be seen that there is no huge benefit in terms of the abstraction rate as the graph appears to be flat indicating that there is a small increase in abstraction rate for a large increase in the pipe cost, for all the assigned minimum pressures.

It is shown that at a residual pressure of 10 m, for the candidate pipe configurations analysed, it was not possible to achieve an abstraction rate of 10 ℓ/min as set by DWAF and in attempting to achieve this abstraction rate the pipe cost needs to be increased significantly. Similar behaviour is evident when the abstraction rate is analysed at a residual pressure of 15 m.

Table 4.6 shows percentage increases in abstraction rate that can be gained for a corresponding percentage increase in pipe cost for the assigned pressures.

The percentages reflected in the table represent the capital pipe cost and abstraction rate shown in Table 4.5 as a percentage of the lowest capital cost option of R 374 379 and the associated maximum abstraction rate that can be achieved respectively.

| Demand | | | | Percentage Increase in Pipe Cost (%) |
|---|---|---|---|---|
| 5m | 7m | 10m | 15m | |
| Percentage Increase in Abstraction Rate (%) | | | | |
| 0 | 0 | 0 | 0 | 0 |
| 300 | 300 | 200 | 200 | 15 |
| 400 | 300 | 300 | 200 | 31 |
| 500 | 500 | 400 | 300 | 102 |
| 900 | 900 | 800 | 600 | 118 |
| 1000 | 1000 | 900 | 700 | 136 |
| 1600 | 1500 | 1300 | 1100 | 213 |
| 2200 | 2000 | 1800 | 1500 | 231 |
| 2600 | 2500 | 2200 | 1800 | 334 |
| 5700 | 5400 | 4900 | 3900 | 640 |
| 16900 | 15900 | 14400 | 11600 | 1488 |

***Table 4.6: Corresponding percentage increase in abstraction rate and pipe cost***

Figure 4.11 shows the relationship of the percentage increases in the maximum demand rate and pipe cost at a residual pressure of 10 m as shown in Table 4.6.

Figure 4.11 shows the relationship of the corresponding percentage increases in abstraction rate and pipe cost at a residual pressure of 10 m as shown in Table 4.6.

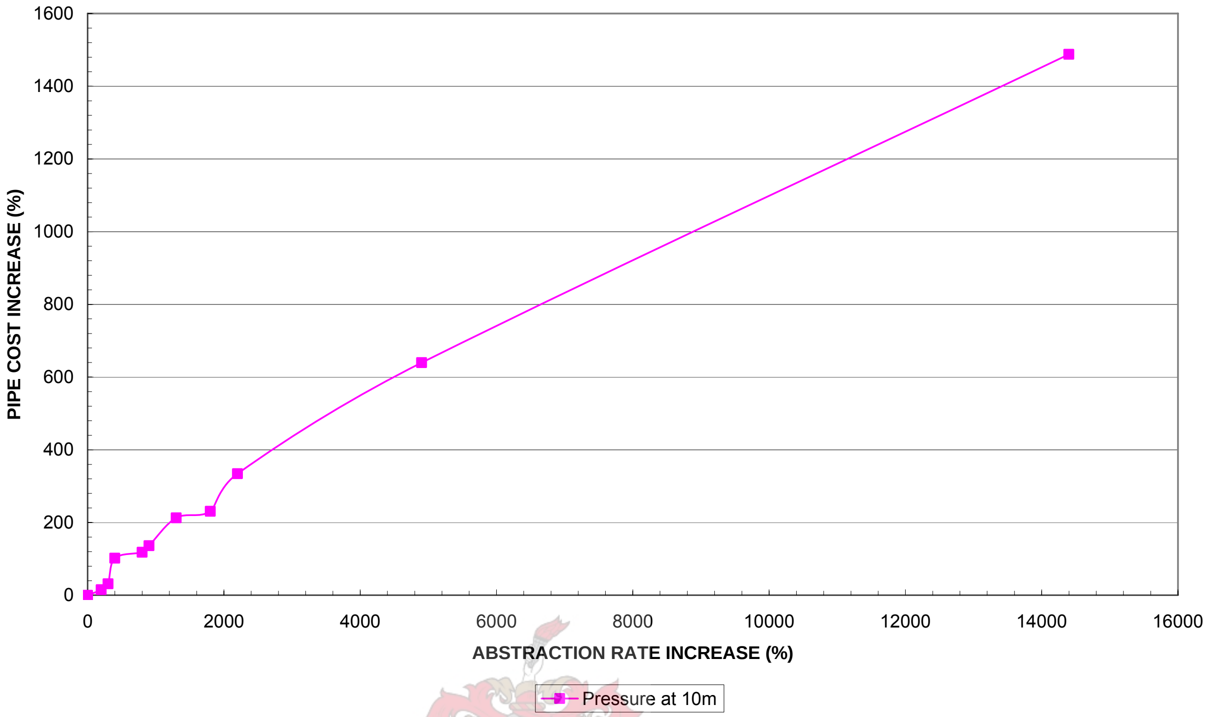

***Figure 4.11: Relationship of corresponding percentage increases in pipe cost and abstraction rate at 10m***

It can be seen from Table 4.6 and Fig 4.11 that as the percentage in pipe cost increases there is also a percentage increase in the abstraction rate that is realised.

Thus, it is noted that though Figure 4.11 indicates a huge percentage increase in the abstraction rate as the percentage in pipe cost increases, from Table 5.6 it is seen that the margin of increase in abstraction rate is small compared to the cost that is incurred in order to raise the abstraction rate by a small margin.

In order to achieve a high abstraction rate a very high cost would have to be incurred.

Figure 4.12 shows a portion of Figure 4.11 with the percentage increase in pipe cost plotted up to 100% and the abstraction rate increase plotted between 0% and 400%.

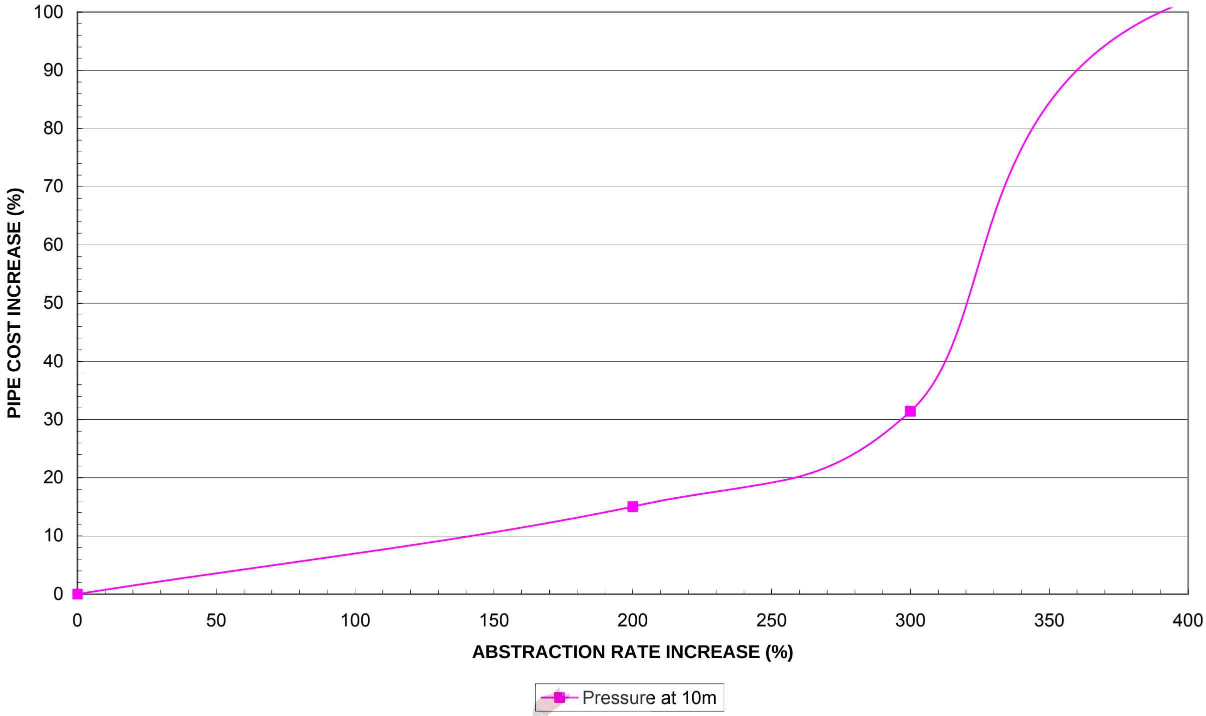

***Figure 4.12: Portion of Relationship of corresponding percentage increases in pipe cost and abstraction rate at 10m***

Figure 4.12 shows that there is a significant percentage increase in flow rate up to a percentage increase in pipe cost of 15% and if the cost is increased further, the increase in the flow rate starts to diminish, indicating that if the pipe cost keeps increasing the flow rate to be achieved will not change much.

This is the reason why it is observed in Table 4.5 and Figure 4.9 that in order to obtain high flow rates at 10 ℓ/min as required by DWAF, very high pipe costs have to be incurred.

As mentioned, the margins of increases are small compared to the cost that is incurred to achieve the related gain in moving from one pipe cost to the other although the percentage increases look significant.

Considering the margins of increase, at 10 m pressure, the pipe cost increases from R 374 379 to R 430 675 indicating a marginal increase of R 56 296 and the abstraction rate increases from 0.06 ℓ/min to 0.24 ℓ/min indicating an increase of 0.18 ℓ/min. The increase in pipe cost is high compared to the gain in abstraction rate achieved. This relationship is evident in all cases of the assigned pressures.

It is noticed that the pattern of the graphs for the analysis of the demand rate and the abstraction rate is the same. This is because in both analyses pressure was fixed and the demand was allowed to vary each time the pipe configuration was changed. However the results indicate that while it is possible to achieve high values of demand rate at relatively low cost as proved in section 4.1.2, it would require high capital costs to achieve the minimum standard of 10 ℓ/min required for the abstraction rate.

Based on the results for the investigation of abstraction rate it can be said that:

- Without dropping the minimum pressure below 10m as set by DWAF, significant cost investment has to be made in order to obtain a minimum abstraction rate of 10 ℓ/min. It is thus very expensive to achieve this standard.

Thus in order to prevent the high pipe costs being incurred to achieve 10 ℓ/min the use of the on-site storage tanks could be considered at the abstraction locations in order to achieve 10 ℓ/min as used in the *Nooightgedacht* water supply project. An investigation to evaluate the condition of achieving an abstraction rate of 10 ℓ/min at the abstraction point using storage tanks was undertaken as explained below:

## 4.2. Investigation into the use of storage tanks to achieve an abstraction rate of 10 ℓ/min

During the investigation into the use of storage tanks at the abstraction locations in order to achieve an abstraction rate of 10 ℓ/min, the following assumptions were made:

**Storage tank**

- The capacity of the storage tank is 2000 ℓ with a continuous constant water flow from the network system. Flow into the tank is controlled by the use of a ball valve in the tank which regulates the flow to prevent overflowing.
- No abstraction takes place during night time (12 hours) and the tank will therefore fill during this period. The tank capacity is sufficient to supply the total demand during the day time for a period of 12 hours.
- The head of the storage tank is 2 m.
- Exit loss coefficient at the outlet of 0.6 is used to account for exit losses at the outflow valve when water is abstracted.
- The full supply level of the tank is 1.5 m.
- Minimum supply level is 0.5 m.

Analysing at 1.5 m:

At a head of 1.5 m in the tank (full supply level), the velocity, $V$ to be achieved by using a specific valve is calculated using the formula,

$$V = \sqrt{2gh}$$

where

$V$ = Velocity of flow in the valve (m/s)

g = gravitation acceleration constant ($ms^{-2}$)

$h$ = head of water in the storage tank (m)

Therefore $V = \sqrt{2 \times 9.81 \times 1.5}$

$$= 5.4 \text{ m/s}$$

Therefore, at a velocity of 5.4 m/s, in order to achieve an abstraction rate of 10 ℓ/min a minimum diameter size of valve is calculated using the continuity equation:

$$Q = C_dVA$$

where $Q$ = discharge rate

$C_d$ = Coefficient of discharge at the valve = 0.6

$A$ = Area of the opening of the valve used

and therefore $$A = \frac{Q}{C_dV}$$

$$= \frac{(0.00017)}{(0.6)(5.4)}$$

$$= 0.0000525 \text{ m}^2$$

Using the formula $$A = \frac{\pi d^2}{4}$$

Where $d$ is the diameter of the valve

We have $$d = \sqrt{\frac{(4)(0.0000525)}{\pi}}$$

$$d = 0.008 \text{ m}$$

$$= 8 \text{ mm}$$

Hence, at a head of 1.5 m, the minimum diameter size of a valve to be used in order to achieve an abstraction rate of 10 $l$/min or 0.17 $l$/sec is 8 mm. The common taps used for water supply are 15 mm and 20 mm diameter taps as described in Section 2.6.1 (d).

Analysing with a 15mm tap and a head of 1.5m with a velocity of 5.4 m/s, the discharge rate that can be achieved is calculated using the continuity equation as follows:

$$Q = AV$$

$$= \frac{\pi(0.6)(0.015)^2(5.4)}{4}$$

$$= 0.000572265 \text{ m}^3\text{/s}$$

$$= 0.57 \ l\text{/sec}$$

$$= 34.2 \ l\text{/min}$$

Analysing at 0.5m:

At a head of 0.5m in the tank (minimum supply level), velocity, $V$ to be achieved by using a 15mm valve is calculated as:

$$V = \sqrt{2 \times 9.81 \times 0.5}$$

$$= 3.13 \text{ m/s}$$

At a velocity of 3.13 m/s, the discharge rate from the valve will be;

$$Q = C_d AV$$

$$= \frac{\pi (0.6)(0.015)^2 (3.13)}{4}$$

$$= 0.00033 \text{ m}^3\text{/s}$$

$$= 0.33 \ l\text{/sec}$$

$$= 20 \ l\text{/min}$$

Therefore when the head of water in the tank drops to 0.5m a discharge rate of 20 $l$/min can be obtained.

At full supply level in the tank and at minimum supply level it is still possible to maintain an abstraction rate of 10 ℓ/min as it has been seen that at a head of 1.5m and 0.5m draw down in the tank an abstraction rate above 10 ℓ/min is achieved.

However the minimum head in the tank required to obtained a minimum flow of 10 ℓ/min is as shown below,

Since $\qquad Q = C_d AV$

And $\qquad V = \sqrt{2gh}$

Therefore $\qquad h_{\min} = \dfrac{\left( \dfrac{Q}{C_d A} \right)^2}{2g}$

$$= \frac{\left( \dfrac{0.00017}{(0.6)(0.00018)} \right)^2}{(2)(9.81)}$$

$$= 0.13 \text{ m}$$

at this minimum head the velocity that can be achieved is calculated as

$$V = \sqrt{(2)(9.81)(0.13)}$$

$$= 1.6 \text{ m/s}$$

It can be seen in the investigation that if a storage tank is used, an abstraction rate of $10l$/min as required by DWAF can be achieved without having to incur very high pipe costs as shown in the results in the previous analysis on abstraction rate. It has also been shown that at a minimum head of 0.13 m in the tank required to discharge 10 ℓ/min a minimum velocity of 1.6 m/s, above 0.3 m/s as required by DWAF can be achieved.

It should be mentioned that with this condition the other minimum standard on residual pressure will be maintained in the system at the connection point to the storage tank and therefore the head of 10m as set by DWAF required for purposes of upgrading of the systems will still be preserved.

The storage tank that can be used at the abstraction point for rural water supply is as shown in Figure 4.13.

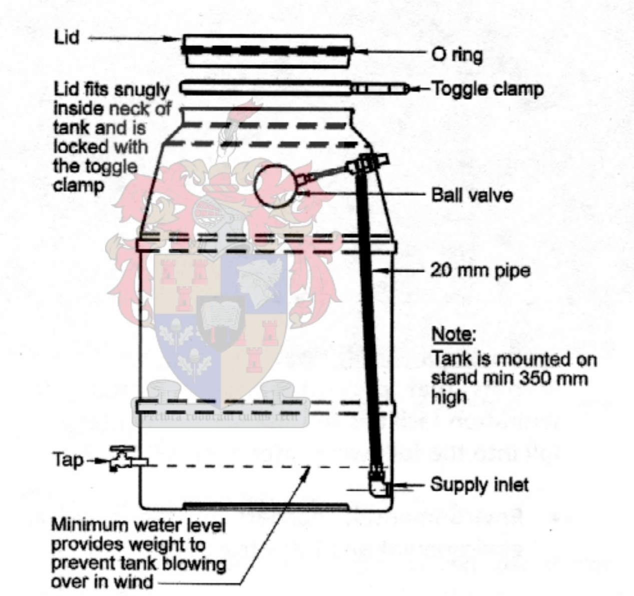

***Figure 4.13: Example of an on-site storage tank (CSIR, 2000)***

It has been proved that the demand rate above 25 ℓ/c/day can be achieved. Considering that the plastic storage tanks that can be used have a capacity of 2000ℓ, sizing of the storage volume required will depend on the populations to be served at the abstraction point in order to ensure that the required demand rate is delivered.

In communities with large populations where the capacity of one tank is not enough several tanks can be placed side by side connected to the inlet pipe in order to meet the required demand rate.

The storage capacity required should be able to provide the peak demand at peak periods. Therefore a peak factor should be multiplied with the total storage volume required in order to provide the total volume of storage that will meet the peak demand for the population to be served.

Each tank should be designed to be able to meet the instantaneous peak demand of the number of people to be served. Therefore as already discussed in Section 2.7.2.2 (d), if the rate of inflow from the inlet pipe is not sufficient to meet the instantaneous peak demand, a balancing volume has to be provided for the storage tank. The required balancing volume can be determined from the equation:

Balancing Volume = (Total consumption from the tank during peak period) – (total flow into tank during peak period)

The balancing volume will serve to equalise the difference between the total inflow capacity and the instantaneous demand at peak periods so that the tank is not drawn almost empty and people do not have to wait for the tank to fill before they can start drawing again.

## 4.3 Investigation into the requirements of a balancing volume to meet the instantaneous demand at peak period

For the *Nooightgedacht* case study, investigation of the requirements of a balancing volume to meet the demand at peak periods at the lowest cost (R 374 379) was analysed at a minimum residual pressure of 10 m as shown below:

The population at the critical node (node 60) = 4 people
The abstraction rate from the tap of the on-site storage tank = 10 ℓ/min (proved from Section 4.3.1.1)
The inflow rate into the storage tank = 0.06 ℓ/min (from Table 4.5)

Annual average daily demand rate = 25 ℓ/c/day

Therefore

The total volume of water required at peak period = Population x average demand x peak daily factor

= 4 x 25 x 3

= 300 ℓ

At instantaneous peak demand at peak periods, with an abstraction rate of 10 ℓ/min.

The time taken to satisfy the total instantaneous demand (minutes)

$$= \frac{total\ water\ demand}{flow\ rate}$$

$$= \frac{300}{10} \text{ minutes}$$

= 30 minutes

The inflow capacity into the storage tank at an inflow of 0.06 ℓ/min over 30 min

= 0.06 x 30

= 1.8 litres

Therefore the inflow capacity is not enough to meet the instantaneous demand over a period of 30 minutes. However, as mentioned, it is considered that there will be no abstraction for a period of 12 hours during the night during which the tank will be filling. Analysing the inflow capacity into the tank over a period of inflow of 12 hours,

the inflow capacity into the storage tank at an inflow of 0.06 ℓ/min

= 0.06 x 12 x 60

= 43.2 litres

Therefore the inflow capacity supplied over a period of 12 hours is still not enough to meet the required instantaneous demand at peak periods and a balancing volume would be required from the storage tank.

The required balancing storage volume is calculated from Equation (2.10)

Balancing Volume = 300 – (0.06 x 12 x 60)

= 256.8 litres

The volume required to provide storage for a period of 48 hours as required by DWAF is calculated as

= 2 x 300

= 600 litres

Therefore the total volume required for the on site storage for a period of 48 hours and for the tank to be able to meet the instantaneous demand at peak period will be the sum of the 48 hour storage volume and the balancing volume to meet instantaneous demand at peak periods.

Total volume = 600 + 257

= 857 litres

Thus the 2000 *l* capacity of the on-site storage tanks is adequate to meet the total volume required at the critical abstraction node in order to provide 48 hour storage and to meet the peak demand as well as the instantaneous demand at peak periods.

However as indicated, if one storage tank is not sufficient to provide the 48 hours storage volume, two or more storage tanks could be placed side by side connected to a single supply inlet in order to provide for 48 hours storage volume.

Therefore with the provision of storage tanks it is possible to achieve the minimum standards as set by DWAF, namely: residual pressure (10m), demand rate (25 ℓ/c/day) and abstraction rate (10 ℓ/min). These standards can be achieved at a relatively low cost.

Even if the demand rate was increased to 50 ℓ/c/day, the other standards would still be met as the only thing that would be required to increase would be the total storage volume.

## *4.4 Results of economic analysis of different rural water supply systems*

Economic analysis aimed at achieving the secondary objectives of this study. Economic analysis of the different rural water supply systems involved:

- Comparison of net present value costs of the rural water supply systems
- Sensitivity analysis of the different water supply systems

The results of each analysis are presented in this section.

### 4.4.1 Results of comparison of net present value cost

The methodology of budgeting considerations on the evaluation of the economic viability of the different systems of rural water supply was carried out as explained in Section 3.4.1

The results of this investigation have been presented in terms of the net present value of investment, in order to determine which system would require the lowest investment. The results are for three types of rural water delivery systems which can be alternative water supply options for the *Nooightgedacht water supply project.* The options are;

a) Conventional piped water supply system
b) Supply of water using wells and boreholes
c) Hauling

The results of each system are presented in the Tables 4.7, 4.8 and 4.9:

|  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **GENERAL DATA (Assumed)** |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Inflation rate |  | 7.0% per annum |  |  |  |  |  |  |  |  |
|  | Interest on Capital Redemption |  |  | 10% |  |  |  |  |  |  |  |  |
|  | Annual Pipe Maintenance Costs |  |  | 2% of Pipeline Capital Costs |  |  |  |  |  |  |  |  |
|  | Annual Reservoir maintenance costs |  |  | 2% of Reservoir Capital Costs |  |  |  |  |  |  |  |  |
|  | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first ye |  |  |  |  |  |  |  |  |  |  |  |
| **Capital costs** |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Pipeline |  | R 1,480,770 |  |  |  |  |  |  |  |  |  |
|  | Reservoir |  | R 53,529 |  |  |  |  |  |  |  |  |  |
|  | **Total** |  | **R 1,534,299** |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Annual Maintenace and operation costs (M & O)** |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Reservoir |  | R 1,071 |  |  |  |  |  |  |  |  |  |
|  | pipeline |  | R 29,615 |  |  |  |  |  |  |  |  |  |
|  | Total |  | **R 30,686** |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Calculations** |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
|  |  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** |  | 1,534,299 |  |  |  |  |  |  |  |  |  |  |
| **M & O ( R )** |  | 30,686 | 32,834 | 35,132 | 37,592 | 40,223 | 43,039 | 46,051 | 49,275 | 52,724 | 56,415 | 60,364 |
| **Cash flow ( R )** |  | **1,564,985** | **32,834** | **35,132** | **37,592** | **40,223** | **43,039** | **46,051** | **49,275** | **52,724** | **56,415** | **60,364** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| **NPV** | **R 1,829,384** |  |  |  |  |  |  |  |  |  |  |  |

*Table 4.7: Results of Net Present Value for conventional piped water supply system*

| **Borehole** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **General data (Assumed)** | | | | | | | | | | | | |
| | | Inflation rate | | 7.0% | per annum | | | | | | | |
| Interest on Capital Redemption | | | | 10% | | | | | | | | |
| **Maintenance and operation costs** | | | | | | | | | | | | |
| | | Electric pump | | 4% | of pump cost per annum | | | | | | | |
| | | Borehole | | 7% | of borehole cost per annum | | | | | | | |
| | | Resevoir | | 1% | of Reservoir cost per annum | | | | | | | |
| | | Cost of one pump | | R 20 000 | | | | | | | | |
| | | 17 boreholes to be drilled for the 17 villages in the whole Water Supply Scheme | | | | | | | | | | |
| | | It is assumed electricity is available within the scheme | | | | | | | | | | |
| | | Electric pumps to be used in the scheme: 1pump operational and 1pump on standby at each site | | | | | | | | | | |
| | | Therefore 34 electric pumps are required for the whole scheme. | | | | | | | | | | |
| | | Water distribution cost to each site = R5 000 | | | | | | | | | | |
| **Capital Cost per borehole** | | | | | | | | | | | | |
| **Establishment Cost** | | | | | | | | | | | | |
| Drilling team | | | | R 10 000 | | | | | | | | |
| Head works cost | | | | R 15 000 | | | | | | | | |
| Consulting Fees | | | | R 20 000 | | | | | | | | |
| Drilling costs | | | | R 34 000 | | | | | | | | |
| Borehole tests cost | | | | R 25 500 | | | | | | | | |
| Reservoir cost | | | | R 20 000 | | | | | | | | |
| 2 Electric pumps cost | | | | R 40 000 | | | | | | | | |
| Piped Water distribution cost | | | | R 5 000 | | | | | | | | |
| **Total** | | | | R 169 500 | | | | | | | | |
| **Total for 17 boreholes** | | | | **R 2 881 500** | | | | | | | | |
| **Annual Maintenance and Operation (M & O)costs per borehole** | | | | | | | | | | | | |
| Maintenance costs per borehole | | | | | | | | | | | | |
| Electric pump | | | | R 800 | per annum | | | | | | | |
| Borehole | | | | R 7 665 | per annum | | | | | | | |
| Reservoir | | | | R 200 | per annum | | | | | | | |
| Operation costs per borehole | | | | R 16 060 | per annum | | | | | | | |
| **Total M & O costs** | | | | **R 24 725** | per annum | | | | | | | |
| **Total for 17 boreholes** | | | | **R 420 325** | per annum | | | | | | | |
| **Calculation for 17 boreholes** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | | | | | | | | |
| **Capital cost( R )** | | 2 881 500 | | | | | | | | | | |
| **M & O ( R )** | | 420 325 | 449 748 | 481 230 | 514 916 | 550 960 | 589 528 | 630 794 | 674 950 | 722 197 | 772 750 | 826 843 |
| **Cash flows ( R )** | | **3 301 825** | **449 748** | **481 230** | **514 916** | **550 960** | **589 528** | **630 794** | **674 950** | **722 197** | **772 750** | **826 843** |
| | | | | | | | | | | | | |
| | NPV | **R 6 923 464** | | | | | | | | | | |

***Table 4.8: Results of Net Present Value for borehole system***

| **HAULING** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GENERAL DATA** | | | | | | | | | | | | |
| | | Inflation rate | | 7.0% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | | Fixed costs | | 2.07 | R/Km | | | | | | | |
| | | Running Costs | | 1.28 | R/Km | | | | | | | |
| | Total Operation and maintenance cost | | | **3.35** | R/km | | | | | | | |
| | Total distance travelled | | | 43,800 | Km per annum | | | | | | | |
| | Vehicle economic life | | | 5 | years | | | | | | | |
| | Truck cost | | | R 350,000 | | | | | | | | |
| | Cost of Employing a Driver | | | R 60,000 | per annum | | | | | | | |
| | 2 vehicles required, one operational and one on standby | | | | | | | | | | | |
| **Capital cost** | | | | | | | | | | | | |
| 2 Vehicles cost | | | | | R 700,000 | | | | | | | |
| | | | | | | | | | | | | |
| Annual Operation and Maintenance costs | | | | | R 146,730 | per annum | | | | | | |
| Annual Drivers Salary | | | | | R 60,000 | per annum | | | | | | |
| **Total Annual Operation and Maintenance Costs** | | | | | **R 206,730** | **per annum** | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **CALCULATIONS** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | | | | | | | | |
| **Capital costs ( R )** | | 700,000 | | | | | 490,893 | | | | | |
| **Maintenance Costs ( R )** | | 206,730 | 221,201 | 236,685 | 253,253 | 270,981 | 289,950 | 310,246 | 331,963 | 355,201 | 380,065 | 406,669 |
| **Cash flows ( R )** | | **906,730** | **221,201** | **236,685** | **253,253** | **270,981** | **780,843** | **310,246** | **331,963** | **355,201** | **380,065** | **406,669** |
| | | | | | | | | | | | | |
| **NPV** | **R 2,992,780** | | | | | | | | | | | |

*Table 4.9: Results of Net Present Value for hauling System*

The resulting Net Present Values (NPV) of the different systems are listed in Table 5.10

| No | System | NPV |
|---|---|---|
| 1 | Pipeline reticulation | R 1 829 384 |
| 2 | Hauling | R 2 992 780 |
| 3 | Borehole | R 6 923 464 |

*Table 4.10: Ranking of water systems regarding Net Present Value (NPV)*

It can be seen that the net present value (NPV) of the pipeline reticulation water supply option in this case a gravity fed system, has the lowest net present value of the three options and is therefore the best option.

### 4.4.2 Results of sensitivity analysis of economic factors on Net Present Value cost of different rural water supply options

In order to obtain an indication of the influence of economic factors on the Net Present Value of the conventional pipe water supply, borehole and hauling systems, a sensitivity analysis on Net Present Value cost of each of the systems was carried out on the following economic factors:

- Maintenance and Operation (M & O) costs
- Interest rate on capital cost
- Inflation rate

The results of this investigation have been presented in terms of the net present value of investment when the economic factors are varied at different percentage points from the base case scenario as explained in Section 3.4.2.

The results of sensitivity analysis on the net present value for each of the economic variables at different percentage points for each system are summarised in Tables 4.11, 4.12 and 4.13. Examples of Excel spreadsheets of how the percentage points were varied for the maintenance and operation costs, interest on redemption costs and inflation rate are shown in Appendix K for the conventional piped water supply. For the other systems, the sensitivity analysis was performed using the same procedure.

**(a) Conventional Piped Water Supply System**

The result of the sensitivity analysis on the net present value cost of the piped water supply system as a result of varying the economic factors at different percentages from the base case is shown in Table 4.11

| Deviation from Base Case (%) | Maintenance Costs NPV ( R ) | Redemption Cost NPV ( R ) | Inflation Rate NPV ( R ) |
|---|---|---|---|
| -0.30 | 1 740 859 | 1 871 845 | 1 803 533 |
| -0.20 | 1 770 367 | 1 856 644 | 1 811 824 |
| -0.10 | 1 799 876 | 1 842 521 | 1 820 436 |
| 0 | 1 829 384 | 1 829 384 | 1 829 384 |
| 10 | 1 858 893 | 1 817 150 | 1 838 680 |
| 20 | 1 888 401 | 1 805 743 | 1 848 337 |
| 30 | 1 917 910 | 1 795 097 | 1 858 370 |

***Table 4.11: Net Present Value at different deviations from base case for the pipeline option***

Based on Table 4.11, Figure 4.14 shows a graph of the sensitivity analysis of the pipeline option to the variables.

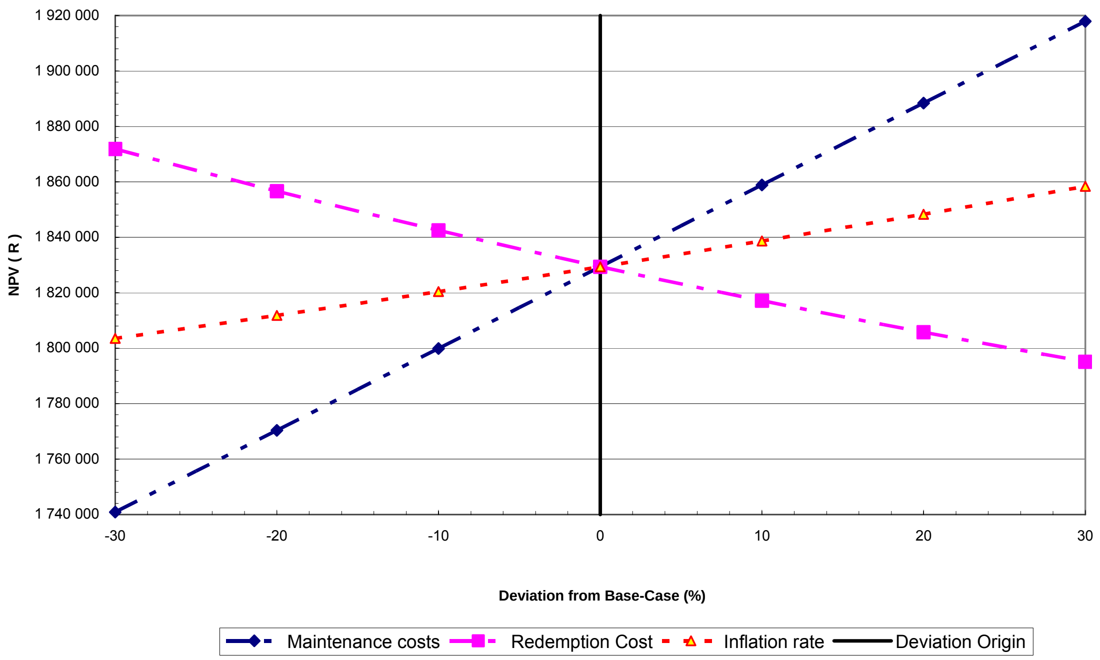

*Figure 4.14: Sensitivity analysis of the pipeline option*

It can be seen from the graph in Figure 4.14 that the Net Present Value of the pipeline option is less sensitive to changes in interest rate on capital cost followed by inflation rate but very sensitive to changes in maintenance costs. For the same percentage change in the three variables the net present value is affected most by the change in maintenance costs.

### (b) Borehole Water Supply System

Table 4.12 shows the results of the net present value at different deviation scenarios of the variables for the borehole option.

| Deviation from Base Case | Maintenance Costs NPV ( R ) | Redemption Cost NPV ( R ) | Inflation Rate NPV ( R ) |
|---|---|---|---|
| -0.30 | 5 710 875 | 7 505 075 | 6 569 361 |
| -0.20 | 6 115 071 | 7 296 858 | 6 682 926 |
| -0.10 | 6 519 267 | 7 103 408 | 6 800 903 |
| 0 | 6 923 464 | 6 923 464 | 6 923 464 |
| 10 | 7 327 660 | 6 755 886 | 7 050 790 |
| 20 | 7 731 856 | 6 599 645 | 7 183 070 |
| 30 | 8 136 053 | 6 453 808 | 7 320 496 |

*Table 4.12: Net Present Value at different deviations from base for the borehole option*

From Table 4.12, Figure 4.15 shows a graph of the sensitivity analysis of the borehole option to the variation of the economic factors.

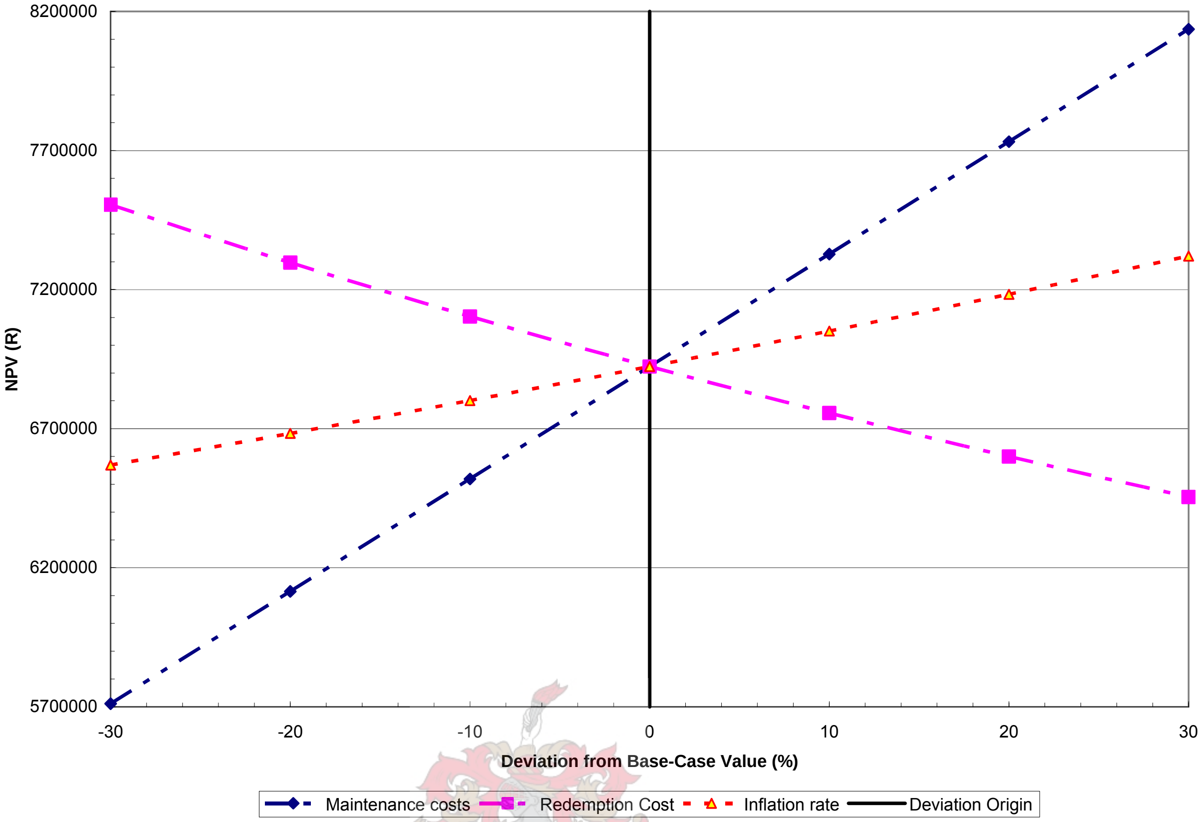

*Figure 4.15: Sensitivity analysis of the Borehole option*

For the borehole option, the same behaviour of results that was displayed in the conventional piped water supply system is seen in the graph of Figure 4.15. It is seen that the net present value is less sensitive to inflation rate where the graph is less steep, fairly sensitive to changes in the interest rate on capital redemption as its graph tilts more than the sensitivity graph of inflation rate, and very sensitive to maintenance costs where the graph is very steep

**(C) Hauling Water Supply System**

Table 4.13 shows the results of the net present value at different deviation scenarios from the base case of the variation of the economic factors for the hauling option

| Deviation from Base Case | Maintenance Costs NPV ( R ) | Redemption Cost NPV ( R ) | Inflation Rate NPV ( R ) |
|---|---|---|---|
| -0.3 | 2 396 388 | 3 324 030 | 2 789 861 |
| -0.2 | 2 595 185 | 3 205 715 | 2 855 050 |
| -0.1 | 2 793 983 | 3 095 523 | 2 922 660 |
| 0 | 2 992 780 | 2 992 780 | 2 992 780 |
| 1 | 3 191 577 | 2 896 875 | 3 065 505 |
| 2 | 3 390 375 | 2 807 255 | 3 140 932 |
| 3 | 3 589 172 | 2 723 419 | 3 219 162 |

*Table 4.13: Net Present Value at different deviations from base for the hauling option*

From Table 4.13, Figure 4.16 shows a graph of the sensitivity analysis of the hauling option to the variation of the economic factors

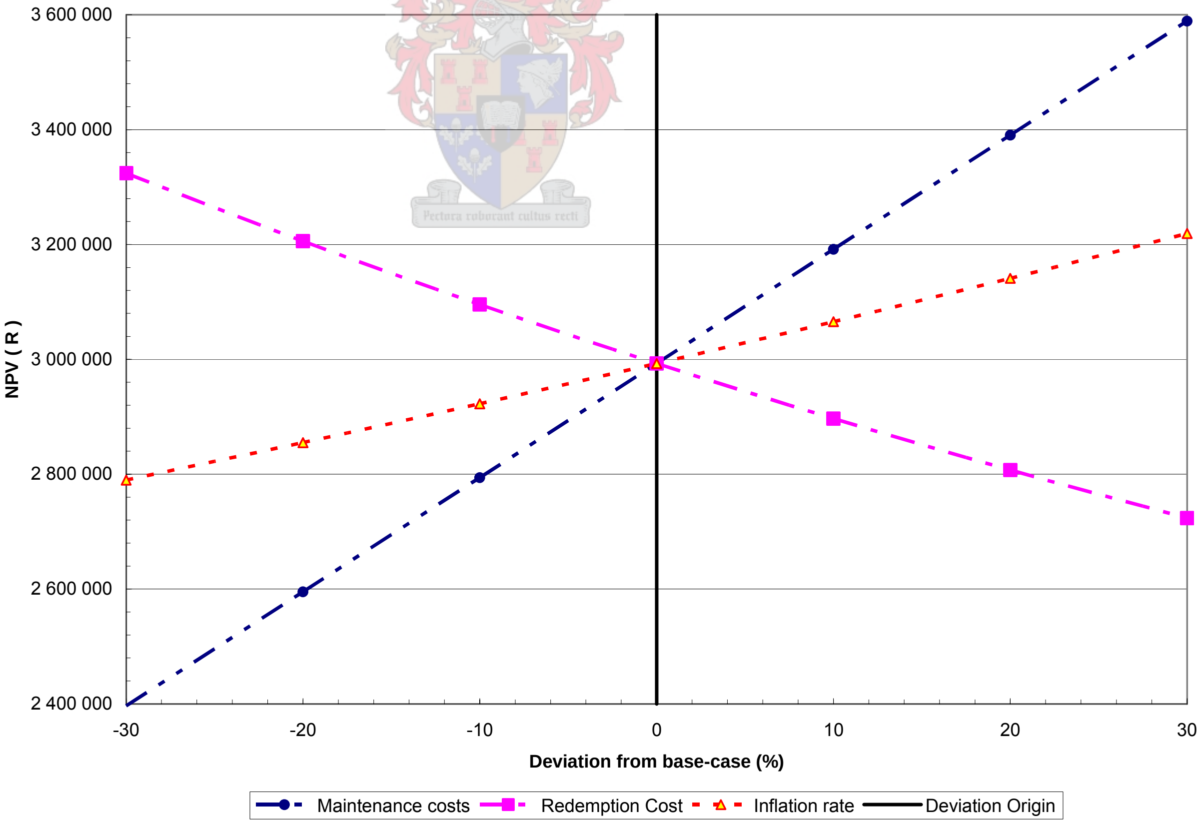

*Figure 4.16: Sensitivity analysis of the hauling option*

The same behaviour of results as shown for the pipeline and borehole systems is shown in the results of the hauling option. The net present value of this project is less sensitive to inflation rate, fairly sensitive to interest on redemption cost and very sensitive to maintenance costs.

For all the three water supply systems, it has been seen that out of the three economic factors analysed, it is the maintenance and operation costs that influence the net present value cost of the systems the most followed by redemption cost and lastly inflation rate.

## 5.0 CONCLUSIONS

Considering the findings of this study as discussed in Section 4, the following conclusions are drawn based on the study objectives:

It should be mentioned that, since the analyses in this study were carried out on a specific case study which is a gravity fed system, the findings, conclusions and objectives drawn from this study are applicable to gravity fed systems only and specifically to this case study project and scenarios which the case study can be considered to be generally representative of.

### *5.1 Evaluation of minimum standards of rural piped water supply systems*

Based on the findings of the evaluation of the minimum standards carried out on the *Nooightgedacht* case study project the following conclusions can be reached for a gravity fed system:

1. Demand rate and residual pressure

    - It is feasible to achieve the current standards of residual pressure and a demand rate at 10 m and 25 ℓ/c/day as set by DWAF at low investment cost.

    - The study indicated that for a small percentage increase in pipe cost, it is possible to increase the demand rate to 50 ℓ/c/day without dropping the residual pressure below 10 m. DWAF considers a demand rate of 50 ℓ/c/day as the target for the minimum level of service on condition that there is enough assurance on the availability of water.

    - It was found that, while the demand rate was increased to 50 ℓ/c/day at a relatively small percentage increase in pipe cost, it was also possible to increase the residual pressure to 15 m.

      It was shown that with a 15% increase in pipe cost a demand rate of 87 ℓ/c/day could be achieved without dropping the residual pressure below 10 m. This represents a 164% increase in demand and is above the maximum possible target demand rate of 50 ℓ/c/day as suggested by DWAF.

      It was also shown that with a 15% increase in pipe cost, if the demand rate is fixed at 50 ℓ/c/day, a residual pressure of 15 m can be achieved. Similarly fixing the residual pressure at 15 m, a demand rate of 69 ℓ/c/day was obtained representing a 165% increase in demand rate from the initial demand obtained at this pressure.

      Significant gain in demand rate was achieved by increasing the pipe cost by 15%. The increase in pipe cost is therefore justified, taking the associated benefit that can be achieved into consideration.

2. Abstraction rate

- An abstraction rate of 10 ℓ/min was found to be too high to be met at a low cost, at a residual pressure of 10 m as set by DWAF. Very high investment costs have to be incurred in order to meet this standard.

  At the lowest cost case analysed at which DWAF minimum standards on the demand rate (25 ℓ/c/day) and residual pressure (10 m) were achieved, the minimum abstraction rate (10 ℓ/min) could not be achieved without a substantial increase in capital cost

3) On-site storage tanks

- In order to achieve the minimum abstraction rate of 10 ℓ/min, storage tanks with a minimum head of 2 m, have to be used at the abstraction point. This ensures that all the standards are met at a relatively low cost.

- With the use of storage tanks, it is possible to achieve a demand rate of 25 ℓ/c/day and a residual pressure of 10 m at the lowest cost and also satisfy the abstraction rate of 10 ℓ/min.

  However, a residual pressure of 10 m is not available to the end user by supplying via the tank tap, nonetheless it can be maintained at the connection point to the storage tank and could be utilised for upgrading of the system to a yard connection when the need arises.

It is generally concluded that of the three minimum standards that are required for rural pipe water supply in terms of the minimum level of service, the abstraction rate is the most critical to achieve.

The results have indicated that the current standard of residual pressure and demand rate of 10 m and 25 ℓ/c/day respectively can be met at a low cost and this would render the systems affordable, but the current standard of flow rate at 10 ℓ/min is difficult to achieve at such a low cost. However the introduction of a storage tank in the design will ensure that the standard on abstraction rate can be met.

In line with the government's objective to increase the minimum water demand to 50 ℓ/c/day (DWAF, 1997), it is predicted that 50 ℓ/c/day can be delivered with a small percentage increase in cost. The associated benefit that can be achieved is significant. It is therefore worthwhile to consider increasing the standard on residual pressure and demand rate for design purposes if an adequate assurance of water supply is available.

### *5.2 Conclusion on economic cost analysis of different rural water supply systems*

Based on the results of the economic cost analysis carried out on the *Nooightgedacht* case study project involving a cost comparison of the water systems, and a sensitivity analysis of the economic factors that influence the net present cost of the systems, the conclusions drawn are as presented:

1. The conventional pipeline water supply system (gravity fed system) is the most economic option to consider as the cost over the life of the project is lower when compared with the other options using the net present cost when capital, operation and maintenance costs are considered.

2. The results indicate that capital expenditure should not be used in isolation to make a decision regarding cost effectiveness of preferred water supply options. The study has proved that, although hauling does have the lowest capital cost, the pipeline system still provides the lowest net present value. This is due to the very high annual maintenance and operation costs of the hauling option.

3. Therefore the low maintenance and operation costs of the pipeline system (gravity fed) indicate that the system is more sustainable than the other systems, followed by the hauling system and then the borehole system.

4. The net present cost of the three water supply options is mostly affected by the change in maintenance costs followed by the interest rate on capital redemption and lastly by change in inflation rate.

   This result emphasises the need for maintenance and operation costs not be isolated in making a decision of a preferred water supply option, especially where sustainability of a preferred option in terms of financial factors is being considered.

   Therefore in selecting a system to use for rural water supply, one should critically look at how the maintenance costs will vary during the economic life of the system.

# 6.0 Recommendations

## *6.1 Evaluation of minimum standards for rural piped water supply systems*

For a rural gravity fed water supply system specifically one of which the *Nooightgedacht* case study project is representative, the following recommendations are made:

- Depending on the topography of a specific area and hence the available head, the minimum pressure of 10m could be increased to 15 m without many cost implications.

- With an adequate assurance of a sustainable water supply available, increasing the demand rate to 50 ℓ/c/day could be considered. At this demand rate the full range of water use for the basic level of service will be met with only a small increase in capital cost from what could be spent to meet the present standards.

- The current standard of a flow rate of 10 ℓ/min should be reconsidered because of its negative influence on capital pipe costs. As an alternative to achieving a flow rate of 10 ℓ/min and at a relatively low cost, on-site plastic storage tanks could be used.

  Although 10 ℓ/min will be obtained using on-site storage tanks the head at the supply pipe to the user might not satisfy the DWAF minimum requirement of 10 m. Nonetheless a residual pressure of 10m will be achieved at the connection point to the storage tank which could be required for the upgrading of the system.

## *6.2 Economic cost analysis of different rural water supply systems*

- Although each project needs to be evaluated separately, the conventional pipe reticulation proves to be the best option in the *Nooightgedacht* case study project and could be the best option in projects of similar scenario and should therefore be evaluated.

- The low capital hauling option proves to be very expensive due to its high maintenance and operation costs and should not be considered if alternative water sources are available.

- Maintenance and operation costs need to be calculated and evaluated carefully before any final decision is made, since the net present value proves to be extremely sensitive to changes in maintenance and operational costs.

## 7.0 References

(1) Automobile Association of South Africa. 2005. *Automobile Association of South Africa Rates for Vehicle Operating Costs.*
Site visited: August 3rd, 2003
Available: http://www.aa.co.za/live/content.php?Item_ID=593

(2) Babbit H. E, Doland J.J. and Cleasby J.L. 1962. *Water Supply Engineering, Sixth Edition.* McGraw-Hill Book Company. (pp 22-23, 45-60)

(3) Carter R.C, Tyrrel S.F. and Howsam P. 1996. *Strategies for Handpump water supply Programmes in Less Developed Countries.* Journal of the Chartered Institution of Water and Environmental Management. Volume 10. No 2 (pp 130-136)

(4) Chadwick A. and Morfett J. 1985 *Hydraulics in civil Engineering.* Allen and Unwin, London

(5) Chow, V. 1969. *Handbook of Applied Hydrology*. McGraw-Hill Book Company. (pp 13-17)

(6) CSIR, Building and Construction Technology. 2000. *Guidelines for Human Settlement Planning and Design (The Redbook).* Chapter 9. Revised 2003

(7) Department of Water Affairs and Forestry (DWAF). 1997a. *White Paper on Water Policy*

(8) Department of Water Affairs and Forestry (DWAF). 1997b. *Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation Programme.* First Edition.

(9) Department of Water Affairs and Forestry (DWAF). 1999. *Guidelines for the Provision and Maintenance of Community Water Supply Schemes*

(10) Department of Water Affairs and Forestry (DWAF). 2002 *Guidelines for Compulsory National Standards and, Norms and Standards for Water Services Tariffs*
http://www.dwaf.gov.za/Documents/Other/WS/Booklet-Guidelines to S9 and S10 regs March-2002_.doc

(11) Department of Water Affairs and Forestry (DWAF). 2003a, *Strategic Framework for Water Services*

(12) Department of Water Affairs and Forestry (DWAF). 2003b. *Cost Benchmarks: Typical Unit Cost for Water Services Development Projects.* A Guide for Local Authorities

(13) Deborah A. and Bob E. 1999. *Integrated Development for Water and Sanitation, Low Cost Technology Drilling Techniques* 25th WEDC conference, Addis Ababa, Ethiopia.

(14) Fair, G.M. and Geyer, J.C. 1954. *Water Supply and Waste Water Disposal.* John Wiley and Sons, Inc (pp 29-30)

(15) GLS Engineering Software. 2003. *Wadiso SA Software Program* Version 4.0

(16) Government of Malawi. 2001. Ministry of Water Development, *Design and Technical Specification for the Construction of Water Supply Facilities in Rural Areas*. Technical Manual. (pp 5-23)

(17) Government of Tanzania, Ministry of Water. 1997. *Design Manual for water Supply and Waste Water Disposal.* Volume 1 (pp 35-38)

(18) Harvey, P.M. and Kayaga, S.M. 2003. *Sustainable Handpump Projects in Africa*. Report on fieldwork in South Africa. WEDC, Loughborough University, UK (pp19-25)
http://wedc.lboro.ac.uk/projects/proj_contents/WEJWHandpumps/www/outputs/SouthAfrica report.pdf

(19) Harvey P.A. and Reed P. 2004. *Rural Water Supply in Africa: Building Blocks for Handpump Sustainability*, WEDC, Loughborough University, UK

(20) Hawawini, G. and Viallet, C. 2000. *Finance for executives*, 2nd Edition. South-Western Thomson Learning. USA (pp 185-198)

(21) Hazelton, D.G. 2000. *The Development of Effective Community Water supply Systems Using Deep and Shallow Well Handpumps*, *Report No. TT 132/00*, Water Research Commission. (pp 1-15).

(22) Illemobade A.A. and Stephenson D. 2003. *Generic Optimisation of Small Water Reticulation Networks using Water Decision Support System (Wadessy)* Technical paper, Journal of the South African Institution of Civil Engineering, 45(4) 2003. (pp 2-9)

(23) Kerr C. 1988 *Community Water Development* Intermediate Technologies Publication Ltd, London. pp 72 – 93

(24) Morgan P. 1990 *Rural Water Supplies and Sanitation* Macmillan

(25) Norwegian Agency for Development Coorperation (NORAD) and Department of Water Affairs and Forestry (DWAF). 2003. *Standard Descriptors of Boreholes*. Version 1.0

(26) Pearson, L.A. Bhagwan, J. Kariuki, W. and Banda, W. 2002. *Guidelines on appropriate technologies for water supply and sanitation in developing communities.* Water Research Commission Report No 520/1/01,

(27) Rural water systems. *Handpump option in Africa*. Site visited: June 4, 2005
Available: http://www.handpump.org/
Directly available: http://www.handpump.org/handpump.htm

(28) Shaw R. 1999. *Running Water* International Technical Publications, London

(29) Skinner B.H and Shaw R.J. 1992. *Protecting Springs – An Alternative to Spring Boxes* Technical Brief No 34, Waterlines: Journal of Appropriate Technologies for Water Supplies and Sanitation. pp 15 – 18

(30) Stapleton C.K. 1983. *Tube Wells and their Construction* Waterlines Volume 2 No 1. IT Publications

(31) Steel E.W. 1960. *Water Supply and Sewerage*, *Fourth Edition* McGraw-Hill Book Company Inc. Tokyo

(32) Streeter V.L, Wylie B.E and Bedford K.W. 1997. *Fluid Mechanics* 9th Edition McGraw-Hill Book Company

(33) Turneaure F. E. and Russel H. L. 1947. *Public Water Supplies,* Fourth Edition, John Wiley and Sons, Inc. (pp 32, 97)

(34) Todd, David K. 1980. *Groundwater Hydrology,* 2nd Edition. John Wiley and Sons. (pp 42-44, 165-184).

(35) Twort A.C, Hoather R.C and Law F.M. 1974. *Water supply* 2nd Edition, Edward Anold, London

(36) United States Army Corps of Engineers (USACE). 1999. Technical Manual *EM 1110-2-142,1 Groundwater Hydrology Engineering and Design*

(37) Van Schalkwyk A. 1996. *Guidelines for the Estimation of Domestic Water Demand of Developing Communities in the Northern Transvaal*, Water Research Commission, Report No 480/1/96. (pp 13-31)

(46) Water aid. *Gravity Schemes*
http://www.wateraid.org.uk/site/in_depth/technology_notes/296.asp

(47) Water aid. 2004 *Rainwater Harvesting*
http://www.wateraid.org.uk/site/in_depth/technology_notes/301.asp

(38) Water for the world. 2005. *Methods of Developing Sources of Groundwater* Technical note No RWS 2.M. Site Visited: May 20, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws2m.pdf

(39) Water for the World. 2005. *Designing Driven Wells* Technical Note No RWS 2.D.2 Site Visited: May 20, 2005.
Available: www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws2d2.pdf

(40) Water for the World. 2005. *Designing Bore or Augered Wells* Technical Note No RWS 2.D.4. Site Visited: May 20, 2005
Available: www.lifewater.org

Directly Available: http://www.lifewater.org/resources/rws2/rws2d4.pdf

(41) Water for the World. 2005. *Designing Cable Tool Wells* Technical Note No RWS 2.D.5. Site Visited: May 20, 2005
Available: www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws2d5.pdf

(42) Water for the world. 2005. *Methods of Developing Sources of Surface Water* Technical note No RWS 1.M. Site Visited: May 20, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws1/rws1m.pdf

(43) Water for the world. 2005. *Designing Intakes for Ponds, Lakes and Reservoirs* Technical note No RWS 1.D.2. Site Visited: May 23, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws1d2.pdf

(44) Water for the world. 2005 *Designing Intakes for Rivers and Streams* Technical note No RWS 1.D.3. Site Visited: May 23, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws1d3.pdf

(45) Water for the world. 2005. *Designing a System for Gravity Flow* Technical note No RWS 4.M Site Visited: May 23, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws4m.pdf

(46) Water for the world. 2005. *Evaluating Rainfall Catchments* Technical note No RWS 1.P.5 Site Visited: May 23, 2005
Available www.lifewater.org
Directly Available: http://www.lifewater.org/resources/rws2/rws4m.pdf

(47) Watt S.B. and Wood M. 1985. *Hand-dug wells and their Construction* International Technology Publication, London

(48) Webster M.J. 1999. *Effective Demand for Rural Water Supply in South Africa: Technical and financial implications of designing to meet demand*. WEDC, Loughborough University, UK.
http://www.wedc.lboro.ac.uk/publications/pdfs/edrwssa/edrwssa.pdf

(49) Wood M. 1994. *Are Handpumps really affordable*, 20th WEDC Conference, Colombo, Sri Lanka. (pp 3)

(50) Ajay Industrial Corporation. 2004. *Handpumps*. http://www.ajayindcorp.com

(a) *India Mark II Handpump*

(b) *India Mark III Handpump*

(c) *Afridev Handpump*

# APPENDIX A

# HANDPUMP OPTIONS AND THEIR SPECIFIC APPLICATIONS

| Type of pump | Depth of operation | Delivery rate (litres/hour) | application | Advantages | Disadvantages |
|---|---|---|---|---|---|
| Volanta | 50-80m and more | 240 | Deep wells | • The water point can further be equipped with other water facilities like a public tap and laundry facilities<br>• Improved hygiene around the borehole<br>• Where large amounts are needed the pump can be equipped with a solar or diesel powered system<br>• It is easy to install and requires low maintenance costs | • In deep water tables a problem arises when using PVC rising mains. While pumping, pressure fluctuations develop in the rising main causing the PVC pipe to contract and expand. This results in a reduction in the water discharge and eventually failure of the pipe |
| Bush hand pump | 10-80m or more depending on cylinder size used | 1800 for 10m-540 for 60m | Medium and Deep wells | • Low cost<br>• One pump can serve up to 500 people<br>• Removable parts have minimal resale value, therefore risk of theft is low<br>• Easy to install and maintain | • Use is limited to small communities |
| Afridev handpump | 10-45m | 900 - 1350 depending on depth | Deep wells | • Functions well in corrosive water<br>• It has an adjustable handle to suit various installation depths<br>• Easy installation and low maintenance costs<br>• Lightweight uPVC riser pipes hence easy to handle | • Spare parts easily breakdown |
|  | 45m | 720 | Deep wells | • Functions well in corrosive soils<br>• Reliable and proven community handpump<br>• Pump can be easily adapted for use with a windmill or for motorized operation | • |

| | | | | | |
|---|---|---|---|---|---|
| India Mark II | | | | • Easy operation and installation<br>• Low maintenance costs<br>• Spare parts are easily available<br>• It is suitable for open well installations<br>• The design provides adequate sealing of the borehole, thereby avoiding contamination by external sources | |
| India Mark III | 45 | 600-900 depending on diameter of riser pipe | Deep wells | • Lower capital costs<br>• It has an option of using a PVC or galvanized iron riser pipe depending on its use<br>• It can be used in unlined wells<br>• Easy maintenance | • Its use is limited to non corrosive waters |
| Vergnet handpump | 30-100 | 600-1500 depending on depth of lift | Deep and shallow wells | • Low maintenance costs<br>• Easy maintenance since all standard wear parts are at ground level<br>• install<br>• Can be used by a wide range of users, from young children to strong fully grown men. | • High capital costs. |
| Windmill pump | | 380-12000 | | • It can be used in a situation where resources are not available to pipe or haul the water nearer to the point of use<br>• It can be used where it is beyond the capability of the village community to operate a more complicated system<br>• It can be used where the water source has a small yield | • Risk of contamination of water when being carried home is high |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Mono pump | 25-60 | 9-16 depending on the depth of well | Deep and shallow wells | • This is a robust and durable pump | • Difficult to maintain at village community level |
| Barry pump | 10 - 100 | | Medium and deep wells | • Does not require an expesive diaphragm down the hole<br>• It is simple to maintain and repair | • Skilled labour is required as wear parts are located at the bottom of the riser pipe.<br>• Wearing out of the submersible unit due to rubbing against the side of the borehole.<br>• Pumping rates are lower |
| Bucket pump | 15 | 600 | Shallow wells | • Technology is simple and can be manufactured in any small town<br>• Repair is easy and no specialist is required | • Not appropriate for deeper groundwater areas<br>• Slow delivery rate of water |
| Tara pump | 18 | 1440 | Shallow and medium wells | • Corrosion resistance<br>• Simple maintenance<br>• Easy installation<br>• Low pump cost | • |

**Table A1: Type of handpump options**


Pectora roborant cultus recti


Pectora roborant cultus recti


Pectora roborant cultus recti


Pectora roborant cultus recti


Pectora roborant cultus recti

# APPENDIX B

# SCHEMATIC LAYOUT SHOWING LOCATION OF NOOIGHTGEDACHT WATER SUPPLY PROJECT

# APPENDIX C

# DESCRIPTION AND DESIGN USING WADISO SA (VERSION 4.0)

## B1.0 WADISO SA SOFTWARE

Wadiso SA version 4.0 (GLS Engineering software Ltd) was used in this study to design and carry out the hydraulic computations for the Nooightgedacht rural water supply project in order to evaluate the minimum standards with respect to capital pipe cost.

"Wadiso SA" program is a tool for designing, planning and analysis of water distribution systems. It allows for steady state analysis, optimisation, extended time simulation and water quality simulation of complex distribution systems. The program relies on the EPANET or WADISO hydraulic analysis engines which employ the nodal method to determine flow characteristics in a water distribution network system.

The nodal method uses the Hazen-Williams or the Darcy-Weisbach equations to calculate friction head losses in a distribution pipeline network. In the program, a network consists of pipes, nodes (pipe junctions and abstraction nodes), pumps, valves and storage reservoirs.

*EPANET* or *WADISO* hydraulic analysis engines models a water distribution network system as a collection of links connected to nodes and reservoirs. The links represent pipes, pumps and control valves. Thus the program is able to model and track the flow of water in each pipe, the pressure at each node, and the flow of water into or out from each node and reservoir.

The program has a CAD environment in which most of the data capturing, model editing and viewing of results can be done. The three basic modules of the program which can be used separately or in an integrated manner are:

- Steady State Simulation – this is the part of the software which calculates the level of the energy gradeline and pressure at each node, the flows and head losses in each pipe, flow and head for each pump and mode of operation for any type of valve available in a water supply pipe network. This simulation works for looped and branched networks.

- Time/Water Quality Simulation – For checking system performance and water quality over an extended period under fluctuating demand and operational conditions

- Optimization – To size pipes, pumps and storage tanks to meet certain design criteria (e.g. minimum pressures) whilst ensuring an economically optimal solution

### *B1.1 Steady state simulation*

This is the basic module that is used in the design of a water supply scheme, which allows for the input and editing of system data and parameters, and which calculates the flow and pressure distribution in the system under specific steady state conditions.

The steady state condition assumes that all demands and pressures should be met at the same time and at all points of delivery according to the required specifications. Such calculations allow the user to analyse existing systems, to determine reasons for bad system performance and to develop improvement schemes.

### *B1.2 Time and water quality simulation*

The time and water quality simulation module permits network simulation over a period of time. Such analysis will let the user determine reservoir water level and pressure fluctuations over extended time periods and is required in particular to determine required tank volumes.

It provides a means to simulate water demand as a function of time, to control pumps and valves through time or pressure switches, and to simulate fire flows and pipe breaks.

The water quality option allows for the tracking of a dissolved substance in the system, the tracing of a water source, or water age analysis.

### *B1.3 Optimisation*

This module allows for the determination of future improvement needs, with the objective being to minimize capital expenditure and present worth of operational costs, while adhering to specified operational criteria. The cost trade-off between pipes and pumping costs, and pipes and storage cost are taken into account for the optimization. The optimisation routine may also provide alternative solutions, which are near optimum.

In this research the steady state simulation module has been used in the design and analysis of the network system since the pipe size configurations are pre-selected and the objective was to observe the variation of the minimum standards as the pipe configuration changes.

A set of selected values of minimum standards was fixed and a steady state condition was analysed at all the abstraction nodes as the pre-selected configurations are tested one by one on the designed system. The evaluation of the minimum requirements is therefore also based on the steady state simulation.

### *B2.0 Description of Wadiso SA and Design of the Nooightgedacht water supply project*

The following is a description of the components of "Wadiso SA version 4" and how the program was used to design the *Nooightgedacht* water supply system. The design involved the setting up of the project and upon setting up the project, the entry of input parameters in the different component parts of the program was done using the steady state module.

Once the input of design data was done, the designed system was balanced using the engaged network solver(EPANET or WADISO) to calculate the friction head losses in the system and check that the specified minimum standards can be met in a steady state condition for the parameters entered.

### *B2.1 Setting up the project*

The user interface of the program has eight items each directing the user to a different module of the programme. The items are:

- File
- Steady state
- Optimisation
- Cost data
- Time/water quality simulation
- Cad graphics
- Window
- Help

In order to carry out a design project in *Wadiso SA*, the program requires the user to set up the project settings to define the parameters and tools to be used in the analysis of the system. During the design of the project the “file” tab chosen from the user interface was used to set up the project. In setting up the project the “file” menu allowed the user to specify the job name, select a unit system, flow equation and a network solver to be used for the hydraulic computations.

In order to set up the project, “project settings” was chosen from the drop down menu of the “file tab” in order to specify the parameters that will be used in designing and balancing the network system.

In the “project settings” menu, the following project settings were defined

- Co-ordinate mode was set to ON. This mode requires the user to enable the program to use the geometric co-ordinates of the nodes to be used so that the project layout can be modelled.

- “WADISO” network solver was specified. The other solver that can be specified is the “EPANET” network solver. The network solver is the one which is used by the program to balance the system by calculating the friction head losses in a system. In balancing the system the network solver checks if the design parameters specified for the operation of the system can be met.

  “EPANET” network solver is specified if the system has any nodes with emitter coefficients other than 0.0, any pump with a multi point curve or with a relative speed > 1.0, otherwise “WADISO” network solver is specified. The system data for this project did not contain these parameters hence specifying the “WADISO” network solver.

- The Hazen-Williams flow equation was specified for use in the calculation of the friction head losses and the associated flows in the system.

  The Hazen-Williams is given as:

$$h_f = \frac{10.675 * L * Q^{1.85}}{C^{1.85} * d^{4.87}}$$

Where:

$h_f =$ Head loss due to friction (m)

L = Length (m) of pipeline

Q = Required discharge rate ($m^3/s$).

C = Hazen-Williams roughness coefficient

d = Diameter of pipe (m)

- The default diameter that was used for the system is 100 mm. The program will assume this pipe size when running the program, when no diameter is specified in the "link topology" table. Link topology is explained in section B2.2.1.1. However for this project different pipe size configurations are specified as input to evaluate the minimum standards.

- The Hazen-Williams coefficient was specified as 125.

- The unit-system used in the design was metric (SI) units. Metric units used are:

  Length = metres (m)
  Flow = litres per second (l/s)
  Diameter = millimetres (mm)
  Pressure = metres (m)

- Description of the project.

  The project was specified as "*Nooightgedacht rural water supply project*".

### *B2.2 Steady state analysis input data requirements*

Upon entering the project settings, the next step in the design of the project was to enter and define the steady state analysis input data.

In order to enter data required in design for the steady state analysis, the "Steady State" module was selected from the user interface. In the drop down menu of this module three functions are displayed namely:

- Edit system data
- Balance system
- View results

"Edit system data" function allows the user to enter the input design data required to define a projects network system layout and the system data required for hydraulic computation for the steady state analysis.

"Balance system" allows the user to check the hydraulic adequacy of the system for the data entered in the "Edit system data" for the steady state condition. Balance system function engages the network solver to solve the hydraulic equations through an iterative process using the nodal method. Thus pressure and flow distributions in the system are calculated.

“View results” allows the user to view the steady state analysis results upon balancing the system allowing the user to analyse the designed system, determine reasons of bad system performance and develop improvement schemes. .

To enter the data required to design the system for the steady state analysis, the “Edit system data” tab was selected from the drop down menu of the “steady state” module chosen from the user interface.

Upon selecting the “Edit system data” the “Edit system data ” menu is displayed in which the input data required for designing a system is entered in spreadsheet tables selected under different tabs in this menu. The terms of the data entered in the tables selected under the different tabs and their definitions are explained below:

- Links.

  These are pipes that convey water from one node to another. Flow direction is from the end with a higher hydraulic head to that at lower head. A link can also be a pipe joined to a valve or to a pump. The pipe is assumed to have a constant diameter between the two nodes it connects. The principal hydraulic input parameters for a link are:

  - Start and end nodes
  - Diameter
  - Length
  - Roughness coefficient (for determining head loss)
  - Status (open, closed, or contains a check valve).

  The status parameter allows pipes to implicitly contain shutoff (gate) valves and check (nonreturn) valves (which allow flow in only one direction). Pipes can be set open or closed at preset times or when specific conditions exist, such as when tank levels fall below or above certain set points, or when nodal pressures fall below or above certain values. Computed outputs for pipes will be:

  - Flow rate
  - Velocity
  - Head loss.

  The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls is computed using the Hazen-Williams or the Darcy-weisbach.

- Nodes.

  These are the end points of links where water enters or leaves the network. One or more links connect a node to the network. In this project the nodes include the water supply points where water is abstracted by the water users within the water distribution system. The basic input data required for junctions are:

  - Elevation above some reference (usually mean sea level)
  - Water demand (rate of withdrawal from the network).

The output results computed for junctions at all time periods of a simulation are:

- Hydraulic head (internal energy per unit weight of fluid)
- Pressure.

- Reservoir/Tank.

  This is also considered as a node with a storage capacity in “Wadiso SA” environment. It has a known water level or hydraulic grade line. The node ground elevation is the elevation of the foot of the tank.

  The tank water level indicates the vertical distance from the foot of the tank to the free surface. In “Wadiso SA”, the net inflow or outflow from the tank is computed by the program and therefore it cannot be assigned a flow input or flow output.

- Output.

  This refers to the rate of water extraction, which is withdrawn from the system at a node. In Wadiso SA, a node with varying output cannot be assigned simultaneously a constant head.

In order to complete the design process of Nooightgedacht water supply project the design data was entered in different tables in the “system data editor” menu under the “steady state” tab of the main menu as mentioned.

### B2.2.1 Data entry in the system data editors menu

The input data required for the design of the Nooightgedacht project was entered under the “system data editor” tab where several tables are selected to enter the design data.

The input system design data on the distribution system is handled by “Wadiso SA” in these different tables:

- Link (pipe) topology table
- node topology table
- pipe/CV (check valve) table
- node table
- tank table

#### B2.2.1.1 System topology

System topology refers to the way the various links (pipes) and nodes of the network are linked together. In order to define the projects system layout, the design of the system required the entry of system data in the “topology” section of the “systems data editors” menu. In this section the link topology data and the node topology data are entered.

a) Link topology table

The “link topology table” is accessed by selecting “links” from the “topology” tab in the “system data editor” menu. This table is for the basic data describing the links or pipes in the system. For each link in the system, the following link topology items were required

- Link number or pipe number.

  The program requires the entry of a unique integer number for the link, between 1 and 100 000

- Type of link.

  This can be a pipe, with or without a check valve, a pump or a valve.

- The two nodes which are connected by the link and the geometric route of the link between the two nodes need to be entered.

  FROM NODE, the integer number of the node on the one end of the link
  TO NODE, the integer number of the node on the other end of the link

- Intermediate co-ordinates Y1, X1 to Y5, X5.

  These are pairs of co-ordinates describing the geographic route of the link between the “from node” and the “to node”. If none are entered, the link follows a straight line between from and to nodes.

Thus a link is defined by its link number, and the number of the two nodes it connects. The links do not need to be numbered consecutively. These inputs are entered in “link topology table”

The mentioned inputs were entered in a spreadsheet window of *Wadiso SA* under link topology window as shown in Appendix D for input data.

b) Node topology

The “Node topology table” is accessed by selecting “Nodes” from the “topology” tab. This table is for the basic data describing the nodes in the system. The following node topology inputs were required for each node:

- Type.

  The type of the node, i.e. one of the following two

  - Node: which is an ordinary node at which the water pressure can fluctuate and at which an output or an input can be modelled
  - Tank: this is a node representing a reservoir, storage tank or elevated tank. It has a fixed water level and therefore also a fixed pressure

- Number.

  A unique integer number of the node, between 1 and 100 000. The nodes do not need to be numbered consecutively.

- Elevation.

  The ground elevation of the node in height units above a datum level

- X Y co-ordinates.

  The geographic location of the node.

Typical node input data that has been used in the design for the node topology is shown in Appendix D.

Once the data defining the topology of the *Nooightgedacht* project was entered, the next input data required was the node and link data. The node and link data describe the characteristics for the links and the nodes defined in the "Topology" section above.

Data describing the link (pipe) characteristics is entered in the "Pipe/Check Valve" table under "Link data". Data describing the node characteristics is entered in the "Node" and "Tank" tables under "Node data". "Node data" and "Link data" functions are accessed from the "system data editors" menu.

#### B2.2.1.2 Pipe/CV (Check valve) table

As mentioned above, this table is accessed from the "Link data" section under the "System data editors" menu. For each pipe that was defined in the "link topology table", the pipe characteristics are required. The "pipe/CV table" is used to specify the pipeline characteristics (properties) associated with each pipe. The pipe/CV input data items required for entry was as follows:

- Diameter.

  This is the diameter of each pipe in the network.

- Calculated length.

  This is the length calculated internally by the program, based on the geographic route of the Pipe.

- User Length.

  This is an optional item, which, if entered will override the calculated length based on the geographic route of the Pipe. This feature has not been used in the design of the scheme. The lengths that have been used are the calculated lengths.

- Coefficient.

  The roughness coefficient of the pipe i.e. the C-value if the Hazen-Williams flow equation is used, or the absolute roughness if the Darcy-weisbasch flow equation is selected. Selection of the flow equation is optional. The program returns the roughness coefficient that has been entered when setting up the project, and in this case the roughness coefficient was specified as 125

- Open/Closed status.

  When the pipe is in the open mode it means that that section of a pipe will allow water to flow through and if it is in the closed mode, the program will assume a zero diameter for the pipe when performing the analysis i.e. the pipe will act as an isolation valve. For this project the status was put on open as all the nodes are expected to be able to supply water when the system is operational.

- Minor loss coefficient.

  This is a dimensionless constant value which takes into account the head loss over the pipe, to account for bends, elbows, etc.

The six items are the minimum compulsory items required for Wadiso SA in order to perform flow and pressure calculations.

In this window the data that was entered in the “link topology” table is returned and additional information mentioned above has to be entered. In this study the diameter was a variable as different pipe size configuratios are used to investigate the effect of cost on pressure. When the “Pipe characteristics was entered the node characteristics were entered in the “Node table”.

#### B2.2.1.3 Node table

The node table is accessed by selecting “nodes” from the “nodes data” tab, under “system data editors” menu. In this table the data that was entered in the “Node topology table” is retained and additional system data fields need to be entered. The system data fields are:

- Output.

  This is the water demand at the node.

- Emitter coefficient.

  This is the discharge coefficient of an emitter (e.g. sprinkler or nozzle) placed at the node. A default value of 0.0 is used if there is no emitter present.

In “Wadiso SA” the entry of the output is based on the populations of the community that will be serviced by a particular node. The output is expressed as an abstraction rate in litres per second. This is the flow rate that is required to satisfy the total daily demand of the users at each abstraction node.

For each node the value entered as output is determined by multiplying the required demand rate by the population to be served at a particular node. Since the output value is entered in litres per second, and the demand rate is expressed in litres per capita per day, the following expression was used to obtain the output value at each node for each specified demand rate or output.

$$Output\ (l\ /\ s)\ =\ \frac{Demand\ rate\ (l\ /\ c\ /\ day)\times\ Population\ at\ a\ node}{86400\ \text{(sec)}}$$

Thus for the design of the *Nooightgedacht* project the demand rate input was converted to an output rate based on the populations of the respective communities and the demand rate used for each analysis.

### B2.2.1.4 Tank table

The “tank table” is accessed in the same way as the “Node table”. The data required for entry is the tank water level and the ground elevation. The water elevation can also be specified in the ground elevation column. The information of the tank entered under “node topology” is retained in the “tank table”

During the analysis the Nooightgedacht water supply project the reservoir was assumed to be the source of the system with an infinitely large capacity and therefore to maintain a fixed water level at all times. Thus in *Wadiso SA* the elevation of the reservoir was designated as the elevation of the free water surface i.e. the node elevation and elevation of the water surface coincide.

The data entered for the tank is as shown in Appendix D

After entering all the system data mentioned, the design procedure of the system is finished and the layout of the system network is viewed using the “CADGraphics” menu as shown in figure 3.1.

## *B3.0 Balancing the system*

Once the system data have been entered and edited to the satisfaction of the user, the hydraulic computation of the flow and pressure can be performed. This is achieved by selecting “Steady State” from the Main Menu and then “Balance System” from its drop down menu.

Two balancing options otherwise known as network solvers are available, which are:

- Wadiso
- Epanet

If the system data contains one or more valves, any links with minor loss coefficients other than 0.0, any node with emitter coefficient greater or less than 0.0, any pump with a multi point curve, or any pump with a relative speed less or greater than 1.0, then the program will automatically revert to the EPANET solver, since the Wadiso solver does not accommodate these features. The same applies if there are pumps or valves with

OFF/CLOSED status in the system. However in the analysis of this project the Wadiso balancing option was used since no valves and emitters are used in the system

The Wadiso network solver is initiated when balancing the system. A window appears, showing the progress of the flow/pressure balancing computations, iteration-by-iteration, until the predefined accuracy criteria are met.

### *B4.0 Viewing the balanced results for the steady state analysis*

Once balanced, the system data and the results are viewed by selecting "steady state" from the main menu, and from its drop down menu select "view results".

The results are displayed as follows

- Link (pipe) data, with three options for:
  - Pipes/CV: to view the Pipe/Check Valve table with results
  - Pumps: to view the pump table with results
  - Valves: to view the valve table with results

- Node data, with two options for:
  - Nodes: to view the node table with results
  - Tanks: to view the tank table with results

### *B4.1 Pipe/CV (Check valve) results*

The Pipe/CV table is accessed by selecting "Pipe/CV" from the system results viewer menu. The Pipe/CV system data is displayed, together with the following balanced results for each Pipe/CV in the network.

- The nodes are displayed in the flow direction, From - To.
- The balanced status (open/closed/removed) of the Pipe.
- Flow rate in a pipe linking two nodes in the direction of flow.
- Velocity in a pipe linking two nodes in the direction of flow.
- Head loss over Pipe.
- Energy gradient over Pipe.
- Energy head at upstream node.
- Energy head at downstream node.
- Pressure head at upstream node.
- Pressure head at downstream node.

User fields, optimization data, time/water quality simulation data, and the water quality results also appear in the table of the balanced results.

### *B4.2 Node results table*

The "node results table" is accessed by selecting nodes from the "system results viewers" menu. The system data is displayed together with the following balanced results for each node in the system.

- The emitter flow at the node.
- The energy grade line (EGL) head at the node.
- The residual head at the node.
- The residual pressure at the node.

User fields, optimization data, time/water quality simulation data, and the water quality results also appear in the table.

Thus with the node and pipe data from the *Nooightgedacht* rural water supply project defining the project layout, pipe and node characteristics it was possible to evaluate the minimum standards to satisfy the steady state conditions for any parameters fixed during each analysis.

# APPENDIX C

# LOCATION OF THE NOOIGHTGEDACHT RURAL WATER SUPPLY PROJECT

# APPENDIX D

# INPUT DATA FOR TOPOLOGY

## LINK TOPOLOGY TABLE

## Input data

| TYPE | No | From Node | To Node | Y1 (m) | X1 (m) | Y2 (m) | X2 ( m ) | Y3 ( m ) | X3 ( m ) | Y4 ( m ) | X4 ( m ) | Y5 ( m ) | X5 ( m ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | | | | | | | | | | |
| PIPE | 2 | 2 | 3 | | | | | | | | | | |
| PIPE | 5 | 3 | 6 | | | | | | | | | | |
| PIPE | 6 | 6 | 10 | | | | | | | | | | |
| PIPE | 10 | 10 | 11 | | | | | | | | | | |
| PIPE | 11 | 2 | 14 | | | | | | | | | | |
| PIPE | 14 | 14 | 15 | | | | | | | | | | |
| PIPE | 15 | 14 | 18 | | | | | | | | | | |
| PIPE | 18 | 18 | 22 | | | | | | | | | | |
| PIPE | 22 | 22 | 23 | | | | | | | | | | |
| PIPE | 23 | 23 | 24 | | | | | | | | | | |
| PIPE | 24 | 23 | 26 | | | | | | | | | | |
| PIPE | 26 | 26 | 27 | | | | | | | | | | |
| PIPE | 27 | 26 | 28 | | | | | | | | | | |
| PIPE | 28 | 28 | 29 | | | | | | | | | | |
| PIPE | 29 | 28 | 32 | | | | | | | | | | |
| PIPE | 32 | 32 | 33 | | | | | | | | | | |
| PIPE | 33 | 32 | 34 | | | | | | | | | | |
| PIPE | 34 | 34 | 36 | | | | | | | | | | |
| PIPE | 36 | 36 | 40 | | | | | | | | | | |
| PIPE | 40 | 40 | 71 | | | | | | | | | | |
| PIPE | 42 | 42 | 71 | | | | | | | | | | |
| PIPE | 43 | 43 | 71 | | | | | | | | | | |
| PIPE | 44 | 46 | 71 | | | | | | | | | | |
| PIPE | 45 | 46 | 45 | | | | | | | | | | |
| PIPE | 47 | 46 | 49 | | | | | | | | | | |
| PIPE | 50 | 46 | 50 | | | | | | | | | | |
| PIPE | 51 | 50 | 51 | | | | | | | | | | |
| PIPE | 52 | 50 | 52 | | | | | | | | | | |
| PIPE | 53 | 52 | 53 | | | | | | | | | | |
| PIPE | 54 | 52 | 54 | | | | | | | | | | |
| PIPE | 55 | 54 | 57 | | | | | | | | | | |
| PIPE | 58 | 54 | 59 | | | | | | | | | | |
| PIPE | 60 | 59 | 60 | | | | | | | | | | |
| PIPE | 61 | 59 | 63 | | | | | | | | | | |
| PIPE | 64 | 63 | 67 | | | | | | | | | | |
| PIPE | 68 | 63 | 68 | | | | | | | | | | |
| PIPE | 69 | 68 | 69 | | | | | | | | | | |
| PIPE | 70 | 69 | 70 | | | | | | | | | | |
| PIPE | 71 | 22 | 70 | | | | | | | | | | |

# NODE TOPOLOGY TABLE

## Input data

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) |
|---|---|---|---|---|
| TANK | 1 | 41608.785 | 59619.449 | 160 |
| NODE | 2 | 41684.832 | 59579.738 | 60 |
| NODE | 3 | 41838.137 | 59494.414 | 60 |
| NODE | 6 | 42976.551 | 58769.633 | 60 |
| NODE | 10 | 43206.449 | 57711.070 | 60 |
| NODE | 11 | 40230.684 | 62047.141 | 70 |
| NODE | 14 | 40422.926 | 62089.008 | 100 |
| NODE | 15 | 39166.254 | 63687.059 | 95 |
| NODE | 18 | 39268.738 | 64822.898 | 95 |
| NODE | 22 | 39909.063 | 64775.117 | 100 |
| NODE | 23 | 40070.000 | 65120.000 | 97 |
| NODE | 24 | 40709.41 | 64695.695 | 100 |
| NODE | 26 | 40975.656 | 65193.734 | 87 |
| NODE | 27 | 41044.617 | 64654.902 | 95 |
| NODE | 28 | 41081.301 | 64201.805 | 90 |
| NODE | 29 | 42718.156 | 64386.148 | 85 |
| NODE | 32 | 42956.480 | 64035.477 | 60 |
| NODE | 33 | 43508.605 | 65097.652 | 60 |
| NODE | 34 | 44139.660 | 66521.734 | 90 |
| NODE | 36 | 44388.234 | 69100.500 | 65 |
| NODE | 40 | 41641.988 | 68676.688 | 95 |
| NODE | 42 | 41374.945 | 70183.242 | 83 |
| NODE | 43 | 39038.203 | 69644.320 | 90 |
| NODE | 45 | 39189.031 | 69502.156 | 103 |
| NODE | 46 | 40124.359 | 67848.398 | 80 |
| NODE | 49 | 38080.191 | 69118.727 | 100 |
| NODE | 50 | 38105.000 | 68782.109 | 102 |
| NODE | 51 | 35361.816 | 68379.352 | 105 |
| NODE | 52 | 35206.309 | 68640.992 | 120 |
| NODE | 53 | 35765.785 | 67745.406 | 120 |
| NODE | 54 | 36578.992 | 68008.797 | 135 |
| NODE | 57 | 36688.852 | 65692.633 | 115 |
| NODE | 59 | 35872.203 | 65411.215 | 110 |
| NODE | 60 | 37318.598 | 64874.715 | 135 |
| NODE | 63 | 37404.902 | 62941.973 | 120 |
| NODE | 67 | 37963.340 | 64869.645 | 103 |
| NODE | 68 | 38401.652 | 64864.680 | 110 |
| NODE | 69 | 39026.297 | 64844.723 | 100 |
| NODE | 70 | 41455.762 | 69424.383 | 105 |
| NODE | 71 | 41608.785 | 59619.449 | 83 |

## TANK TABLE

### Input data

| TYPE | No | Ground Elevation ( m ) | Water level ( m ) |
|---|---|---|---|
| Resevoir | 1 | 160 | 0 |
| | | | |
| | | | |
| | | | |
| | | | |

# APPENDIX E

# INPUT DATA FOR PIPE CHARACTERISTICS OF THE PIPE CONFIGURATIONS USED IN THE SYSTEM FOR THE EVALUATION OF THE MINIMUM STANDARDS

Pipeline layout characteristics for pipe of diameter size 25mm

| TYPE | No | From Node | To Node | Diameter (mm ) | Calculated Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 25 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 25 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 25 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 25 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 25 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 25 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 25 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 25 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 25 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 25 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 25 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 25 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 25 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 25 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 25 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 25 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 25 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 25 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 25 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 25 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 25 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 25 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 25 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 25 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 25 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 25 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 25 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 25 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 25 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 50mm and 25mm used in combination

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 50 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 25 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 25 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 50 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 50 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 50 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 50 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 25 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 25 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 25 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 25 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 25 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 25 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 25 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 25 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 25 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 25 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 25 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 25 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 25 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 25 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 25 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 25 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 25 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 25 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 25 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 25 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 25 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 25 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 63mm and 25mm used in combination

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 25 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 25 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 63 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 25 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 25 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 25 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 25 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 25 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 25 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 25 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 25 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 25 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 25 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 25 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 25 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 25 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 25 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 25 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 25 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 25 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 25 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 25 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 25 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 25 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 25 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 25 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 50mm.

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 50 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 50 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 50 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 50 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 50 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 50 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 50 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 50 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 50 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 50 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 50 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 50 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 50 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 50 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 50 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 50 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 50 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 50 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 50 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 50 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 50 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 50 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 50 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 50 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 50 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 50 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 50 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 50 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 50 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 63mm and 50mm used in combination

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 50 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 50 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 63 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 50 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 50 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 50 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 50 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 50 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 50 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 50 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 50 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 50 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 50 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 50 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 50 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 50 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 50 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 50 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 50 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 50 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 50 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 50 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 50 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 50 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 50 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 75mm and 50mm used in combination

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 50 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 50 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 75 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 50 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 50 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 50 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 50 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 50 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 50 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 50 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 50 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 50 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 50 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 50 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 50 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 50 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 50 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 50 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 50 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 50 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 50 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 50 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 50 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 50 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 50 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 50 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 63mm

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 63 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 63 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 63 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 63 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 63 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 63 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 63 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 63 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 63 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 63 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 63 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 63 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 63 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 63 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 63 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 63 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 63 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 63 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 63 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 63 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 63 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 63 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 63 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 63 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 63 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 63 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 63 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 63 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 63 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 63 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 63 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 63 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 63 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 63 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 63 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 63 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 75mm and 63mm used in combination

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 63 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 63 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 63 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 63 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 75 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 63 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 63 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 63 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 63 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 63 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 63 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 63 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 63 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 63 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 63 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 63 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 63 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 63 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 63 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 63 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 63 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 63 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 63 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 63 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 63 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 63 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 63 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 63 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 63 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 63 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 63 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 63 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 63 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 63 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 63 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 63 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 75mm

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 75 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 75 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 75 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 75 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 75 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 75 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 75 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 75 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 75 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 75 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 75 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 75 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 75 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 75 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 75 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 75 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 75 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 75 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 75 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 75 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 75 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 75 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 75 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 75 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 75 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 75 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 75 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 75 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 75 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 75 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 75 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 75 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 75 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 75 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 75 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 75 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 100mm

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 100 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 100 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 100 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 100 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 100 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 100 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 100 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 100 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 100 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 100 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 100 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 100 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 100 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 100 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 100 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 100 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 100 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 100 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 100 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 100 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 100 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 100 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 100 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 100 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 100 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 100 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 100 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 100 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 100 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 100 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 100 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 100 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 100 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 100 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 100 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 100 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 100 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 100 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 100 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 100 | 245 | 0 | 125 | 0 | OPEN |

Pipeline layout characteristics for pipe of diameter size 150mm

| TYPE | No | From Node | To Node | Diameter (mm ) | C. Length | U. Length | HW Coefficient | Minor Loss | Open/ Closed |
|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 150 | 210 | 0 | 125 | 0 | OPEN |
| PIPE | 2 | 2 | 3 | 150 | 85 | 0 | 125 | 0 | OPEN |
| PIPE | 5 | 3 | 6 | 150 | 175 | 0 | 125 | 0 | OPEN |
| PIPE | 6 | 6 | 10 | 150 | 1350 | 0 | 125 | 0 | OPEN |
| PIPE | 10 | 10 | 11 | 150 | 1085 | 0 | 125 | 0 | OPEN |
| PIPE | 11 | 2 | 14 | 150 | 2790 | 0 | 125 | 0 | OPEN |
| PIPE | 14 | 14 | 15 | 150 | 195 | 0 | 125 | 0 | OPEN |
| PIPE | 15 | 14 | 18 | 150 | 1955 | 0 | 125 | 0 | OPEN |
| PIPE | 18 | 18 | 22 | 150 | 1140 | 0 | 125 | 0 | OPEN |
| PIPE | 22 | 22 | 23 | 150 | 640 | 0 | 125 | 0 | OPEN |
| PIPE | 23 | 23 | 24 | 150 | 380 | 0 | 125 | 0 | OPEN |
| PIPE | 24 | 23 | 26 | 150 | 805 | 0 | 125 | 0 | OPEN |
| PIPE | 26 | 26 | 27 | 150 | 565 | 0 | 125 | 0 | OPEN |
| PIPE | 27 | 26 | 28 | 150 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 28 | 28 | 29 | 150 | 455 | 0 | 125 | 0 | OPEN |
| PIPE | 29 | 28 | 32 | 150 | 1695 | 0 | 125 | 0 | OPEN |
| PIPE | 32 | 32 | 33 | 150 | 425 | 0 | 125 | 0 | OPEN |
| PIPE | 33 | 32 | 34 | 150 | 1065 | 0 | 125 | 0 | OPEN |
| PIPE | 34 | 34 | 36 | 150 | 1560 | 0 | 125 | 0 | OPEN |
| PIPE | 36 | 36 | 40 | 150 | 2590 | 0 | 125 | 0 | OPEN |
| PIPE | 40 | 40 | 71 | 150 | 2950 | 0 | 125 | 0 | OPEN |
| PIPE | 42 | 42 | 71 | 150 | 770 | 0 | 125 | 0 | OPEN |
| PIPE | 43 | 43 | 71 | 150 | 765 | 0 | 125 | 0 | OPEN |
| PIPE | 44 | 46 | 71 | 150 | 2270 | 0 | 125 | 0 | OPEN |
| PIPE | 45 | 46 | 45 | 150 | 205 | 0 | 125 | 0 | OPEN |
| PIPE | 47 | 46 | 49 | 150 | 1900 | 0 | 125 | 0 | OPEN |
| PIPE | 50 | 46 | 50 | 150 | 1175 | 0 | 125 | 0 | OPEN |
| PIPE | 51 | 50 | 51 | 150 | 340 | 0 | 125 | 0 | OPEN |
| PIPE | 52 | 50 | 52 | 150 | 2815 | 0 | 125 | 0 | OPEN |
| PIPE | 53 | 52 | 53 | 150 | 305 | 0 | 125 | 0 | OPEN |
| PIPE | 54 | 52 | 54 | 150 | 750 | 0 | 125 | 0 | OPEN |
| PIPE | 55 | 54 | 57 | 150 | 855 | 0 | 125 | 0 | OPEN |
| PIPE | 58 | 54 | 59 | 150 | 2250 | 0 | 125 | 0 | OPEN |
| PIPE | 60 | 59 | 60 | 150 | 865 | 0 | 125 | 0 | OPEN |
| PIPE | 61 | 59 | 63 | 150 | 1030 | 0 | 125 | 0 | OPEN |
| PIPE | 64 | 63 | 67 | 150 | 1935 | 0 | 125 | 0 | OPEN |
| PIPE | 68 | 63 | 68 | 150 | 645 | 0 | 125 | 0 | OPEN |
| PIPE | 69 | 68 | 69 | 150 | 440 | 0 | 125 | 0 | OPEN |
| PIPE | 70 | 69 | 70 | 150 | 625 | 0 | 125 | 0 | OPEN |
| PIPE | 71 | 22 | 70 | 150 | 245 | 0 | 125 | 0 | OPEN |

# APPENDIX F

# INPUT DATA AT THE NODES DEFINING THE NODE CHARACTERISTICS FOR THE DEMAND RATES USED IN THE ANALYSIS

Input node characteristics data for demand rate at 10 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 15 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 20 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 25 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.007 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.007 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 30 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.012 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 35 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 4() | Scenario 3() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.011 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.007 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.014 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Input node characteristics data for demand rate at 40 l/c/day

| TYPE | No | Elevation ( m ) | Output ( l/s ) | Emmitter Coeff (l/s/m^g) | Scenario 1() | Scenario 2() | Scenario 3() | Scenario 4() | Scenario 5() |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 6 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 11 | 70 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 14 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 15 | 95 | 0.013 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 18 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 22 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 23 | 97 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 24 | 100 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 26 | 87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 27 | 95 | 0.008 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 28 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 29 | 85 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 32 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 33 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 34 | 90 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 36 | 65 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 40 | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 42 | 83 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 43 | 90 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 45 | 103 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 46 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 49 | 100 | 0.011 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 50 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 51 | 105 | 0.005 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 52 | 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 53 | 120 | 0.011 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 54 | 135 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 57 | 115 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 59 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 60 | 135 | 0.002 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 63 | 120 | 0.016 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 67 | 103 | 0.006 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 68 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 69 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 70 | 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NODE | 71 | 83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPENDIX G

## AUTOMOBILE ASSOCIATION OF SOUTH AFRICA RATES FOR VEHICLE OPERATING COST TABLES

To determine the total operating cost of a vehicle, you need to:

1. Establish what the vehicle's **Fixed Cost** value is (see Fixed Costs Table)
2. Determine the **Running Cost** value (see appropriate Running Costs Table)
3. Add these two figures together (Fixed Cost and Running Cost) to get the **Total Vehicle Operating Cost** in cents per km.

## 1. Fixed Costs

The **Fixed Cost** values (which are inclusive of VAT) include:

a) the depreciation on the vehicle's value

b) comprehensive insurance

c) the licensing of the vehicle.

Hire purchase repayments are not included in the calculation of the vehicle's Fixed Cost values.

### Using the Fixed Costs Table

Select from the first column the purchase price (not the current value) you paid for the vehicle. It does not matter whether you bought it new or used.

Decide how many kilometers you travel on average each year (include both business and personal travel)

The value depicted where the row and column is the **Fixed Cost** value of the vehicle.

*Example:*
*If a vehicle with a purchase price of R60 000 travels an average of 20 000km per year, the* ***Fixed Cost*** *value will be R0.97c/km.*

| FIXED COSTS TABLE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| AVERAGED FIXED COST (c/km) – all costs inclusive of VAT | | | | | | | | |
| PURCHASE PRICE (VAT incl) | ANNUAL DISTANCE TRAVELLED | | | | | | | |
| | 10 000km | 15 000km | 20 000km | 25 000km | 30 000km | 35 000km | 40 000km | 45 000km |
| up to R30,000 | 77 | 51 | 39 | 31 | 26 | 23 | 21 | 19 |
| R30,001 - R50,000 | 130 | 87 | 65 | 53 | 44 | 39 | 35 | 32 |
| R50,001 - R75,000 | 192 | 129 | 97 | 78 | 66 | 58 | 52 | 47 |
| R75,001 - R100,000 | 259 | 173 | 130 | 105 | 89 | 78 | 70 | 63 |
| R100,001 - R125,000 | 312 | 208 | 157 | 127 | 107 | 95 | 84 | 76 |
| R125,001 - R150,000 | 376 | 251 | 189 | 153 | 129 | 114 | 101 | 92 |
| R150,001 - R175,000 | 422 | 282 | 212 | 172 | 145 | 128 | 114 | 104 |
| R175,001 - R200,000 | 485 | 324 | 244 | 198 | 167 | 147 | 131 | 119 |
| R200,001 - R250,000 | 611 | 408 | 307 | 249 | 210 | 185 | 165 | 150 |
| R250,001 - R300,000 | 706 | 472 | 355 | 288 | 243 | 215 | 191 | 174 |
| R300,001 - R350,000 | 831 | 555 | 418 | 339 | 286 | 253 | 225 | 205 |
| R350,001 - R400,000 | 958 | 640 | 482 | 390 | 329 | 291 | 259 | 236 |
| more than R400,001 | 1087 | 726 | 547 | 443 | 373 | 330 | 294 | 267 |

***Table G1: Fixed cost table***

## 2. Running Costs

The **Running Cost** values include:

a) maintenance costs (servicing, repairs, tyres and lubrication)

b) fuel

### Using the Running Cost Tables

Select the appropriate table depending on the type of vehicle and the type of fuel. (Note: ordinary vehicles include passenger cars and multi purpose vehicles (MPVs), while light commercial vehicles (LCVs) include bakkies and double-cabs with a load box.)

Select the appropriate engine capacity of the vehicle.

Multiply Column A (fuel factor) by the current fuel price in **Rands per litre** . The resultant figure will be in **cents per kilometre** .

To this, add Column B (service and repair costs) AND Column C (tyre costs).

Example :
*If the vehicle has an engine capacity of 1.6 and is petrol driven, choose the Running Cost Table for Petrol Vehicles and select the engine capacity 1501 – 1800.*

*Multiply Column A (9.97) by the current petrol price (R5.62) = 56.0314*
*Add Column B (16.74) and Column C (13.71) = 73.48 c/km*
*Round off to the nearest decimal point = R0.86 cents per kilometer*

### Additional Running Cost adjustments

Where applicable, add the following percentages to the Running Costs only

**Bakkies:**
Bakkie fully loaded – add 12%

4x4 unloaded – add 18%

4x4 fully loaded – add 25%

**Trailers:**
Single axle trailer – add 8%

Double axle trailer – add 10%

| **RUNNING COSTS TABLE – DIESEL LCVs** | | | |
|---|---|---|---|
| **AVERAGED RUNNING COST (c/km) – all costs inclusive of VAT** | | | |
| | | | |
| **ENGINE CAPACITY (cc)** | **FUEL** | **MAINTENANCE** | |
| | **Diesel Factor** | **Service and repair costs** | **Tyre costs** |
| | | (in cents) | (in cents) |
| | **A** | **B** | **C** |
| <2000 | 7.91 | 17.61 | 9.25 |
| 2001 - 2500 | 12.11 | 23.06 | 12.26 |
| 2501 - 3000 | 11.52 | 21.72 | 18.32 |
| >3001 | 13.95 | 31.81 | 19.28 |

***Table G2: Running cost table***

**Running Costs calculation (c/km)** = (A multiplied by diesel price in R/litre) + B + C

## 3. Total Vehicle Operating Cost

The **Total Vehicle Operating Cost** (measured in cents per km) is then obtained by adding the **Fixed Cost** value to the **Running Cost** value.

*Example:*

*Add the Fixed Cost value of 97c/km to the Running Cost value of 86c/km and the Total Operating Cost will be R1.83 per kilometer.*

# APPENDIX H

# RESULTS OF EFFECT OF PRESSURE ON COST

# DEMAND RATE AT 25 l/c/day

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 25mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.662 | 99.662 | 977.349 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.662 | 99.662 | 977.347 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.662 | 99.662 | 977.342 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.658 | 99.658 | 977.31 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.656 | 89.656 | 879.217 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 155.425 | 55.425 | 543.529 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 155.419 | 60.419 | 592.5 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 153.106 | 58.106 | 569.82 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 151.754 | 51.754 | 507.527 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 151.581 | 54.581 | 535.253 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 151.578 | 51.578 | 505.8 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 151.423 | 64.423 | 631.773 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 151.416 | 56.416 | 553.246 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 151.383 | 61.383 | 601.957 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 151.383 | 66.383 | 650.987 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 151.204 | 91.204 | 894.399 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 151.204 | 91.204 | 894.399 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 151.092 | 61.092 | 599.100 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 150.947 | 85.947 | 842.844 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 150.737 | 55.737 | 546.586 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 150.490 | 67.490 | 661.852 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 150.493 | 60.493 | 593.234 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 150.451 | 47.451 | 465.334 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 150.452 | 70.452 | 690.897 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 150.404 | 50.404 | 494.295 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 150.462 | 48.462 | 475.247 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 150.460 | 45.460 | 445.810 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 150.530 | 30.530 | 299.395 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 150.522 | 30.522 | 299.319 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 150.597 | 15.597 | 152.951 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 150.595 | 35.595 | 349.062 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 150.854 | 40.854 | 400.638 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **150.853** | **15.853** | **155.468** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 150.986 | 30.986 | 303.866 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 150.969 | 47.969 | 470.409 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 151.239 | 41.239 | 404.416 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 151.412 | 51.412 | 504.176 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 151.657 | 46.657 | 457.550 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 150.497 | 67.497 | 661.919 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at (50mm with 25mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.975 | 99.975 | 980.413 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.975 | 99.975 | 980.411 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.974 | 99.974 | 980.407 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.971 | 99.971 | 980.374 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.968 | 89.968 | 882.282 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.659 | 59.659 | 585.050 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.658 | 64.658 | 634.078 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.486 | 64.486 | 632.387 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.385 | 59.385 | 582.365 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.212 | 62.212 | 610.09 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.209 | 59.209 | 580.637 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.055 | 72.054 | 706.610 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.047 | 64.047 | 628.082 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.014 | 69.014 | 676.793 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.014 | 74.014 | 725.823 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 158.835 | 98.835 | 969.233 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 158.835 | 98.835 | 969.233 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 158.723 | 68.723 | 673.934 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 158.578 | 93.578 | 917.679 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 158.368 | 63.368 | 621.421 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 158.122 | 75.122 | 736.688 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 158.124 | 68.124 | 668.070 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 158.082 | 55.082 | 540.170 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 158.083 | 78.083 | 765.733 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 158.036 | 58.036 | 569.131 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 158.093 | 56.093 | 550.083 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 158.091 | 53.091 | 520.646 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 158.161 | 38.161 | 374.231 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 158.153 | 38.153 | 374.156 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 158.228 | 23.228 | 227.787 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 158.226 | 43.226 | 423.899 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 158.485 | 48.485 | 475.475 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **158.485** | **23.485** | **230.305** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 158.617 | 38.617 | 378.703 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 158.600 | 55.600 | 545.246 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 158.870 | 48.870 | 479.253 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.043 | 59.043 | 579.014 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.289 | 54.289 | 532.388 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 158.129 | 75.129 | 736.755 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at (63mm with 25mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.992 | 99.992 | 980.577 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.991 | 99.991 | 980.573 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.988 | 99.988 | 980.540 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.985 | 89.985 | 882.448 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.889 | 59.889 | 587.303 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.888 | 64.888 | 636.334 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.832 | 64.832 | 635.782 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.799 | 59.799 | 586.426 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.626 | 62.626 | 614.151 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.623 | 59.623 | 584.698 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.469 | 72.469 | 710.670 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.461 | 64.461 | 632.143 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.428 | 69.428 | 680.854 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.428 | 74.428 | 729.884 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.249 | 99.249 | 973.294 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.249 | 99.249 | 973.294 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.137 | 69.137 | 677.995 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 158.992 | 93.992 | 921.740 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 158.782 | 63.782 | 625.482 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 158.536 | 75.536 | 740.748 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 158.539 | 68.539 | 672.130 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 158.496 | 55.496 | 544.231 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 158.498 | 78.498 | 769.794 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 158.450 | 58.450 | 573.192 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 158.507 | 56.507 | 554.144 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 158.505 | 53.505 | 524.707 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 158.575 | 38.575 | 378.292 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 158.568 | 38.568 | 378.217 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 158.642 | 23.642 | 231.848 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 158.640 | 43.640 | 427.960 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 158.899 | 48.899 | 479.536 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **158.899** | **23.899** | **234.366** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.031 | 39.031 | 382.764 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.014 | 56.014 | 549.307 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.285 | 49.285 | 483.314 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.457 | 59.457 | 583.075 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.703 | 54.703 | 536.449 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 158.543 | 75.543 | 740.816 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 50mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.975 | 99.975 | 980.413 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.975 | 99.975 | 980.413 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.975 | 99.975 | 980.413 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.975 | 99.975 | 980.411 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.974 | 89.974 | 882.343 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.659 | 59.659 | 585.053 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.659 | 64.659 | 634.081 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.486 | 64.486 | 632.391 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.386 | 59.386 | 582.370 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.373 | 62.373 | 611.664 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.372 | 59.372 | 582.242 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.361 | 72.361 | 709.615 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.360 | 64.360 | 631.157 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.358 | 69.358 | 680.166 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.358 | 74.358 | 729.198 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.345 | 99.345 | 974.233 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.345 | 99.345 | 974.233 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.336 | 69.336 | 679.953 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.325 | 94.325 | 925.012 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.310 | 64.310 | 630.66 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.291 | 76.291 | 748.159 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.292 | 69.292 | 679.515 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.288 | 56.288 | 551.999 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.289 | 79.289 | 777.551 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.285 | 59.285 | 581.384 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.289 | 57.289 | 561.813 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.289 | 54.289 | 532.392 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.294 | 39.294 | 385.344 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.294 | 39.294 | 385.338 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.299 | 24.299 | 238.294 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.299 | 44.299 | 434.424 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.318 | 49.318 | 483.647 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.318** | **24.318** | **238.481** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.328 | 39.328 | 385.677 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.327 | 56.327 | 552.377 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.347 | 49.347 | 483.928 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.36 | 59.360 | 582.121 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.378 | 54.378 | 533.267 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.292 | 76.292 | 748.164 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at (63mm with 50mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.991 | 99.991 | 980.576 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.991 | 89.991 | 882.508 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.888 | 59.888 | 587.302 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.888 | 64.888 | 636.334 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.832 | 64.832 | 635.781 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.799 | 59.799 | 586.424 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.786 | 62.786 | 615.718 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.786 | 59.786 | 586.295 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.774 | 72.774 | 713.668 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.774 | 64.774 | 635.21 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.771 | 69.771 | 684.219 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.771 | 74.771 | 733.252 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.758 | 99.758 | 978.285 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.758 | 99.758 | 978.285 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.749 | 69.749 | 684.005 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.739 | 94.739 | 929.065 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.723 | 64.723 | 634.713 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.705 | 76.705 | 752.212 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.705 | 69.705 | 683.568 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.702 | 56.702 | 556.052 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.702 | 79.702 | 781.604 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.698 | 59.698 | 585.437 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.703 | 57.703 | 565.866 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.702 | 54.702 | 536.445 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.708 | 39.708 | 389.397 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.707 | 39.707 | 389.392 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.713 | 24.713 | 242.347 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.713 | 44.713 | 438.478 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.732 | 49.732 | 487.700 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.732** | **24.732** | **242.535** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.742 | 39.742 | 389.731 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.74 | 56.740 | 556.430 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.761 | 49.761 | 487.982 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.773 | 59.773 | 586.174 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.792 | 54.792 | 537.321 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.705 | 76.705 | 752.217 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at (75mm with 50mm)

‘

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.992 | 99.992 | 980.579 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.992 | 99.992 | 980.578 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.992 | 89.992 | 882.512 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.889 | 59.889 | 587.304 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.888 | 64.888 | 636.336 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.832 | 64.832 | 635.783 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.799 | 59.799 | 586.428 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.795 | 62.795 | 615.806 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.795 | 59.795 | 586.386 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.791 | 72.791 | 713.835 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.791 | 64.791 | 635.38 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.790 | 69.790 | 684.405 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.790 | 74.790 | 733.438 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.786 | 99.786 | 978.56 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.786 | 99.786 | 978.56 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.783 | 69.783 | 684.336 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.780 | 94.780 | 929.466 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.775 | 64.775 | 635.218 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.769 | 76.769 | 752.838 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.769 | 69.769 | 684.193 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.768 | 56.768 | 556.697 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.768 | 79.768 | 782.249 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.766 | 59.766 | 586.106 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.768 | 57.768 | 566.506 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.768 | 54.768 | 537.086 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.770 | 39.770 | 390.004 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.769 | 39.769 | 390.002 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.771 | 24.771 | 242.921 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.771 | 44.771 | 439.052 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.777 | 49.777 | 488.147 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.777** | **24.777** | **242.982** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.781 | 39.781 | 390.112 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.78 | 56.78 | 556.82 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.787 | 49.787 | 488.239 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.791 | 59.791 | 586.346 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.797 | 54.797 | 537.372 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.769 | 76.769 | 752.84 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 63mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.998 | 99.998 | 980.641 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.998 | 89.998 | 882.573 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.978 | 59.978 | 588.183 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.978 | 64.978 | 637.216 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.967 | 64.967 | 637.109 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.961 | 59.961 | 588.013 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.948 | 62.948 | 617.307 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.948 | 59.948 | 587.884 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.936 | 72.936 | 715.258 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.936 | 64.936 | 636.799 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.933 | 69.933 | 685.808 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.933 | 74.933 | 734.841 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.920 | 99.920 | 979.875 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.920 | 99.920 | 979.875 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.912 | 69.912 | 685.596 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.901 | 94.901 | 930.654 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.885 | 64.885 | 636.303 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.867 | 76.867 | 753.802 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.867 | 69.867 | 685.158 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.864 | 56.864 | 557.641 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.864 | 79.864 | 783.194 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.860 | 59.860 | 587.027 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.865 | 57.865 | 567.456 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.865 | 54.865 | 538.034 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.870 | 39.870 | 390.986 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.869 | 39.869 | 390.981 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.875 | 24.875 | 243.936 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.875 | 44.875 | 440.067 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.894 | 49.894 | 489.289 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.894** | **24.894** | **244.124** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.904 | 39.904 | 391.320 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.902 | 56.902 | 558.019 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.923 | 49.923 | 489.571 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.935 | 59.935 | 587.763 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.954 | 54.954 | 538.909 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.867 | 76.867 | 753.807 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at (75mm x 63mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.998 | 99.998 | 980.643 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.998 | 89.998 | 882.577 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.978 | 59.978 | 588.183 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.978 | 64.978 | 637.216 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.967 | 64.967 | 637.109 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.961 | 59.961 | 588.013 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.957 | 62.957 | 617.391 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.957 | 59.957 | 587.971 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.953 | 72.953 | 715.419 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.953 | 64.953 | 636.965 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.952 | 69.952 | 685.990 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.952 | 74.952 | 735.023 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.948 | 99.948 | 980.145 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.948 | 99.948 | 980.145 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.945 | 69.945 | 685.921 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.941 | 94.941 | 931.051 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.936 | 64.936 | 636.803 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.930 | 76.930 | 754.423 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.930 | 69.930 | 685.778 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.929 | 56.929 | 558.282 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.929 | 79.929 | 783.834 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.928 | 59.928 | 587.690 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.929 | 57.929 | 568.091 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.929 | 54.929 | 538.671 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.931 | 39.931 | 391.589 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.931 | 39.931 | 391.587 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.933 | 24.933 | 244.505 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.933 | 44.933 | 440.637 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.939 | 49.939 | 489.732 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.939** | **24.939** | **244.567** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.942 | 39.942 | 391.697 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.942 | 56.942 | 558.405 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.948 | 49.948 | 489.824 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.953 | 59.953 | 587.931 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.959 | 54.959 | 538.957 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.93 | 76.93 | 754.425 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 75mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.998 | 99.998 | 980.644 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 159.998 | 89.998 | 882.578 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.978 | 59.978 | 588.183 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.978 | 64.978 | 637.216 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.967 | 64.967 | 637.109 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.961 | 59.961 | 588.013 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.96 | 62.960 | 617.424 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.96 | 59.960 | 588.004 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.959 | 72.959 | 715.483 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.959 | 64.959 | 637.03 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.959 | 69.959 | 686.061 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.959 | 74.959 | 735.094 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.958 | 99.958 | 980.251 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.958 | 99.958 | 980.251 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.958 | 69.958 | 686.048 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.957 | 94.957 | 931.206 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.956 | 64.956 | 636.998 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.955 | 76.955 | 754.666 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.955 | 69.955 | 686.02 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.955 | 56.955 | 558.532 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.955 | 79.955 | 784.084 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.954 | 59.954 | 587.95 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.955 | 57.955 | 568.339 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.955 | 54.955 | 538.919 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.955 | 39.955 | 391.824 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.955 | 39.955 | 391.823 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.955 | 24.955 | 244.728 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.955 | 44.955 | 440.86 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.957 | 49.957 | 489.905 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.957** | **24.957** | **244.74** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.957 | 39.957 | 391.845 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.957 | 56.957 | 558.556 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.958 | 49.958 | 489.923 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.959 | 59.959 | 587.997 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.96 | 54.96 | 538.975 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.955 | 76.955 | 754.666 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 100mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 160.000 | 100.000 | 980.656 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 160.000 | 100.000 | 980.656 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 160.000 | 100.000 | 980.656 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 160.000 | 100.000 | 980.656 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 160.000 | 90.000 | 882.59 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.995 | 59.995 | 588.344 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.995 | 64.995 | 637.377 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.992 | 64.992 | 637.35 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.99 | 59.99 | 588.302 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.99 | 62.99 | 617.719 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.99 | 59.99 | 588.299 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.99 | 72.99 | 715.784 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.99 | 64.99 | 637.331 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.99 | 69.99 | 686.363 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.99 | 74.99 | 735.396 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.99 | 99.99 | 980.559 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.99 | 99.99 | 980.559 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.99 | 69.99 | 686.36 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.989 | 94.989 | 931.523 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.989 | 64.989 | 637.323 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.989 | 76.989 | 754.999 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.989 | 69.989 | 686.353 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.989 | 56.989 | 558.867 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.989 | 79.989 | 784.419 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.989 | 59.989 | 588.286 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.989 | 57.989 | 568.674 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.989 | 54.989 | 539.254 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.989 | 39.989 | 392.155 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.989 | 39.989 | 392.155 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.989 | 24.989 | 245.057 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.989 | 44.989 | 441.189 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.989 | 49.989 | 490.225 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **159.989** | **24.989** | **245.06** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.989 | 39.989 | 392.161 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.989 | 56.989 | 558.873 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.99 | 49.99 | 490.23 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.99 | 59.99 | 588.298 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.99 | 54.99 | 539.267 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.989 | 76.989 | 754.999 |

Results of residual pressure with demand rate at 25 l/c/day and pipe size at 150mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 160.000 | 100.000 | 980.659 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 160.000 | 100.000 | 980.659 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 160.000 | 100.000 | 980.659 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 160.000 | 100.000 | 980.659 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.002 | 0 | 160.000 | 90.000 | 882.594 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.999 | 59.999 | 588.389 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.008 | 0 | 159.999 | 64.999 | 637.422 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.999 | 64.999 | 637.418 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.999 | 59.999 | 588.383 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.999 | 62.999 | 617.803 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.004 | 0 | 159.999 | 59.999 | 588.383 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.999 | 72.999 | 715.868 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.005 | 0 | 159.999 | 64.999 | 637.415 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.999 | 69.999 | 686.448 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 159.999 | 74.999 | 735.481 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 159.999 | 69.999 | 686.448 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 159.999 | 94.999 | 931.613 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.998 | 64.998 | 637.414 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.004 | 0 | 159.998 | 76.998 | 755.093 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.003 | 0 | 159.998 | 69.998 | 686.447 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.003 | 0 | 159.998 | 56.998 | 558.961 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.998 | 79.998 | 784.513 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.007 | 0 | 159.998 | 59.998 | 588.381 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.998 | 57.998 | 568.768 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.003 | 0 | 159.998 | 54.998 | 539.348 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.998 | 39.998 | 392.249 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.007 | 0 | 159.998 | 39.998 | 392.249 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.998 | 24.998 | 245.15 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.002 | 0 | 159.998 | 44.998 | 441.282 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.999 | 49.999 | 490.315 |
| **NODE** | **60** | 35872.203 | 65411.215 | **135** | **0.001** | **0** | **159.999** | **24.999** | **245.15** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.01 | 0 | 159.999 | 39.999 | 392.25 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.004 | 0 | 159.999 | 56.999 | 558.962 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.999 | 49.999 | 490.316 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.999 | 59.999 | 588.382 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.999 | 54.999 | 539.35 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.998 | 76.998 | 755.093 |

# DEMAND AT 50 l/c/day

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 25mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 158.781 | 98.781 | 968.711 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 158.781 | 98.781 | 968.703 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 158.779 | 98.779 | 968.688 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 158.767 | 98.767 | 968.569 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 158.757 | 88.757 | 870.408 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 143.489 | 43.489 | 426.482 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 143.467 | 48.467 | 475.293 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 135.121 | 40.121 | 393.453 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 130.242 | 30.242 | 296.567 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 129.619 | 32.619 | 319.879 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 129.607 | 29.607 | 290.340 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 129.050 | 42.050 | 412.370 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 129.023 | 34.023 | 333.647 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 128.905 | 38.905 | 381.521 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 128.903 | 43.903 | 430.543 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 128.259 | 68.259 | 669.387 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 128.259 | 68.259 | 669.387 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 127.854 | 37.854 | 371.215 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 127.331 | 62.331 | 611.251 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 126.572 | 31.572 | 309.617 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 125.684 | 42.684 | 418.583 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 125.694 | 35.694 | 350.039 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 125.542 | 22.542 | 221.061 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 125.546 | 45.546 | 446.651 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 125.373 | 25.373 | 248.824 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 125.581 | 23.581 | 231.249 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 125.574 | 20.574 | 201.766 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 125.826 | 5.826 | 57.131 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 125.798 | 5.798 | 56.859 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 126.067 | 0.898 | 8.806 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 126.059 | 11.059 | 108.452 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 126.995 | 16.995 | 166.661 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **126.993** | **0.872** | **8.551** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 127.471 | 7.471 | 73.263 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 127.408 | 24.408 | 239.363 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 128.385 | 18.385 | 180.293 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 129.009 | 29.009 | 284.475 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 129.894 | 24.894 | 244.129 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 125.709 | 42.709 | 418.827 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at (50 mm with 25 mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.909 | 99.909 | 979.769 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.908 | 99.908 | 979.761 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.907 | 99.907 | 979.746 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.895 | 99.895 | 979.628 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.885 | 89.885 | 881.467 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 158.769 | 58.769 | 576.322 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 158.767 | 63.767 | 625.338 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 158.145 | 63.145 | 619.235 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 157.781 | 57.781 | 566.633 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 157.158 | 60.158 | 589.944 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 157.146 | 57.146 | 560.404 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 156.589 | 69.589 | 682.433 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 156.562 | 61.562 | 603.710 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 156.443 | 66.443 | 651.583 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 156.442 | 71.442 | 700.605 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 155.797 | 95.797 | 939.445 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 155.797 | 95.797 | 939.445 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 155.392 | 65.392 | 641.274 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 154.869 | 89.869 | 881.311 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 154.111 | 59.111 | 579.678 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 153.223 | 70.223 | 688.645 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 153.233 | 63.233 | 620.101 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 153.081 | 50.081 | 491.123 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 153.085 | 73.085 | 716.713 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 152.912 | 52.912 | 518.887 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 153.120 | 51.120 | 501.311 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 153.113 | 48.113 | 471.828 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 153.365 | 33.365 | 327.194 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 153.337 | 33.337 | 326.922 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 153.606 | 18.606 | 182.458 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 153.598 | 38.598 | 378.515 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 154.534 | 44.534 | 436.726 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **154.532** | **19.532** | **191.54** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 155.010 | 35.010 | 343.328 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 154.947 | 51.947 | 509.428 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 155.924 | 45.924 | 450.359 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 156.548 | 56.548 | 554.541 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 157.434 | 52.434 | 514.195 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 153.247 | 70.247 | 688.889 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size (63 mm with 25mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.970 | 99.970 | 980.369 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.970 | 99.970 | 980.362 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.968 | 99.968 | 980.346 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.956 | 99.956 | 980.228 |
| NODE | 11 | 43206.449 | 57711.07 | 70 | 0.004 | 0 | 159.946 | 89.946 | 882.067 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.598 | 59.598 | 584.452 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.597 | 64.597 | 633.479 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.394 | 64.394 | 631.486 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.275 | 59.275 | 581.287 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 158.652 | 61.652 | 604.597 |
| NODE | 24 | 40070 | 65120 | 100 | 0.008 | 0 | 158.640 | 58.640 | 575.057 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 158.083 | 71.083 | 697.084 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 158.056 | 63.056 | 618.361 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 157.937 | 67.937 | 666.234 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 157.936 | 72.936 | 715.256 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 157.291 | 97.291 | 954.094 |
| NODE | 33 | 42956.48 | 64035.477 | 60 | 0 | 0 | 157.291 | 97.291 | 954.094 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 156.886 | 66.886 | 655.922 |
| NODE | 36 | 44139.66 | 66521.734 | 65 | 0.002 | 0 | 156.363 | 91.363 | 895.957 |
| NODE | 40 | 44388.234 | 69100.5 | 95 | 0 | 0 | 155.604 | 60.604 | 594.323 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 154.716 | 71.716 | 703.288 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 154.726 | 64.726 | 634.743 |
| NODE | 45 | 39038.203 | 69644.32 | 103 | 0.006 | 0 | 154.574 | 51.574 | 505.763 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 154.578 | 74.578 | 731.353 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 154.405 | 54.405 | 533.527 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 154.613 | 52.613 | 515.953 |
| NODE | 51 | 38105 | 68782.109 | 105 | 0.006 | 0 | 154.606 | 49.606 | 486.47 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 154.858 | 34.858 | 341.839 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 154.830 | 34.830 | 341.567 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 155.099 | 20.099 | 197.104 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 155.091 | 40.091 | 393.161 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 156.028 | 46.028 | 451.375 |
| NODE | 60 | 35872.203 | 65411.215 | 135 | 0.002 | 0 | 156.026 | 21.026 | 206.189 |
| **NODE** | **63** | **37318.598** | **64874.715** | **120** | **0.02** | **0** | **156.504** | **36.504** | **357.978** |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 156.441 | 53.441 | 524.078 |
| NODE | 68 | 37963.34 | 64869.645 | 110 | 0 | 0 | 157.418 | 47.418 | 465.01 |
| NODE | 69 | 38401.652 | 64864.68 | 100 | 0 | 0 | 158.042 | 58.042 | 569.193 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 158.928 | 53.928 | 528.848 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 154.741 | 71.741 | 703.531 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 50 mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.909 | 99.909 | 979.769 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.909 | 99.909 | 979.768 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.909 | 99.909 | 979.767 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.908 | 99.908 | 979.758 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.907 | 89.907 | 881.685 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 158.769 | 58.769 | 576.320 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 158.767 | 63.767 | 625.336 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 158.144 | 63.144 | 619.232 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 157.780 | 57.780 | 566.630 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 157.734 | 60.734 | 595.594 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 157.733 | 57.733 | 566.165 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 157.692 | 70.692 | 693.244 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 157.690 | 62.690 | 614.771 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 157.681 | 67.681 | 663.718 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 157.681 | 72.681 | 712.75 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 157.633 | 97.632 | 957.443 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 157.633 | 97.632 | 957.443 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 157.602 | 67.602 | 662.949 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 157.563 | 92.563 | 907.731 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 157.507 | 62.507 | 612.979 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 157.441 | 74.441 | 730.008 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 157.441 | 67.441 | 661.370 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 157.430 | 54.430 | 533.773 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 157.430 | 77.430 | 759.327 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 157.417 | 57.417 | 563.069 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 157.433 | 55.433 | 543.608 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 157.432 | 52.432 | 514.183 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 157.451 | 37.451 | 367.268 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 157.449 | 37.449 | 367.248 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 157.469 | 22.469 | 220.346 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 157.469 | 42.469 | 416.472 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 157.538 | 47.538 | 466.189 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **157.538** | **22.538** | **221.023** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 157.574 | 37.574 | 368.472 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 157.569 | 54.569 | 535.138 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 157.642 | 47.642 | 467.206 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 157.689 | 57.689 | 565.728 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 157.755 | 52.755 | 517.343 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 157.442 | 74.442 | 730.026 |

Results of pressure pressure with demand rate at 50 l/c/day and pipe size at (63mm with 50 mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.970 | 99.970 | 980.369 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.970 | 99.970 | 980.369 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.970 | 99.970 | 980.367 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.969 | 99.969 | 980.359 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.969 | 89.969 | 882.286 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.598 | 59.598 | 584.454 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.597 | 64.597 | 633.481 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.394 | 64.394 | 631.489 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.275 | 59.275 | 581.291 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.229 | 62.229 | 610.255 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.228 | 59.228 | 580.826 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.187 | 72.187 | 707.906 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.185 | 64.185 | 629.433 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.176 | 69.176 | 678.379 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.176 | 74.176 | 727.411 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.128 | 99.128 | 972.106 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.128 | 99.128 | 972.106 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.097 | 69.097 | 677.611 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.058 | 94.058 | 922.393 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.002 | 64.002 | 627.641 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 158.936 | 75.936 | 744.670 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 158.936 | 68.936 | 676.031 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 158.925 | 55.925 | 548.434 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 158.925 | 78.925 | 773.989 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 158.912 | 58.912 | 577.730 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 158.928 | 56.928 | 558.269 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 158.927 | 53.927 | 528.845 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 158.946 | 38.946 | 381.930 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 158.944 | 38.944 | 381.909 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 158.964 | 23.964 | 235.007 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 158.964 | 43.964 | 431.133 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.033 | 49.033 | 480.850 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.033** | **24.033** | **235.684** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.069 | 39.069 | 383.133 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.064 | 56.064 | 549.799 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.137 | 49.137 | 481.867 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.184 | 59.183 | 580.389 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.250 | 54.250 | 532.003 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 158.937 | 75.937 | 744.688 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at (75mm with 50 mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.970 | 99.970 | 980.369 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.970 | 99.970 | 980.369 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.970 | 99.970 | 980.368 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.970 | 99.970 | 980.365 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.970 | 89.970 | 882.297 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.598 | 59.598 | 584.451 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.597 | 64.597 | 633.479 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.394 | 64.394 | 631.485 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.275 | 59.275 | 581.286 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.260 | 62.260 | 610.557 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.260 | 59.260 | 581.134 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.246 | 72.246 | 708.487 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.245 | 64.245 | 630.028 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.242 | 69.242 | 679.032 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.242 | 74.242 | 728.065 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.227 | 99.227 | 973.076 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.227 | 99.227 | 973.076 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.217 | 69.217 | 678.781 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.204 | 94.204 | 923.821 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.186 | 64.186 | 629.442 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.164 | 76.164 | 746.909 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.164 | 69.164 | 678.266 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.160 | 56.16 | 550.743 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.161 | 79.161 | 776.296 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.156 | 59.156 | 580.123 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.161 | 57.161 | 560.559 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.161 | 54.161 | 531.138 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.167 | 39.167 | 384.099 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.167 | 39.167 | 384.092 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.173 | 24.173 | 237.058 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.173 | 44.173 | 433.188 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.196 | 49.196 | 482.444 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.196** | **24.196** | **237.279** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.207 | 39.207 | 384.492 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.206 | 56.206 | 551.189 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.230 | 49.230 | 482.777 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.245 | 59.245 | 580.991 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.267 | 54.267 | 532.170 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.165 | 76.165 | 746.915 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 63 mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.994 | 99.994 | 980.602 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.993 | 99.993 | 980.593 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.992 | 89.992 | 882.520 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.922 | 59.922 | 587.628 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.922 | 64.922 | 636.660 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.882 | 64.882 | 636.272 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.859 | 59.859 | 587.012 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.812 | 62.812 | 615.977 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.812 | 59.812 | 586.548 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.770 | 72.770 | 713.627 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.768 | 64.768 | 635.154 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.759 | 69.759 | 684.100 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.759 | 74.759 | 733.133 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.711 | 99.711 | 977.826 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.711 | 99.711 | 977.826 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.681 | 69.681 | 683.332 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.642 | 94.642 | 928.114 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.585 | 64.585 | 633.362 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.519 | 76.519 | 750.391 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.520 | 69.520 | 681.753 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.508 | 56.508 | 554.155 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.509 | 79.509 | 779.710 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.496 | 59.496 | 583.451 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.511 | 57.511 | 563.99 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.511 | 54.511 | 534.566 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.530 | 39.530 | 387.651 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.528 | 39.528 | 387.630 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.548 | 24.548 | 240.728 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.547 | 44.547 | 436.854 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.617 | 49.617 | 486.572 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.617** | **24.617** | **241.405** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.652 | 39.652 | 388.854 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.648 | 56.648 | 555.521 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.720 | 49.720 | 487.589 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.767 | 59.767 | 586.110 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.833 | 54.833 | 537.725 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.521 | 76.521 | 750.409 |

Results of residual Pressure with demand rate at 50 l/c/day and pipe size at (75mm with 63 mm)

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.994 | 99.994 | 980.604 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.994 | 99.994 | 980.601 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.994 | 89.994 | 882.533 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.922 | 59.922 | 587.628 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.922 | 64.922 | 636.661 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.882 | 64.882 | 636.273 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.859 | 59.859 | 587.013 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.847 | 62.847 | 616.318 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.847 | 59.847 | 586.896 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.837 | 72.837 | 714.280 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.836 | 64.836 | 635.823 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.834 | 69.834 | 684.834 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.834 | 74.834 | 733.867 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.822 | 99.822 | 978.914 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.822 | 99.822 | 978.914 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.814 | 69.814 | 684.641 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.805 | 94.805 | 929.711 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.790 | 64.790 | 635.374 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.774 | 76.774 | 752.890 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.774 | 69.774 | 684.246 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.771 | 56.771 | 556.732 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.771 | 79.771 | 782.285 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.768 | 59.768 | 586.121 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.772 | 57.772 | 566.546 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.772 | 54.772 | 537.125 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.776 | 39.776 | 390.072 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.776 | 39.776 | 390.067 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.781 | 24.781 | 243.017 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.781 | 44.781 | 439.148 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.798 | 49.798 | 488.352 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.798** | **24.780** | **243.009** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.807 | 39.807 | 390.373 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.806 | 56.806 | 557.074 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.824 | 49.824 | 488.607 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.836 | 59.836 | 586.787 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.852 | 54.852 | 537.916 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.774 | 76.774 | 752.895 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 75 mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.994 | 99.994 | 980.603 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.994 | 89.994 | 882.536 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.922 | 59.922 | 587.628 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.922 | 64.922 | 636.660 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.882 | 64.882 | 636.272 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.859 | 59.859 | 587.012 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.856 | 62.856 | 616.403 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.856 | 59.856 | 586.983 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.853 | 72.853 | 714.443 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.853 | 64.853 | 635.989 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.853 | 69.853 | 685.016 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.853 | 74.853 | 734.049 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.850 | 99.850 | 979.184 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.850 | 99.850 | 979.184 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.848 | 69.848 | 684.967 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.845 | 94.845 | 930.108 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.842 | 64.842 | 635.875 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.837 | 76.837 | 753.512 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.837 | 69.837 | 684.867 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.837 | 56.837 | 557.374 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.837 | 79.837 | 782.926 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.836 | 59.836 | 586.786 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.837 | 57.837 | 567.182 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.837 | 54.837 | 537.762 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.838 | 39.838 | 390.675 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.838 | 39.838 | 390.673 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.839 | 24.839 | 243.587 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.839 | 44.839 | 439.719 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.844 | 49.844 | 488.795 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.843** | **24.843** | **243.63** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.846 | 39.846 | 390.751 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.845 | 56.845 | 557.461 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.850 | 49.850 | 488.860 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.853 | 59.853 | 586.955 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.857 | 54.857 | 537.963 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.837 | 76.837 | 753.514 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 100 mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.999 | 99.999 | 980.646 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 159.999 | 89.999 | 882.580 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.981 | 59.981 | 588.207 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.981 | 64.981 | 637.240 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.971 | 64.971 | 637.144 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.965 | 59.965 | 588.055 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.965 | 62.965 | 617.468 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.965 | 59.965 | 588.048 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.964 | 72.964 | 715.527 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.964 | 64.964 | 637.074 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.964 | 69.964 | 686.106 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.964 | 74.964 | 735.139 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.963 | 99.963 | 980.297 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.963 | 99.963 | 980.297 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.962 | 69.962 | 686.094 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.962 | 94.962 | 931.253 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.961 | 64.961 | 637.046 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.960 | 76.960 | 754.715 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.960 | 69.960 | 686.069 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.960 | 56.960 | 558.582 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.960 | 79.960 | 784.133 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.960 | 59.960 | 587.999 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.960 | 57.960 | 568.389 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.960 | 54.960 | 538.969 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.960 | 39.960 | 391.872 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.960 | 39.960 | 391.872 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.960 | 24.960 | 244.776 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.960 | 44.960 | 440.908 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.961 | 49.961 | 489.952 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.961** | **24.961** | **244.787** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.962 | 39.962 | 391.892 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.962 | 56.962 | 558.603 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.963 | 49.963 | 489.968 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.964 | 59.964 | 588.041 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.965 | 54.965 | 539.018 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.960 | 76.960 | 754.715 |

Results of residual pressure with demand rate at 50 l/c/day and pipe size at 150 mm

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 160.000 | 100.000 | 980.658 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 160.000 | 100.000 | 980.658 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 160.000 | 100.000 | 980.658 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 160.000 | 100.000 | 980.658 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.004 | 0 | 160.000 | 90.000 | 882.592 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 159.997 | 59.997 | 588.370 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.016 | 0 | 159.997 | 64.997 | 637.403 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 159.996 | 64.996 | 637.39 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 159.995 | 59.995 | 588.349 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 159.995 | 62.995 | 617.768 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.008 | 0 | 159.995 | 59.995 | 588.348 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 159.995 | 72.995 | 715.833 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.01 | 0 | 159.995 | 64.995 | 637.38 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 159.995 | 69.995 | 686.413 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.002 | 0 | 159.995 | 74.995 | 735.445 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 159.995 | 99.995 | 980.610 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 159.995 | 99.995 | 980.610 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.002 | 0 | 159.995 | 69.995 | 686.411 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.002 | 0 | 159.995 | 94.995 | 931.575 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 159.995 | 64.995 | 637.376 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.008 | 0 | 159.994 | 76.994 | 755.054 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.006 | 0 | 159.994 | 69.994 | 686.407 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.006 | 0 | 159.994 | 56.994 | 558.922 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 159.994 | 79.994 | 784.473 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.014 | 0 | 159.994 | 59.994 | 588.341 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 159.994 | 57.994 | 568.728 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.006 | 0 | 159.994 | 54.994 | 539.308 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 159.994 | 39.994 | 392.210 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.014 | 0 | 159.994 | 39.994 | 392.210 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 159.995 | 24.995 | 245.111 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.004 | 0 | 159.994 | 44.994 | 441.243 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 159.995 | 49.995 | 490.278 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.002** | **0** | **159.995** | **24.995** | **245.113** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.02 | 0 | 159.995 | 39.995 | 392.212 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.008 | 0 | 159.995 | 56.995 | 558.924 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 159.995 | 49.995 | 490.280 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 159.995 | 59.995 | 588.347 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 159.995 | 54.995 | 539.315 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 159.994 | 76.994 | 755.054 |

# APPENDIX I

# RESULTS OF EFFECT OF DEMAND RATE ON COST

# PRESSURE AT 10 m

Results of pressure head at pipe size of 25mm

Maximum Demand rate = 33 l/c/day

| TYPE | No | Y (m) | X (m) | Elevation (m) | Output (l/s) | Emitter Coeff (l/s/m^g) | E.G.L. (m) | Head (m) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.449 | 99.449 | 975.257 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.449 | 99.449 | 975.253 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.448 | 99.448 | 975.244 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.441 | 99.441 | 975.174 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.003 | 0 | 159.435 | 89.435 | 877.053 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.595 | 52.595 | 515.782 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.011 | 0 | 152.584 | 57.584 | 564.704 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 148.905 | 53.905 | 528.621 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 146.752 | 46.752 | 458.483 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.479 | 49.479 | 485.224 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.005 | 0 | 146.474 | 46.474 | 455.754 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 146.228 | 59.228 | 580.825 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.007 | 0 | 146.214 | 51.214 | 502.232 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 146.167 | 56.167 | 550.804 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.001 | 0 | 146.166 | 61.166 | 599.833 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 145.888 | 85.888 | 842.273 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 145.888 | 85.888 | 842.273 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.001 | 0 | 145.714 | 55.714 | 546.361 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.001 | 0 | 145.482 | 80.482 | 789.251 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 145.135 | 50.135 | 491.65 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.005 | 0 | 144.729 | 61.729 | 605.351 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.004 | 0 | 144.733 | 54.733 | 536.740 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.004 | 0 | 144.660 | 41.660 | 408.542 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.662 | 64.662 | 634.111 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.009 | 0 | 144.585 | 44.585 | 437.232 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.676 | 42.676 | 418.508 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.004 | 0 | 144.673 | 39.673 | 389.058 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 144.783 | 24.783 | 243.039 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.009 | 0 | 144.771 | 24.771 | 242.919 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 144.889 | 9.889 | 96.977 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.003 | 0 | 144.884 | 29.884 | 293.065 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.313 | 35.313 | 346.299 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.001** | **0** | **145.312** | **10.312** | **101.128** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.013 | 0 | 145.525 | 25.525 | 250.309 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.005 | 0 | 145.498 | 42.498 | 416.765 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 145.930 | 35.930 | 352.348 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 146.206 | 46.206 | 453.124 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.599 | 41.599 | 407.941 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 144.739 | 61.739 | 605.453 |

Results of pressure head at pipe size (50mm with 25mm)

Maximum Demand rate = 87 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.754 | 99.754 | 978.248 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.752 | 99.752 | 978.227 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.748 | 99.748 | 978.184 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.714 | 99.714 | 977.851 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.007 | 0 | 159.686 | 89.686 | 879.516 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 156.672 | 56.672 | 555.757 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.028 | 0 | 156.667 | 61.667 | 604.743 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 154.995 | 59.995 | 588.349 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 154.018 | 54.018 | 529.729 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 152.364 | 55.364 | 542.931 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.014 | 0 | 152.329 | 52.329 | 513.172 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 150.871 | 63.871 | 626.361 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.017 | 0 | 150.798 | 55.798 | 547.186 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 150.491 | 60.491 | 593.208 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.003 | 0 | 150.488 | 65.488 | 642.218 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 148.783 | 88.783 | 870.657 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 148.783 | 88.783 | 870.657 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.003 | 0 | 147.710 | 57.710 | 565.943 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.003 | 0 | 146.306 | 81.306 | 797.331 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.235 | 49.235 | 482.823 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.014 | 0 | 141.806 | 58.806 | 576.682 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.01 | 0 | 141.838 | 51.838 | 508.357 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.01 | 0 | 141.417 | 38.417 | 376.743 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 141.427 | 61.427 | 602.393 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.024 | 0 | 140.958 | 40.958 | 401.663 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 141.517 | 39.517 | 387.526 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.01 | 0 | 141.500 | 36.500 | 357.943 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 142.145 | 22.145 | 217.163 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.024 | 0 | 142.069 | 22.069 | 216.425 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 142.780 | 7.780 | 76.297 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.007 | 0 | 142.759 | 27.759 | 272.218 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.25 | 35.25 | 345.680 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.003** | **0** | **145.245** | **10.245** | **100.470** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.035 | 0 | 146.500 | 26.500 | 259.874 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.014 | 0 | 146.324 | 43.324 | 424.86 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 148.980 | 38.980 | 382.263 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 150.672 | 50.672 | 496.921 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 153.075 | 48.075 | 471.457 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 141.876 | 58.876 | 577.369 |

Results of pressure head at pipe size (63 mm with 25mm)

Maximum Demand rate = 103 l/c/day

| TYPE | No | Y (m) | X (m) | Elevation (m) | Output (l/s) | Emitter Coeff (l/s/m^g) | E.G.L. (m) | Head (m) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.900 | 99.890 | 979.600 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.900 | 99.890 | 979.500 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.900 | 99.880 | 979.500 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.800 | 99.840 | 979.100 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.008 | 0 | 159.800 | 89.800 | 880.700 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 158.500 | 58.500 | 573.600 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.033 | 0 | 158.500 | 63.490 | 622.700 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 157.700 | 62.740 | 615.200 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 157.300 | 57.290 | 561.800 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 155.000 | 57.970 | 568.500 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.016 | 0 | 154.900 | 54.920 | 538.600 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 152.800 | 65.830 | 645.600 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.021 | 0 | 152.700 | 57.720 | 566.100 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 152.300 | 62.290 | 610.900 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.004 | 0 | 152.300 | 67.290 | 659.900 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 149.900 | 89.900 | 881.600 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 149.900 | 89.900 | 881.600 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.004 | 0 | 148.400 | 58.400 | 572.700 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.004 | 0 | 146.500 | 81.460 | 798.800 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 143.600 | 48.640 | 477.000 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.016 | 0 | 140.300 | 57.330 | 562.300 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.012 | 0 | 140.400 | 50.370 | 494.000 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.012 | 0 | 139.800 | 36.780 | 360.700 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 139.800 | 59.800 | 586.400 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.029 | 0 | 139.100 | 39.130 | 383.700 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 139.900 | 37.930 | 371.900 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.012 | 0 | 139.900 | 34.900 | 342.300 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 140.800 | 20.820 | 204.200 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.029 | 0 | 140.700 | 20.710 | 203.100 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 141.700 | 6.725 | 65.950 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.008 | 0 | 141.700 | 26.700 | 261.800 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.200 | 35.190 | 345.100 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.004** | **0** | **145.200** | **10.180** | **99.850** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.041 | 0 | 147.000 | 26.960 | 264.400 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.016 | 0 | 146.700 | 43.740 | 428.900 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 150.400 | 40.370 | 395.900 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 152.700 | 52.700 | 516.800 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 156.000 | 51.000 | 500.100 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 140.400 | 57.420 | 563.100 |

Results of pressure head at pipe size of 50 mm

Maximum Demand rate = 130 l/c/day

| TYPE | No | Y (m) | X (m) | Elevation (m) | Output (l/s) | Emitter Coeff (l/s/m^g) | E.G.L. (m) | Head (m) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.500 | 99.460 | 975.400 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.01 | 0 | 159.500 | 89.460 | 877.300 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.800 | 52.770 | 517.500 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.042 | 0 | 152.800 | 57.760 | 566.400 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 149.100 | 54.120 | 530.700 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 147.000 | 46.980 | 460.700 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.700 | 49.710 | 487.500 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.021 | 0 | 146.700 | 46.710 | 458.000 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 146.500 | 59.460 | 583.100 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.026 | 0 | 146.500 | 51.450 | 504.600 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 146.400 | 56.400 | 553.100 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.005 | 0 | 146.400 | 61.400 | 602.100 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 146.100 | 86.120 | 844.500 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 146.100 | 86.120 | 844.500 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.005 | 0 | 145.900 | 55.940 | 548.600 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.005 | 0 | 145.700 | 80.710 | 791.500 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 145.400 | 50.380 | 494.000 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.021 | 0 | 145.000 | 61.990 | 607.900 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.016 | 0 | 145.000 | 54.990 | 539.300 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.016 | 0 | 144.900 | 41.930 | 411.100 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.900 | 64.930 | 636.700 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.036 | 0 | 144.900 | 44.850 | 439.900 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.900 | 42.940 | 421.100 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.016 | 0 | 144.900 | 39.940 | 391.700 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 145.100 | 25.050 | 245.700 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.036 | 0 | 145.000 | 25.040 | 245.600 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 145.200 | 10.160 | 99.630 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.01 | 0 | 145.200 | 30.160 | 295.700 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.600 | 35.570 | 348.800 |
| NODE | 60 | 35872.203 | 65411.215 | 135 | 0.005 | 0 | 145.600 | 10.560 | 103.600 |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.052 | 0 | 145.800 | 25.770 | 252.700 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.021 | 0 | 145.700 | 42.740 | 419.200 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 146.200 | 36.170 | 354.700 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 146.400 | 46.440 | 455.500 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.800 | 41.830 | 410.200 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 145.000 | 62.000 | 608.000 |

Results of pressure head at pipe size of 50 mm

Maximum Demand rate = 130 l/c/day

| TYPE | No | Y (m) | X (m) | Elevation (m) | Output (l/s) | Emitter Coeff ( l/s/m^g) | E.G.L. (m) | Head (m) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.500 | 99.470 | 975.400 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.500 | 99.460 | 975.400 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.01 | 0 | 159.500 | 89.460 | 877.300 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.800 | 52.770 | 517.500 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.042 | 0 | 152.800 | 57.760 | 566.400 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 149.100 | 54.120 | 530.700 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 147.000 | 46.980 | 460.700 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.700 | 49.710 | 487.500 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.021 | 0 | 146.700 | 46.710 | 458.000 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 146.500 | 59.460 | 583.100 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.026 | 0 | 146.500 | 51.450 | 504.600 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 146.400 | 56.400 | 553.100 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.005 | 0 | 146.400 | 61.400 | 602.100 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 146.100 | 86.120 | 844.500 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 146.100 | 86.120 | 844.500 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.005 | 0 | 145.900 | 55.940 | 548.600 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.005 | 0 | 145.700 | 80.710 | 791.500 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 145.400 | 50.380 | 494.000 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.021 | 0 | 145.000 | 61.990 | 607.900 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.016 | 0 | 145.000 | 54.990 | 539.300 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.016 | 0 | 144.900 | 41.930 | 411.100 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.900 | 64.930 | 636.700 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.036 | 0 | 144.900 | 44.850 | 439.900 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.900 | 42.940 | 421.100 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.016 | 0 | 144.900 | 39.940 | 391.700 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 145.100 | 25.050 | 245.700 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.036 | 0 | 145.000 | 25.040 | 245.600 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 145.200 | 10.160 | 99.630 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.01 | 0 | 145.200 | 30.160 | 295.700 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.600 | 35.570 | 348.800 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.005** | **0** | **145.600** | **10.560** | **103.600** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.052 | 0 | 145.800 | 25.770 | 252.700 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.021 | 0 | 145.700 | 42.740 | 419.200 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 146.200 | 36.170 | 354.700 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 146.400 | 46.440 | 455.500 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.800 | 41.830 | 410.200 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 145.000 | 62.000 | 608.000 |

Results of pressure head at pipe size (63 mm with 50 mm)

Maximum Demand rate = 219 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff ( l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.500 | 99.540 | 976.200 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.500 | 99.540 | 976.200 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.500 | 99.540 | 976.100 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.500 | 99.520 | 976.000 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.018 | 0 | 159.500 | 89.510 | 877.800 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 153.800 | 53.790 | 527.500 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.07 | 0 | 153.800 | 58.790 | 576.500 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 150.600 | 55.650 | 545.700 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 148.800 | 48.810 | 478.700 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 148.100 | 51.100 | 501.100 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.035 | 0 | 148.100 | 48.080 | 471.500 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 147.400 | 60.440 | 592.700 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.044 | 0 | 147.400 | 52.410 | 513.900 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 147.300 | 57.270 | 561.600 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.009 | 0 | 147.300 | 62.270 | 610.700 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 146.500 | 86.530 | 848.600 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 146.500 | 86.530 | 848.600 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.009 | 0 | 146.100 | 56.070 | 549.800 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.009 | 0 | 145.500 | 80.470 | 789.100 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.600 | 49.600 | 486.400 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.035 | 0 | 143.600 | 60.590 | 594.200 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.026 | 0 | 143.600 | 53.600 | 525.600 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.026 | 0 | 143.400 | 40.430 | 396.400 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 143.400 | 63.430 | 622.000 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.061 | 0 | 143.200 | 43.230 | 424.000 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 143.500 | 41.470 | 406.700 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.026 | 0 | 143.500 | 38.460 | 377.200 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 143.700 | 23.750 | 232.900 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.061 | 0 | 143.700 | 23.720 | 232.600 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 144.000 | 9.020 | 88.450 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.018 | 0 | 144.000 | 29.010 | 284.500 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.100 | 35.080 | 344.000 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.009** | **0** | **145.100** | **10.080** | **98.820** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.088 | 0 | 145.600 | 25.630 | 251.300 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.035 | 0 | 145.600 | 42.550 | 417.300 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 146.700 | 36.680 | 359.700 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 147.400 | 47.390 | 464.800 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 148.400 | 43.410 | 425.700 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 143.600 | 60.620 | 594.400 |

Results of pressure head at pipe size (75 mm with 50 mm)

Maximum Demand rate = 242 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g ) | E.G.L. ( m ) | Head ( m ) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.776 | 99.776 | 978.461 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.773 | 99.773 | 978.439 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.769 | 99.769 | 978.394 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.734 | 99.734 | 978.048 |
| NODE | 11 | 43206.449 | 57711.07 | 70 | 0.029 | 0 | 159.705 | 89.705 | 879.704 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 156.962 | 56.962 | 558.601 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.116 | 0 | 156.958 | 61.958 | 607.593 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 155.424 | 60.424 | 592.556 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 154.528 | 54.528 | 534.730 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 152.733 | 55.733 | 546.556 |
| NODE | 24 | 40070 | 65120 | 100 | 0.058 | 0 | 152.698 | 52.698 | 516.785 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 151.100 | 64.100 | 628.605 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.072 | 0 | 151.021 | 56.021 | 549.373 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 150.682 | 60.682 | 595.084 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.014 | 0 | 150.679 | 65.679 | 644.087 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 148.824 | 88.824 | 871.060 |
| NODE | 33 | 42956.48 | 64035.477 | 60 | 0 | 0 | 148.824 | 88.824 | 871.060 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.014 | 0 | 147.657 | 57.657 | 565.416 |
| NODE | 36 | 44139.66 | 66521.734 | 65 | 0.014 | 0 | 146.145 | 81.145 | 795.754 |
| NODE | 40 | 44388.234 | 69100.5 | 95 | 0 | 0 | 143.944 | 48.944 | 479.975 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.058 | 0 | 141.365 | 58.365 | 572.361 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.043 | 0 | 141.396 | 51.396 | 504.021 |
| NODE | 45 | 39038.203 | 69644.32 | 103 | 0.043 | 0 | 140.953 | 37.953 | 372.185 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 140.964 | 60.964 | 597.846 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.101 | 0 | 140.463 | 40.463 | 396.805 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 141.064 | 39.064 | 383.083 |
| NODE | 51 | 38105 | 68782.109 | 105 | 0.043 | 0 | 141.045 | 36.045 | 353.483 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 141.764 | 21.764 | 213.433 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.101 | 0 | 141.684 | 21.684 | 212.645 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 142.458 | 7.458 | 73.133 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.029 | 0 | 142.435 | 27.435 | 269.046 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.134 | 35.134 | 344.543 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.014** | **0** | **145.128** | **10.128** | **99.321** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.145 | 0 | 146.502 | 26.502 | 259.894 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.058 | 0 | 146.319 | 43.319 | 424.816 |
| NODE | 68 | 37963.34 | 64869.645 | 110 | 0 | 0 | 149.150 | 39.150 | 383.926 |
| NODE | 69 | 38401.652 | 64864.68 | 100 | 0 | 0 | 150.956 | 50.956 | 499.706 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 153.522 | 48.522 | 475.834 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 141.438 | 58.437 | 573.073 |

Results of pressure head at pipe size of 63 mm

Maximum Demand rate = 362 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. (m) | Head ( m ) | Pressure (Kpa) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.500 | 99.480 | 975.500 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.500 | 99.480 | 975.500 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.500 | 99.480 | 975.500 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.500 | 99.470 | 975.500 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.029 | 0 | 159.500 | 89.470 | 877.300 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.900 | 52.900 | 518.700 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.116 | 0 | 152.900 | 57.890 | 567.700 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 149.300 | 54.300 | 532.500 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 147.200 | 47.210 | 462.900 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.900 | 49.940 | 489.700 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.058 | 0 | 146.900 | 46.930 | 460.300 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 146.700 | 59.700 | 585.400 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.072 | 0 | 146.700 | 51.680 | 506.800 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 146.600 | 56.630 | 555.400 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.014 | 0 | 146.600 | 61.630 | 604.400 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 146.400 | 86.360 | 846.900 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 146.400 | 86.360 | 846.900 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.014 | 0 | 146.200 | 56.180 | 551.000 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.014 | 0 | 146.000 | 80.960 | 793.900 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 145.600 | 50.630 | 496.500 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.058 | 0 | 145.200 | 62.250 | 610.400 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.043 | 0 | 145.300 | 55.250 | 541.800 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.043 | 0 | 145.200 | 42.190 | 413.700 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 145.200 | 65.190 | 639.300 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.101 | 0 | 145.100 | 45.110 | 442.400 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 145.200 | 43.200 | 423.700 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.043 | 0 | 145.200 | 40.200 | 394.200 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 145.300 | 25.310 | 248.200 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.101 | 0 | 145.300 | 25.300 | 248.100 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 145.400 | 10.410 | 102.100 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.029 | 0 | 145.400 | 30.410 | 298.200 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.800 | 35.810 | 351.200 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.014** | **0** | **145.800** | **10.810** | **106.000** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.145 | 0 | 146.000 | 26.010 | 255.100 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.058 | 0 | 146.000 | 42.990 | 421.500 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 146.400 | 36.410 | 357.000 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 146.700 | 46.670 | 457.700 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 147.100 | 42.060 | 412.400 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 145.300 | 62.260 | 610.600 |

Results of pressure head at pipe size (75 mm with 63 mm)

Maximum Demand rate = 486 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.600 | 99.610 | 976.800 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.600 | 99.610 | 976.800 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.600 | 99.610 | 976.800 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.600 | 99.590 | 976.600 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.039 | 0 | 159.600 | 89.570 | 878.400 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 154.700 | 54.740 | 536.800 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.156 | 0 | 154.700 | 59.730 | 585.700 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 152.100 | 57.070 | 559.700 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 150.500 | 50.520 | 495.400 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 149.500 | 52.500 | 514.800 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.078 | 0 | 149.500 | 49.480 | 485.200 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 148.600 | 61.570 | 603.800 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.097 | 0 | 148.500 | 53.530 | 524.900 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 148.300 | 58.340 | 572.100 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.019 | 0 | 148.300 | 63.330 | 621.100 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 147.300 | 87.280 | 855.900 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 147.300 | 87.280 | 855.900 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.019 | 0 | 146.600 | 56.620 | 555.200 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.019 | 0 | 145.800 | 80.760 | 792.000 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.500 | 49.520 | 485.600 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.078 | 0 | 143.100 | 60.060 | 589.000 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.058 | 0 | 143.100 | 53.080 | 520.500 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.058 | 0 | 142.800 | 39.830 | 390.500 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 142.800 | 62.830 | 616.200 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.136 | 0 | 142.500 | 42.550 | 417.200 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 142.900 | 40.890 | 401.000 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.058 | 0 | 142.900 | 37.880 | 371.500 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 143.300 | 23.290 | 228.400 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.136 | 0 | 143.200 | 23.240 | 227.900 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 143.700 | 8.682 | 85.140 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.039 | 0 | 143.700 | 28.670 | 281.100 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.200 | 35.200 | 345.200 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.019** | **0** | **145.200** | **10.200** | **100.000** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.194 | 0 | 146.000 | 25.980 | 254.800 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.078 | 0 | 145.900 | 42.880 | 420.500 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 147.500 | 37.480 | 367.500 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 148.500 | 48.500 | 475.600 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 149.900 | 44.950 | 440.800 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 143.100 | 60.100 | 589.400 |

Results of pressure head at pipe size of 75 mm

Maximum Demand rate = 587 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.400 | 99.450 | 975.300 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.400 | 99.450 | 975.300 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.400 | 99.450 | 975.300 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.400 | 99.440 | 975.200 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.047 | 0 | 159.400 | 89.440 | 877.100 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.500 | 52.540 | 515.300 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.188 | 0 | 152.500 | 57.530 | 564.200 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 148.800 | 53.770 | 527.300 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 146.600 | 46.560 | 456.600 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.300 | 49.280 | 483.300 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.094 | 0 | 146.300 | 46.280 | 453.800 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 146.000 | 59.030 | 578.900 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.117 | 0 | 146.000 | 51.010 | 500.300 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 146.000 | 55.960 | 548.800 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.023 | 0 | 146.000 | 60.960 | 597.800 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 145.700 | 85.670 | 840.100 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 145.700 | 85.670 | 840.100 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.023 | 0 | 145.500 | 55.490 | 544.100 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.023 | 0 | 145.300 | 80.250 | 787.000 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.900 | 49.910 | 489.400 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.094 | 0 | 144.500 | 61.510 | 603.200 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.07 | 0 | 144.500 | 54.510 | 534.600 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.07 | 0 | 144.400 | 41.440 | 406.400 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.400 | 64.440 | 632.000 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.164 | 0 | 144.400 | 44.370 | 435.100 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.500 | 42.460 | 416.400 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.07 | 0 | 144.500 | 39.460 | 386.900 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 144.600 | 24.570 | 240.900 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.164 | 0 | 144.600 | 24.560 | 240.800 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 144.700 | 9.6780 | 94.900 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.047 | 0 | 144.700 | 29.670 | 291.000 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.100 | 35.100 | 344.200 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.023** | **0** | **145.100** | **10.100** | **99.000** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.235 | 0 | 145.300 | 25.310 | 248.200 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.094 | 0 | 145.300 | 42.280 | 414.600 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 145.700 | 35.720 | 350.300 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 146.000 | 46.010 | 451.200 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.400 | 41.410 | 406.100 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 144.500 | 61.520 | 603.300 |

Results of pressure head at pipe size of 100 mm

Maximum Demand rate = 1253 l/c/day

| TYPE | No | Y<br>( m ) | X<br>( m ) | Elevation<br>( m ) | Output<br>( l/s ) | Emitter Coeff<br>(l/s/m^g) | E.G.L.<br>( m ) | Head<br>( m ) | Pressure<br>( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.400 | 99.450 | 975.200 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.400 | 99.450 | 975.200 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.400 | 99.450 | 975.200 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.400 | 99.440 | 975.200 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.1 | 0 | 159.400 | 89.440 | 877.100 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.500 | 52.500 | 514.800 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 0.401 | 0 | 152.500 | 57.490 | 563.700 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 148.700 | 53.700 | 526.600 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 146.500 | 46.480 | 455.800 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.200 | 49.200 | 482.400 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.2 | 0 | 146.200 | 46.190 | 453.000 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 145.900 | 58.940 | 578.000 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.251 | 0 | 145.900 | 50.920 | 499.400 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 145.900 | 55.870 | 547.900 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.05 | 0 | 145.900 | 60.870 | 596.900 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 145.600 | 85.580 | 839.200 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 145.600 | 85.580 | 839.200 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.05 | 0 | 145.400 | 55.390 | 543.200 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.05 | 0 | 145.200 | 80.160 | 786.100 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.800 | 49.810 | 488.500 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.2 | 0 | 144.400 | 61.410 | 602.200 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.15 | 0 | 144.400 | 54.410 | 533.600 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.15 | 0 | 144.300 | 41.340 | 405.400 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.300 | 64.340 | 631.000 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 0.351 | 0 | 144.300 | 44.270 | 434.100 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.400 | 42.360 | 415.400 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.15 | 0 | 144.400 | 39.360 | 386.000 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 144.500 | 24.470 | 240.000 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 0.351 | 0 | 144.500 | 24.460 | 239.900 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 144.600 | 9.5810 | 93.960 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.1 | 0 | 144.600 | 29.580 | 290.100 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.000 | 35.000 | 343.300 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.05** | **0** | **145.000** | **10.000** | **98.080** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 0.501 | 0 | 145.200 | 25.220 | 247.300 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.2 | 0 | 145.200 | 42.190 | 413.700 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 145.600 | 35.630 | 349.500 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 145.900 | 45.920 | 450.300 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.300 | 41.320 | 405.200 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 144.400 | 61.420 | 602.300 |

Results of pressure head at pipe size of 150 mm

Maximum Demand rate = 3637 l/c/day

| TYPE | No | Y ( m ) | X ( m ) | Elevation ( m ) | Output ( l/s ) | Emitter Coeff (l/s/m^g) | E.G.L. ( m ) | Head ( m ) | Pressure ( Kpa ) |
|---|---|---|---|---|---|---|---|---|---|
| NODE | 2 | 41608.785 | 59619.449 | 60 | 0 | 0 | 159.400 | 99.450 | 975.2 |
| NODE | 3 | 41684.832 | 59579.738 | 60 | 0 | 0 | 159.400 | 99.450 | 975.2 |
| NODE | 6 | 41838.137 | 59494.414 | 60 | 0 | 0 | 159.400 | 99.450 | 975.2 |
| NODE | 10 | 42976.551 | 58769.633 | 60 | 0 | 0 | 159.400 | 99.440 | 975.2 |
| NODE | 11 | 43206.449 | 57711.070 | 70 | 0.291 | 0 | 159.400 | 89.440 | 877.1 |
| NODE | 14 | 40230.684 | 62047.141 | 100 | 0 | 0 | 152.500 | 52.500 | 514.9 |
| NODE | 15 | 40422.926 | 62089.008 | 95 | 1.164 | 0 | 152.500 | 57.490 | 563.8 |
| NODE | 18 | 39166.254 | 63687.059 | 95 | 0 | 0 | 148.700 | 53.700 | 526.6 |
| NODE | 22 | 39268.738 | 64822.898 | 100 | 0 | 0 | 146.500 | 46.490 | 455.9 |
| NODE | 23 | 39909.063 | 64775.117 | 97 | 0 | 0 | 146.200 | 49.200 | 482.5 |
| NODE | 24 | 40070.000 | 65120.000 | 100 | 0.582 | 0 | 146.200 | 46.200 | 453.1 |
| NODE | 26 | 40709.41 | 64695.695 | 87 | 0 | 0 | 145.900 | 58.950 | 578.1 |
| NODE | 27 | 40975.656 | 65193.734 | 95 | 0.727 | 0 | 145.900 | 50.930 | 499.5 |
| NODE | 28 | 41044.617 | 64654.902 | 90 | 0 | 0 | 145.900 | 55.880 | 548 |
| NODE | 29 | 41081.301 | 64201.805 | 85 | 0.145 | 0 | 145.900 | 60.880 | 597 |
| NODE | 32 | 42718.156 | 64386.148 | 60 | 0 | 0 | 145.600 | 85.590 | 839.3 |
| NODE | 33 | 42956.480 | 64035.477 | 60 | 0 | 0 | 145.600 | 85.590 | 839.3 |
| NODE | 34 | 43508.605 | 65097.652 | 90 | 0.145 | 0 | 145.400 | 55.400 | 543.3 |
| NODE | 36 | 44139.660 | 66521.734 | 65 | 0.145 | 0 | 145.200 | 80.170 | 786.1 |
| NODE | 40 | 44388.234 | 69100.500 | 95 | 0 | 0 | 144.800 | 49.820 | 488.6 |
| NODE | 42 | 41641.988 | 68676.688 | 83 | 0.582 | 0 | 144.400 | 61.420 | 602.3 |
| NODE | 43 | 41374.945 | 70183.242 | 90 | 0.436 | 0 | 144.400 | 54.420 | 533.7 |
| NODE | 45 | 39038.203 | 69644.320 | 103 | 0.436 | 0 | 144.400 | 41.350 | 405.5 |
| NODE | 46 | 39189.031 | 69502.156 | 80 | 0 | 0 | 144.400 | 64.350 | 631.1 |
| NODE | 49 | 40124.359 | 67848.398 | 100 | 1.018 | 0 | 144.300 | 44.280 | 434.2 |
| NODE | 50 | 38080.191 | 69118.727 | 102 | 0 | 0 | 144.400 | 42.370 | 415.5 |
| NODE | 51 | 38105.000 | 68782.109 | 105 | 0.436 | 0 | 144.400 | 39.370 | 386.1 |
| NODE | 52 | 35361.816 | 68379.352 | 120 | 0 | 0 | 144.500 | 24.480 | 240.1 |
| NODE | 53 | 35206.309 | 68640.992 | 120 | 1.018 | 0 | 144.500 | 24.470 | 240 |
| NODE | 54 | 35765.785 | 67745.406 | 135 | 0 | 0 | 144.600 | 9.590 | 94.05 |
| NODE | 57 | 36578.992 | 68008.797 | 115 | 0.291 | 0 | 144.600 | 29.590 | 290.1 |
| NODE | 59 | 36688.852 | 65692.633 | 110 | 0 | 0 | 145.000 | 35.010 | 343.3 |
| **NODE** | **60** | **35872.203** | **65411.215** | **135** | **0.145** | **0** | **145.000** | **10.010** | **98.17** |
| NODE | 63 | 37318.598 | 64874.715 | 120 | 1.455 | 0 | 145.200 | 25.230 | 247.4 |
| NODE | 67 | 37404.902 | 62941.973 | 103 | 0.582 | 0 | 145.200 | 42.200 | 413.8 |
| NODE | 68 | 37963.340 | 64869.645 | 110 | 0 | 0 | 145.600 | 35.640 | 349.5 |
| NODE | 69 | 38401.652 | 64864.680 | 100 | 0 | 0 | 145.900 | 45.930 | 450.4 |
| NODE | 70 | 39026.297 | 64844.723 | 105 | 0 | 0 | 146.300 | 41.330 | 405.3 |
| NODE | 71 | 41455.762 | 69424.383 | 83 | 0 | 0 | 144.400 | 61.430 | 602.4 |

# APPENDIX J

# RESULTS OF EFFECT OF ABSTRACTION RATE ON COST

# PRESSURE AT 10

Results of abstraction rate at pipe size of 25mm

Demand rate = 33 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 25 | 210 | 125 | 0 | OPEN | OPEN | 0.086 | 0.175 |
| PIPE | 2 | 2 | 3 | 25 | 85 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 5 | 3 | 6 | 25 | 175 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 11 | 2 | 14 | 25 | 2790 | 125 | 0 | OPEN | OPEN | 0.083 | 0.169 |
| PIPE | 14 | 14 | 15 | 25 | 195 | 125 | 0 | OPEN | OPEN | 0.011 | 0.022 |
| PIPE | 15 | 14 | 18 | 25 | 1955 | 125 | 0 | OPEN | OPEN | 0.072 | 0.147 |
| PIPE | 18 | 18 | 22 | 25 | 1140 | 125 | 0 | OPEN | OPEN | 0.072 | 0.147 |
| PIPE | 22 | 22 | 23 | 25 | 640 | 125 | 0 | OPEN | OPEN | 0.032 | 0.066 |
| PIPE | 23 | 23 | 24 | 25 | 380 | 125 | 0 | OPEN | OPEN | 0.005 | 0.010 |
| PIPE | 24 | 23 | 26 | 25 | 805 | 125 | 0 | OPEN | OPEN | 0.027 | 0.056 |
| PIPE | 26 | 26 | 27 | 25 | 565 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 27 | 26 | 28 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.020 | 0.041 |
| PIPE | 28 | 28 | 29 | 25 | 455 | 125 | 0 | OPEN | OPEN | 0.001 | 0.002 |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 125 | 0 | OPEN | OPEN | 0.019 | 0.039 |
| PIPE | 32 | 33 | 32 | 25 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 125 | 0 | OPEN | OPEN | 0.019 | 0.039 |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 125 | 0 | OPEN | OPEN | 0.018 | 0.037 |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 125 | 0 | OPEN | OPEN | 0.017 | 0.035 |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 125 | 0 | OPEN | OPEN | 0.017 | 0.035 |
| PIPE | 42 | 71 | 42 | 25 | 770 | 125 | 0 | OPEN | OPEN | 0.005 | 0.010 |
| PIPE | 43 | 71 | 43 | 25 | 765 | 125 | 0 | OPEN | OPEN | 0.004 | 0.008 |
| PIPE | 44 | 71 | 46 | 25 | 2270 | 125 | 0 | OPEN | OPEN | 0.008 | 0.017 |
| PIPE | 45 | 46 | 45 | 25 | 205 | 125 | 0 | OPEN | OPEN | 0.004 | 0.008 |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 125 | 0 | OPEN | OPEN | 0.009 | 0.018 |
| PIPE | 50 | 50 | 46 | 25 | 1175 | 125 | 0 | OPEN | OPEN | 0.005 | 0.010 |
| PIPE | 51 | 50 | 51 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.004 | 0.008 |
| PIPE | 52 | 52 | 50 | 25 | 2815 | 125 | 0 | OPEN | OPEN | 0.009 | 0.018 |
| PIPE | 53 | 52 | 53 | 25 | 305 | 125 | 0 | OPEN | OPEN | 0.009 | 0.018 |
| PIPE | 54 | 54 | 52 | 25 | 750 | 125 | 0 | OPEN | OPEN | 0.018 | 0.036 |
| PIPE | 55 | 54 | 57 | 25 | 855 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 58 | 59 | 54 | 25 | 2250 | 125 | 0 | OPEN | OPEN | 0.021 | 0.042 |
| **PIPE** | **60** | **59** | **60** | **25** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.001** | **0.002** |
| PIPE | 61 | 63 | 59 | 25 | 1030 | 125 | 0 | OPEN | OPEN | 0.022 | 0.044 |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 125 | 0 | OPEN | OPEN | 0.005 | 0.010 |
| PIPE | 68 | 68 | 63 | 25 | 645 | 125 | 0 | OPEN | OPEN | 0.040 | 0.081 |
| PIPE | 69 | 69 | 68 | 25 | 440 | 125 | 0 | OPEN | OPEN | 0.040 | 0.081 |
| PIPE | 70 | 70 | 69 | 25 | 625 | 125 | 0 | OPEN | OPEN | 0.040 | 0.081 |
| PIPE | 71 | 22 | 70 | 25 | 245 | 125 | 0 | OPEN | OPEN | 0.040 | 0.081 |

Results of abstraction rate at pipe size (50mm with 25mm)

Demand rate = 87 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 50 | 210 | 125 | 0 | OPEN | OPEN | 0.226 | 0.159 |
| PIPE | 2 | 2 | 3 | 25 | 85 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 5 | 3 | 6 | 25 | 175 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 11 | 2 | 14 | 50 | 2790 | 125 | 0 | OPEN | OPEN | 0.219 | 0.154 |
| PIPE | 14 | 14 | 15 | 50 | 195 | 125 | 0 | OPEN | OPEN | 0.028 | 0.020 |
| PIPE | 15 | 14 | 18 | 50 | 1955 | 125 | 0 | OPEN | OPEN | 0.191 | 0.134 |
| PIPE | 18 | 18 | 22 | 50 | 1140 | 125 | 0 | OPEN | OPEN | 0.191 | 0.134 |
| PIPE | 22 | 22 | 23 | 25 | 640 | 125 | 0 | OPEN | OPEN | 0.085 | 0.174 |
| PIPE | 23 | 23 | 24 | 25 | 380 | 125 | 0 | OPEN | OPEN | 0.014 | 0.029 |
| PIPE | 24 | 23 | 26 | 25 | 805 | 125 | 0 | OPEN | OPEN | 0.071 | 0.145 |
| PIPE | 26 | 26 | 27 | 25 | 565 | 125 | 0 | OPEN | OPEN | 0.017 | 0.035 |
| PIPE | 27 | 26 | 28 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.054 | 0.111 |
| PIPE | 28 | 28 | 29 | 25 | 455 | 125 | 0 | OPEN | OPEN | 0.003 | 0.006 |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 125 | 0 | OPEN | OPEN | 0.051 | 0.105 |
| PIPE | 32 | 32 | 33 | 25 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 125 | 0 | OPEN | OPEN | 0.051 | 0.104 |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 125 | 0 | OPEN | OPEN | 0.048 | 0.098 |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 125 | 0 | OPEN | OPEN | 0.045 | 0.092 |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 125 | 0 | OPEN | OPEN | 0.045 | 0.092 |
| PIPE | 42 | 71 | 42 | 25 | 770 | 125 | 0 | OPEN | OPEN | 0.014 | 0.029 |
| PIPE | 43 | 71 | 43 | 25 | 765 | 125 | 0 | OPEN | OPEN | 0.010 | 0.020 |
| PIPE | 44 | 71 | 46 | 25 | 2270 | 125 | 0 | OPEN | OPEN | 0.021 | 0.043 |
| PIPE | 45 | 46 | 45 | 25 | 205 | 125 | 0 | OPEN | OPEN | 0.010 | 0.020 |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 125 | 0 | OPEN | OPEN | 0.024 | 0.049 |
| PIPE | 50 | 50 | 46 | 25 | 1175 | 125 | 0 | OPEN | OPEN | 0.013 | 0.026 |
| PIPE | 51 | 50 | 51 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.010 | 0.020 |
| PIPE | 52 | 52 | 50 | 25 | 2815 | 125 | 0 | OPEN | OPEN | 0.023 | 0.046 |
| PIPE | 53 | 52 | 53 | 25 | 305 | 125 | 0 | OPEN | OPEN | 0.024 | 0.049 |
| PIPE | 54 | 54 | 52 | 25 | 750 | 125 | 0 | OPEN | OPEN | 0.047 | 0.095 |
| PIPE | 55 | 54 | 57 | 25 | 855 | 125 | 0 | OPEN | OPEN | 0.007 | 0.014 |
| PIPE | 58 | 59 | 54 | 25 | 2250 | 125 | 0 | OPEN | OPEN | 0.054 | 0.109 |
| **PIPE** | **60** | **59** | **60** | **25** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.003** | **0.006** |
| PIPE | 61 | 63 | 59 | 25 | 1030 | 125 | 0 | OPEN | OPEN | 0.057 | 0.116 |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 125 | 0 | OPEN | OPEN | 0.014 | 0.029 |
| PIPE | 68 | 68 | 63 | 25 | 645 | 125 | 0 | OPEN | OPEN | 0.106 | 0.215 |
| PIPE | 69 | 69 | 68 | 25 | 440 | 125 | 0 | OPEN | OPEN | 0.106 | 0.215 |
| PIPE | 70 | 70 | 69 | 25 | 625 | 125 | 0 | OPEN | OPEN | 0.106 | 0.215 |
| PIPE | 71 | 22 | 70 | 25 | 245 | 125 | 0 | OPEN | OPEN | 0.106 | 0.215 |

Results of abstraction rate at pipe size (63 mm with 25mm)

Demand rate = 103 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 125 | 0 | OPEN | OPEN | 0.269 | 0.119 |
| PIPE | 2 | 2 | 3 | 25 | 85 | 125 | 0 | OPEN | OPEN | 0.008 | 0.016 |
| PIPE | 5 | 3 | 6 | 25 | 175 | 125 | 0 | OPEN | OPEN | 0.008 | 0.016 |
| PIPE | 6 | 6 | 10 | 25 | 1350 | 125 | 0 | OPEN | OPEN | 0.008 | 0.016 |
| PIPE | 10 | 10 | 11 | 25 | 1085 | 125 | 0 | OPEN | OPEN | 0.008 | 0.016 |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 125 | 0 | OPEN | OPEN | 0.261 | 0.116 |
| PIPE | 14 | 14 | 15 | 63 | 195 | 125 | 0 | OPEN | OPEN | 0.033 | 0.015 |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 125 | 0 | OPEN | OPEN | 0.228 | 0.101 |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 125 | 0 | OPEN | OPEN | 0.228 | 0.101 |
| PIPE | 22 | 22 | 23 | 25 | 640 | 125 | 0 | OPEN | OPEN | 0.103 | 0.209 |
| PIPE | 23 | 23 | 24 | 25 | 380 | 125 | 0 | OPEN | OPEN | 0.016 | 0.033 |
| PIPE | 24 | 23 | 26 | 25 | 805 | 125 | 0 | OPEN | OPEN | 0.087 | 0.176 |
| PIPE | 26 | 26 | 27 | 25 | 565 | 125 | 0 | OPEN | OPEN | 0.021 | 0.043 |
| PIPE | 27 | 26 | 28 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.066 | 0.133 |
| PIPE | 28 | 28 | 29 | 25 | 455 | 125 | 0 | OPEN | OPEN | 0.004 | 0.008 |
| PIPE | 29 | 28 | 32 | 25 | 1695 | 125 | 0 | OPEN | OPEN | 0.062 | 0.125 |
| PIPE | 32 | 32 | 33 | 25 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 25 | 1065 | 125 | 0 | OPEN | OPEN | 0.061 | 0.125 |
| PIPE | 34 | 34 | 36 | 25 | 1560 | 125 | 0 | OPEN | OPEN | 0.057 | 0.117 |
| PIPE | 36 | 36 | 40 | 25 | 2590 | 125 | 0 | OPEN | OPEN | 0.053 | 0.109 |
| PIPE | 40 | 40 | 71 | 25 | 2950 | 125 | 0 | OPEN | OPEN | 0.053 | 0.109 |
| PIPE | 42 | 71 | 42 | 25 | 770 | 125 | 0 | OPEN | OPEN | 0.016 | 0.033 |
| PIPE | 43 | 71 | 43 | 25 | 765 | 125 | 0 | OPEN | OPEN | 0.012 | 0.024 |
| PIPE | 44 | 71 | 46 | 25 | 2270 | 125 | 0 | OPEN | OPEN | 0.025 | 0.052 |
| PIPE | 45 | 46 | 45 | 25 | 205 | 125 | 0 | OPEN | OPEN | 0.012 | 0.024 |
| PIPE | 47 | 46 | 49 | 25 | 1900 | 125 | 0 | OPEN | OPEN | 0.029 | 0.059 |
| PIPE | 50 | 50 | 46 | 25 | 1175 | 125 | 0 | OPEN | OPEN | 0.016 | 0.032 |
| PIPE | 51 | 50 | 51 | 25 | 340 | 125 | 0 | OPEN | OPEN | 0.012 | 0.024 |
| PIPE | 52 | 52 | 50 | 25 | 2815 | 125 | 0 | OPEN | OPEN | 0.028 | 0.056 |
| PIPE | 53 | 52 | 53 | 25 | 305 | 125 | 0 | OPEN | OPEN | 0.029 | 0.059 |
| PIPE | 54 | 54 | 52 | 25 | 750 | 125 | 0 | OPEN | OPEN | 0.057 | 0.115 |
| PIPE | 55 | 54 | 57 | 25 | 855 | 125 | 0 | OPEN | OPEN | 0.008 | 0.016 |
| PIPE | 58 | 59 | 54 | 25 | 2250 | 125 | 0 | OPEN | OPEN | 0.065 | 0.131 |
| **PIPE** | **60** | **59** | **60** | **25** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.004** | **0.008** |
| PIPE | 61 | 63 | 59 | 25 | 1030 | 125 | 0 | OPEN | OPEN | 0.069 | 0.140 |
| PIPE | 64 | 63 | 67 | 25 | 1935 | 125 | 0 | OPEN | OPEN | 0.016 | 0.033 |
| PIPE | 68 | 68 | 63 | 25 | 645 | 125 | 0 | OPEN | OPEN | 0.126 | 0.256 |
| PIPE | 69 | 69 | 68 | 25 | 440 | 125 | 0 | OPEN | OPEN | 0.126 | 0.256 |
| PIPE | 70 | 70 | 69 | 25 | 625 | 125 | 0 | OPEN | OPEN | 0.126 | 0.256 |
| PIPE | 71 | 22 | 70 | 25 | 245 | 125 | 0 | OPEN | OPEN | 0.126 | 0.256 |

Results of abstraction rate at pipe size of 50 mm

Demand rate = 130 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 50 | 210 | 125 | 0 | OPEN | OPEN | 0.343 | 0.241 |
| PIPE | 2 | 2 | 3 | 50 | 85 | 125 | 0 | OPEN | OPEN | 0.010 | 0.007 |
| PIPE | 5 | 3 | 6 | 50 | 175 | 125 | 0 | OPEN | OPEN | 0.010 | 0.007 |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 125 | 0 | OPEN | OPEN | 0.010 | 0.007 |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 125 | 0 | OPEN | OPEN | 0.010 | 0.007 |
| PIPE | 11 | 2 | 14 | 50 | 2790 | 125 | 0 | OPEN | OPEN | 0.333 | 0.234 |
| PIPE | 14 | 14 | 15 | 50 | 195 | 125 | 0 | OPEN | OPEN | 0.042 | 0.029 |
| PIPE | 15 | 14 | 18 | 50 | 1955 | 125 | 0 | OPEN | OPEN | 0.291 | 0.204 |
| PIPE | 18 | 18 | 22 | 50 | 1140 | 125 | 0 | OPEN | OPEN | 0.291 | 0.204 |
| PIPE | 22 | 22 | 23 | 50 | 640 | 125 | 0 | OPEN | OPEN | 0.131 | 0.092 |
| PIPE | 23 | 23 | 24 | 50 | 380 | 125 | 0 | OPEN | OPEN | 0.021 | 0.015 |
| PIPE | 24 | 23 | 26 | 50 | 805 | 125 | 0 | OPEN | OPEN | 0.110 | 0.077 |
| PIPE | 26 | 26 | 27 | 50 | 565 | 125 | 0 | OPEN | OPEN | 0.026 | 0.018 |
| PIPE | 27 | 26 | 28 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.084 | 0.059 |
| PIPE | 28 | 28 | 29 | 50 | 455 | 125 | 0 | OPEN | OPEN | 0.005 | 0.004 |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 125 | 0 | OPEN | OPEN | 0.079 | 0.055 |
| PIPE | 32 | 32 | 33 | 50 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 125 | 0 | OPEN | OPEN | 0.079 | 0.055 |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 125 | 0 | OPEN | OPEN | 0.074 | 0.052 |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 125 | 0 | OPEN | OPEN | 0.069 | 0.048 |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 125 | 0 | OPEN | OPEN | 0.069 | 0.048 |
| PIPE | 42 | 71 | 42 | 50 | 770 | 125 | 0 | OPEN | OPEN | 0.021 | 0.015 |
| PIPE | 43 | 71 | 43 | 50 | 765 | 125 | 0 | OPEN | OPEN | 0.016 | 0.011 |
| PIPE | 44 | 71 | 46 | 50 | 2270 | 125 | 0 | OPEN | OPEN | 0.032 | 0.022 |
| PIPE | 45 | 46 | 45 | 50 | 205 | 125 | 0 | OPEN | OPEN | 0.016 | 0.011 |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 125 | 0 | OPEN | OPEN | 0.036 | 0.025 |
| PIPE | 50 | 50 | 46 | 50 | 1175 | 125 | 0 | OPEN | OPEN | 0.02 | 0.014 |
| PIPE | 51 | 50 | 51 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.016 | 0.011 |
| PIPE | 52 | 52 | 50 | 50 | 2815 | 125 | 0 | OPEN | OPEN | 0.036 | 0.025 |
| PIPE | 53 | 52 | 53 | 50 | 305 | 125 | 0 | OPEN | OPEN | 0.036 | 0.025 |
| PIPE | 54 | 54 | 52 | 50 | 750 | 125 | 0 | OPEN | OPEN | 0.072 | 0.051 |
| PIPE | 55 | 54 | 57 | 50 | 855 | 125 | 0 | OPEN | OPEN | 0.01 | 0.007 |
| PIPE | 58 | 59 | 54 | 50 | 2250 | 125 | 0 | OPEN | OPEN | 0.082 | 0.058 |
| **PIPE** | **60** | **59** | **60** | **50** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.005** | **0.004** |
| PIPE | 61 | 63 | 59 | 50 | 1030 | 125 | 0 | OPEN | OPEN | 0.087 | 0.061 |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 125 | 0 | OPEN | OPEN | 0.021 | 0.015 |
| PIPE | 68 | 68 | 63 | 50 | 645 | 125 | 0 | OPEN | OPEN | 0.16 | 0.112 |
| PIPE | 69 | 69 | 68 | 50 | 440 | 125 | 0 | OPEN | OPEN | 0.16 | 0.112 |
| PIPE | 70 | 70 | 69 | 50 | 625 | 125 | 0 | OPEN | OPEN | 0.16 | 0.112 |
| PIPE | 71 | 22 | 70 | 50 | 245 | 125 | 0 | OPEN | OPEN | 0.16 | 0.112 |

Results of abstraction rate at pipe size (63 mm x 50 mm)

Demand rate = 219 l/c/day

| TYPE | No | From Node | To Node | Diameter (mm) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 125 | 0 | OPEN | OPEN | 0.579 | 0.257 |
| PIPE | 2 | 2 | 3 | 50 | 85 | 125 | 0 | OPEN | OPEN | 0.018 | 0.013 |
| PIPE | 5 | 3 | 6 | 50 | 175 | 125 | 0 | OPEN | OPEN | 0.018 | 0.013 |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 125 | 0 | OPEN | OPEN | 0.018 | 0.013 |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 125 | 0 | OPEN | OPEN | 0.018 | 0.013 |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 125 | 0 | OPEN | OPEN | 0.561 | 0.249 |
| PIPE | 14 | 14 | 15 | 63 | 195 | 125 | 0 | OPEN | OPEN | 0.070 | 0.031 |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 125 | 0 | OPEN | OPEN | 0.491 | 0.218 |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 125 | 0 | OPEN | OPEN | 0.491 | 0.218 |
| PIPE | 22 | 22 | 23 | 50 | 640 | 125 | 0 | OPEN | OPEN | 0.221 | 0.155 |
| PIPE | 23 | 23 | 24 | 50 | 380 | 125 | 0 | OPEN | OPEN | 0.035 | 0.025 |
| PIPE | 24 | 23 | 26 | 50 | 805 | 125 | 0 | OPEN | OPEN | 0.186 | 0.130 |
| PIPE | 26 | 26 | 27 | 50 | 565 | 125 | 0 | OPEN | OPEN | 0.044 | 0.031 |
| PIPE | 27 | 26 | 28 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.142 | 0.099 |
| PIPE | 28 | 28 | 29 | 50 | 455 | 125 | 0 | OPEN | OPEN | 0.009 | 0.006 |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 125 | 0 | OPEN | OPEN | 0.133 | 0.093 |
| PIPE | 32 | 33 | 32 | 50 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 125 | 0 | OPEN | OPEN | 0.133 | 0.093 |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 125 | 0 | OPEN | OPEN | 0.124 | 0.087 |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 125 | 0 | OPEN | OPEN | 0.115 | 0.081 |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 125 | 0 | OPEN | OPEN | 0.115 | 0.081 |
| PIPE | 42 | 71 | 42 | 50 | 770 | 125 | 0 | OPEN | OPEN | 0.035 | 0.025 |
| PIPE | 43 | 71 | 43 | 50 | 765 | 125 | 0 | OPEN | OPEN | 0.026 | 0.018 |
| PIPE | 44 | 71 | 46 | 50 | 2270 | 125 | 0 | OPEN | OPEN | 0.054 | 0.038 |
| PIPE | 45 | 46 | 45 | 50 | 205 | 125 | 0 | OPEN | OPEN | 0.026 | 0.018 |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 125 | 0 | OPEN | OPEN | 0.061 | 0.043 |
| PIPE | 50 | 50 | 46 | 50 | 1175 | 125 | 0 | OPEN | OPEN | 0.033 | 0.023 |
| PIPE | 51 | 50 | 51 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.026 | 0.018 |
| PIPE | 52 | 52 | 50 | 50 | 2815 | 125 | 0 | OPEN | OPEN | 0.059 | 0.042 |
| PIPE | 53 | 52 | 53 | 50 | 305 | 125 | 0 | OPEN | OPEN | 0.061 | 0.043 |
| PIPE | 54 | 54 | 52 | 50 | 750 | 125 | 0 | OPEN | OPEN | 0.120 | 0.084 |
| PIPE | 55 | 54 | 57 | 50 | 855 | 125 | 0 | OPEN | OPEN | 0.018 | 0.013 |
| PIPE | 58 | 59 | 54 | 50 | 2250 | 125 | 0 | OPEN | OPEN | 0.138 | 0.097 |
| **PIPE** | **60** | **59** | **60** | **50** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.009** | **0.006** |
| PIPE | 61 | 63 | 59 | 50 | 1030 | 125 | 0 | OPEN | OPEN | 0.147 | 0.103 |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 125 | 0 | OPEN | OPEN | 0.035 | 0.025 |
| PIPE | 68 | 68 | 63 | 50 | 645 | 125 | 0 | OPEN | OPEN | 0.270 | 0.190 |
| PIPE | 69 | 69 | 68 | 50 | 440 | 125 | 0 | OPEN | OPEN | 0.270 | 0.190 |
| PIPE | 70 | 70 | 69 | 50 | 625 | 125 | 0 | OPEN | OPEN | 0.270 | 0.190 |
| PIPE | 71 | 22 | 70 | 50 | 245 | 125 | 0 | OPEN | OPEN | 0.270 | 0.190 |

Results of abstraction rate at pipe size (75 mm x 50 mm)

Demand rate = 242 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 125 | 0 | OPEN | OPEN | 0.640 | 0.145 |
| PIPE | 2 | 2 | 3 | 50 | 85 | 125 | 0 | OPEN | OPEN | 0.019 | 0.013 |
| PIPE | 5 | 3 | 6 | 50 | 175 | 125 | 0 | OPEN | OPEN | 0.019 | 0.013 |
| PIPE | 6 | 6 | 10 | 50 | 1350 | 125 | 0 | OPEN | OPEN | 0.019 | 0.013 |
| PIPE | 10 | 10 | 11 | 50 | 1085 | 125 | 0 | OPEN | OPEN | 0.019 | 0.013 |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 125 | 0 | OPEN | OPEN | 0.621 | 0.141 |
| PIPE | 14 | 14 | 15 | 75 | 195 | 125 | 0 | OPEN | OPEN | 0.077 | 0.017 |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 125 | 0 | OPEN | OPEN | 0.544 | 0.123 |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 125 | 0 | OPEN | OPEN | 0.544 | 0.123 |
| PIPE | 22 | 22 | 23 | 50 | 640 | 125 | 0 | OPEN | OPEN | 0.245 | 0.172 |
| PIPE | 23 | 23 | 24 | 50 | 380 | 125 | 0 | OPEN | OPEN | 0.039 | 0.027 |
| PIPE | 24 | 23 | 26 | 50 | 805 | 125 | 0 | OPEN | OPEN | 0.206 | 0.144 |
| PIPE | 26 | 26 | 27 | 50 | 565 | 125 | 0 | OPEN | OPEN | 0.048 | 0.034 |
| PIPE | 27 | 26 | 28 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.158 | 0.111 |
| PIPE | 28 | 28 | 29 | 50 | 455 | 125 | 0 | OPEN | OPEN | 0.010 | 0.007 |
| PIPE | 29 | 28 | 32 | 50 | 1695 | 125 | 0 | OPEN | OPEN | 0.148 | 0.104 |
| PIPE | 32 | 32 | 33 | 50 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 50 | 1065 | 125 | 0 | OPEN | OPEN | 0.148 | 0.104 |
| PIPE | 34 | 34 | 36 | 50 | 1560 | 125 | 0 | OPEN | OPEN | 0.138 | 0.096 |
| PIPE | 36 | 36 | 40 | 50 | 2590 | 125 | 0 | OPEN | OPEN | 0.128 | 0.089 |
| PIPE | 40 | 40 | 71 | 50 | 2950 | 125 | 0 | OPEN | OPEN | 0.128 | 0.089 |
| PIPE | 42 | 71 | 42 | 50 | 770 | 125 | 0 | OPEN | OPEN | 0.039 | 0.027 |
| PIPE | 43 | 71 | 43 | 50 | 765 | 125 | 0 | OPEN | OPEN | 0.029 | 0.020 |
| PIPE | 44 | 71 | 46 | 50 | 2270 | 125 | 0 | OPEN | OPEN | 0.060 | 0.042 |
| PIPE | 45 | 46 | 45 | 50 | 205 | 125 | 0 | OPEN | OPEN | 0.029 | 0.020 |
| PIPE | 47 | 46 | 49 | 50 | 1900 | 125 | 0 | OPEN | OPEN | 0.068 | 0.048 |
| PIPE | 50 | 50 | 46 | 50 | 1175 | 125 | 0 | OPEN | OPEN | 0.037 | 0.026 |
| PIPE | 51 | 50 | 51 | 50 | 340 | 125 | 0 | OPEN | OPEN | 0.029 | 0.020 |
| PIPE | 52 | 52 | 50 | 50 | 2815 | 125 | 0 | OPEN | OPEN | 0.066 | 0.047 |
| PIPE | 53 | 52 | 53 | 50 | 305 | 125 | 0 | OPEN | OPEN | 0.068 | 0.048 |
| PIPE | 54 | 54 | 52 | 50 | 750 | 125 | 0 | OPEN | OPEN | 0.134 | 0.094 |
| PIPE | 55 | 54 | 57 | 50 | 855 | 125 | 0 | OPEN | OPEN | 0.019 | 0.013 |
| PIPE | 58 | 59 | 54 | 50 | 2250 | 125 | 0 | OPEN | OPEN | 0.153 | 0.108 |
| **PIPE** | **60** | **59** | **60** | **50** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.010** | **0.007** |
| PIPE | 61 | 63 | 59 | 50 | 1030 | 125 | 0 | OPEN | OPEN | 0.163 | 0.115 |
| PIPE | 64 | 63 | 67 | 50 | 1935 | 125 | 0 | OPEN | OPEN | 0.039 | 0.027 |
| PIPE | 68 | 68 | 63 | 50 | 645 | 125 | 0 | OPEN | OPEN | 0.299 | 0.210 |
| PIPE | 69 | 69 | 68 | 50 | 440 | 125 | 0 | OPEN | OPEN | 0.299 | 0.210 |
| PIPE | 70 | 70 | 69 | 50 | 625 | 125 | 0 | OPEN | OPEN | 0.299 | 0.210 |
| PIPE | 71 | 22 | 70 | 50 | 245 | 125 | 0 | OPEN | OPEN | 0.299 | 0.210 |

Results of abstraction rate at pipe size of 63 mm

Demand rate = 362 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 63 | 210 | 125 | 0 | OPEN | OPEN | 0.952 | 0.305 |
| PIPE | 2 | 2 | 3 | 63 | 85 | 125 | 0 | OPEN | OPEN | 0.029 | 0.009 |
| PIPE | 5 | 3 | 6 | 63 | 175 | 125 | 0 | OPEN | OPEN | 0.029 | 0.009 |
| PIPE | 6 | 6 | 10 | 63 | 1350 | 125 | 0 | OPEN | OPEN | 0.029 | 0.009 |
| PIPE | 10 | 10 | 11 | 63 | 1085 | 125 | 0 | OPEN | OPEN | 0.029 | 0.009 |
| PIPE | 11 | 2 | 14 | 63 | 2790 | 125 | 0 | OPEN | OPEN | 0.923 | 0.296 |
| PIPE | 14 | 14 | 15 | 63 | 195 | 125 | 0 | OPEN | OPEN | 0.116 | 0.037 |
| PIPE | 15 | 14 | 18 | 63 | 1955 | 125 | 0 | OPEN | OPEN | 0.807 | 0.259 |
| PIPE | 18 | 18 | 22 | 63 | 1140 | 125 | 0 | OPEN | OPEN | 0.807 | 0.259 |
| PIPE | 22 | 22 | 23 | 63 | 640 | 125 | 0 | OPEN | OPEN | 0.362 | 0.116 |
| PIPE | 23 | 23 | 24 | 63 | 380 | 125 | 0 | OPEN | OPEN | 0.058 | 0.019 |
| PIPE | 24 | 23 | 26 | 63 | 805 | 125 | 0 | OPEN | OPEN | 0.304 | 0.098 |
| PIPE | 26 | 26 | 27 | 63 | 565 | 125 | 0 | OPEN | OPEN | 0.072 | 0.023 |
| PIPE | 27 | 26 | 28 | 63 | 340 | 125 | 0 | OPEN | OPEN | 0.232 | 0.074 |
| PIPE | 28 | 28 | 29 | 63 | 455 | 125 | 0 | OPEN | OPEN | 0.014 | 0.004 |
| PIPE | 29 | 28 | 32 | 63 | 1695 | 125 | 0 | OPEN | OPEN | 0.218 | 0.070 |
| PIPE | 32 | 32 | 33 | 63 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 63 | 1065 | 125 | 0 | OPEN | OPEN | 0.218 | 0.070 |
| PIPE | 34 | 34 | 36 | 63 | 1560 | 125 | 0 | OPEN | OPEN | 0.204 | 0.065 |
| PIPE | 36 | 36 | 40 | 63 | 2590 | 125 | 0 | OPEN | OPEN | 0.190 | 0.061 |
| PIPE | 40 | 40 | 71 | 63 | 2950 | 125 | 0 | OPEN | OPEN | 0.190 | 0.061 |
| PIPE | 42 | 71 | 42 | 63 | 770 | 125 | 0 | OPEN | OPEN | 0.058 | 0.019 |
| PIPE | 43 | 71 | 43 | 63 | 765 | 125 | 0 | OPEN | OPEN | 0.043 | 0.014 |
| PIPE | 44 | 71 | 46 | 63 | 2270 | 125 | 0 | OPEN | OPEN | 0.089 | 0.029 |
| PIPE | 45 | 46 | 45 | 63 | 205 | 125 | 0 | OPEN | OPEN | 0.043 | 0.014 |
| PIPE | 47 | 46 | 49 | 63 | 1900 | 125 | 0 | OPEN | OPEN | 0.101 | 0.032 |
| PIPE | 50 | 50 | 46 | 63 | 1175 | 125 | 0 | OPEN | OPEN | 0.055 | 0.018 |
| PIPE | 51 | 50 | 51 | 63 | 340 | 125 | 0 | OPEN | OPEN | 0.043 | 0.014 |
| PIPE | 52 | 52 | 50 | 63 | 2815 | 125 | 0 | OPEN | OPEN | 0.098 | 0.031 |
| PIPE | 53 | 52 | 53 | 63 | 305 | 125 | 0 | OPEN | OPEN | 0.101 | 0.032 |
| PIPE | 54 | 54 | 52 | 63 | 750 | 125 | 0 | OPEN | OPEN | 0.199 | 0.064 |
| PIPE | 55 | 54 | 57 | 63 | 855 | 125 | 0 | OPEN | OPEN | 0.029 | 0.009 |
| PIPE | 58 | 59 | 54 | 63 | 2250 | 125 | 0 | OPEN | OPEN | 0.228 | 0.073 |
| **PIPE** | **60** | **59** | **60** | **63** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.014** | **0.004** |
| PIPE | 61 | 63 | 59 | 63 | 1030 | 125 | 0 | OPEN | OPEN | 0.242 | 0.078 |
| PIPE | 64 | 63 | 67 | 63 | 1935 | 125 | 0 | OPEN | OPEN | 0.058 | 0.019 |
| PIPE | 68 | 68 | 63 | 63 | 645 | 125 | 0 | OPEN | OPEN | 0.445 | 0.143 |
| PIPE | 69 | 69 | 68 | 63 | 440 | 125 | 0 | OPEN | OPEN | 0.445 | 0.143 |
| PIPE | 70 | 70 | 69 | 63 | 625 | 125 | 0 | OPEN | OPEN | 0.445 | 0.143 |
| PIPE | 71 | 22 | 70 | 63 | 245 | 125 | 0 | OPEN | OPEN | 0.445 | 0.143 |

Results of abstraction rate at pipe size (75 mm with 63 mm)

Demand rate = 486 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s ) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 125 | 0 | OPEN | OPEN | 1.281 | 0.290 |
| PIPE | 2 | 2 | 3 | 63 | 85 | 125 | 0 | OPEN | OPEN | 0.039 | 0.017 |
| PIPE | 5 | 3 | 6 | 63 | 175 | 125 | 0 | OPEN | OPEN | 0.039 | 0.017 |
| PIPE | 6 | 6 | 10 | 63 | 1350 | 125 | 0 | OPEN | OPEN | 0.039 | 0.017 |
| PIPE | 10 | 10 | 11 | 63 | 1085 | 125 | 0 | OPEN | OPEN | 0.039 | 0.017 |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 125 | 0 | OPEN | OPEN | 1.242 | 0.281 |
| PIPE | 14 | 14 | 15 | 75 | 195 | 125 | 0 | OPEN | OPEN | 0.156 | 0.035 |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 125 | 0 | OPEN | OPEN | 1.086 | 0.246 |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 125 | 0 | OPEN | OPEN | 1.086 | 0.246 |
| PIPE | 22 | 22 | 23 | 63 | 640 | 125 | 0 | OPEN | OPEN | 0.488 | 0.216 |
| PIPE | 23 | 23 | 24 | 63 | 380 | 125 | 0 | OPEN | OPEN | 0.078 | 0.035 |
| PIPE | 24 | 23 | 26 | 63 | 805 | 125 | 0 | OPEN | OPEN | 0.410 | 0.182 |
| PIPE | 26 | 26 | 27 | 63 | 565 | 125 | 0 | OPEN | OPEN | 0.097 | 0.043 |
| PIPE | 27 | 26 | 28 | 63 | 340 | 125 | 0 | OPEN | OPEN | 0.313 | 0.139 |
| PIPE | 28 | 28 | 29 | 63 | 455 | 125 | 0 | OPEN | OPEN | 0.019 | 0.008 |
| PIPE | 29 | 28 | 32 | 63 | 1695 | 125 | 0 | OPEN | OPEN | 0.294 | 0.130 |
| PIPE | 32 | 32 | 33 | 63 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 63 | 1065 | 125 | 0 | OPEN | OPEN | 0.294 | 0.130 |
| PIPE | 34 | 34 | 36 | 63 | 1560 | 125 | 0 | OPEN | OPEN | 0.275 | 0.122 |
| PIPE | 36 | 36 | 40 | 63 | 2590 | 125 | 0 | OPEN | OPEN | 0.256 | 0.113 |
| PIPE | 40 | 40 | 71 | 63 | 2950 | 125 | 0 | OPEN | OPEN | 0.256 | 0.113 |
| PIPE | 42 | 71 | 42 | 63 | 770 | 125 | 0 | OPEN | OPEN | 0.078 | 0.035 |
| PIPE | 43 | 71 | 43 | 63 | 765 | 125 | 0 | OPEN | OPEN | 0.058 | 0.026 |
| PIPE | 44 | 71 | 46 | 63 | 2270 | 125 | 0 | OPEN | OPEN | 0.120 | 0.053 |
| PIPE | 45 | 46 | 45 | 63 | 205 | 125 | 0 | OPEN | OPEN | 0.058 | 0.026 |
| PIPE | 47 | 46 | 49 | 63 | 1900 | 125 | 0 | OPEN | OPEN | 0.136 | 0.060 |
| PIPE | 50 | 50 | 46 | 63 | 1175 | 125 | 0 | OPEN | OPEN | 0.074 | 0.033 |
| PIPE | 51 | 50 | 51 | 63 | 340 | 125 | 0 | OPEN | OPEN | 0.058 | 0.026 |
| PIPE | 52 | 52 | 50 | 63 | 2815 | 125 | 0 | OPEN | OPEN | 0.132 | 0.059 |
| PIPE | 53 | 52 | 53 | 63 | 305 | 125 | 0 | OPEN | OPEN | 0.136 | 0.06 |
| PIPE | 54 | 54 | 52 | 63 | 750 | 125 | 0 | OPEN | OPEN | 0.268 | 0.119 |
| PIPE | 55 | 54 | 57 | 63 | 855 | 125 | 0 | OPEN | OPEN | 0.039 | 0.017 |
| PIPE | 58 | 59 | 54 | 63 | 2250 | 125 | 0 | OPEN | OPEN | 0.307 | 0.136 |
| **PIPE** | **60** | **59** | **60** | **63** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.019** | **0.008** |
| PIPE | 61 | 63 | 59 | 63 | 1030 | 125 | 0 | OPEN | OPEN | 0.326 | 0.145 |
| PIPE | 64 | 63 | 67 | 63 | 1935 | 125 | 0 | OPEN | OPEN | 0.078 | 0.035 |
| PIPE | 68 | 68 | 63 | 63 | 645 | 125 | 0 | OPEN | OPEN | 0.598 | 0.265 |
| PIPE | 69 | 69 | 68 | 63 | 440 | 125 | 0 | OPEN | OPEN | 0.598 | 0.265 |
| PIPE | 70 | 70 | 69 | 63 | 625 | 125 | 0 | OPEN | OPEN | 0.598 | 0.265 |
| PIPE | 71 | 22 | 70 | 63 | 245 | 125 | 0 | OPEN | OPEN | 0.598 | 0.265 |

Results of abstraction rate at pipe size of 75 mm

Demand rate = 587 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow (l/s) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 75 | 210 | 125 | 0 | OPEN | OPEN | 1.550 | 0.350 |
| PIPE | 2 | 2 | 3 | 75 | 85 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 5 | 3 | 6 | 75 | 175 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 6 | 6 | 10 | 75 | 1350 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 10 | 10 | 11 | 75 | 1085 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 11 | 2 | 14 | 75 | 2790 | 125 | 0 | OPEN | OPEN | 1.500 | 0.340 |
| PIPE | 14 | 14 | 15 | 75 | 195 | 125 | 0 | OPEN | OPEN | 0.190 | 0.040 |
| PIPE | 15 | 14 | 18 | 75 | 1955 | 125 | 0 | OPEN | OPEN | 1.310 | 0.300 |
| PIPE | 18 | 18 | 22 | 75 | 1140 | 125 | 0 | OPEN | OPEN | 1.310 | 0.300 |
| PIPE | 22 | 22 | 23 | 75 | 640 | 125 | 0 | OPEN | OPEN | 0.590 | 0.130 |
| PIPE | 23 | 23 | 24 | 75 | 380 | 125 | 0 | OPEN | OPEN | 0.090 | 0.020 |
| PIPE | 24 | 23 | 26 | 75 | 805 | 125 | 0 | OPEN | OPEN | 0.500 | 0.110 |
| PIPE | 26 | 26 | 27 | 75 | 565 | 125 | 0 | OPEN | OPEN | 0.120 | 0.030 |
| PIPE | 27 | 26 | 28 | 75 | 340 | 125 | 0 | OPEN | OPEN | 0.380 | 0.090 |
| PIPE | 28 | 28 | 29 | 75 | 455 | 125 | 0 | OPEN | OPEN | 0.020 | 0.010 |
| PIPE | 29 | 28 | 32 | 75 | 1695 | 125 | 0 | OPEN | OPEN | 0.360 | 0.080 |
| PIPE | 32 | 32 | 33 | 75 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 75 | 1065 | 125 | 0 | OPEN | OPEN | 0.360 | 0.080 |
| PIPE | 34 | 34 | 36 | 75 | 1560 | 125 | 0 | OPEN | OPEN | 0.330 | 0.080 |
| PIPE | 36 | 36 | 40 | 75 | 2590 | 125 | 0 | OPEN | OPEN | 0.310 | 0.070 |
| PIPE | 40 | 40 | 71 | 75 | 2950 | 125 | 0 | OPEN | OPEN | 0.310 | 0.070 |
| PIPE | 42 | 71 | 42 | 75 | 770 | 125 | 0 | OPEN | OPEN | 0.090 | 0.020 |
| PIPE | 43 | 71 | 43 | 75 | 765 | 125 | 0 | OPEN | OPEN | 0.070 | 0.020 |
| PIPE | 44 | 71 | 46 | 75 | 2270 | 125 | 0 | OPEN | OPEN | 0.150 | 0.030 |
| PIPE | 45 | 46 | 45 | 75 | 205 | 125 | 0 | OPEN | OPEN | 0.070 | 0.020 |
| PIPE | 47 | 46 | 49 | 75 | 1900 | 125 | 0 | OPEN | OPEN | 0.160 | 0.040 |
| PIPE | 50 | 50 | 46 | 75 | 1175 | 125 | 0 | OPEN | OPEN | 0.090 | 0.020 |
| PIPE | 51 | 50 | 51 | 75 | 340 | 125 | 0 | OPEN | OPEN | 0.070 | 0.020 |
| PIPE | 52 | 52 | 50 | 75 | 2815 | 125 | 0 | OPEN | OPEN | 0.160 | 0.040 |
| PIPE | 53 | 52 | 53 | 75 | 305 | 125 | 0 | OPEN | OPEN | 0.160 | 0.040 |
| PIPE | 54 | 54 | 52 | 75 | 750 | 125 | 0 | OPEN | OPEN | 0.320 | 0.070 |
| PIPE | 55 | 54 | 57 | 75 | 855 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 58 | 59 | 54 | 75 | 2250 | 125 | 0 | OPEN | OPEN | 0.370 | 0.080 |
| **PIPE** | **60** | **59** | **60** | **75** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.023** | **0.010** |
| PIPE | 61 | 63 | 59 | 75 | 1030 | 125 | 0 | OPEN | OPEN | 0.390 | 0.090 |
| PIPE | 64 | 63 | 67 | 75 | 1935 | 125 | 0 | OPEN | OPEN | 0.090 | 0.020 |
| PIPE | 68 | 68 | 63 | 75 | 645 | 125 | 0 | OPEN | OPEN | 0.720 | 0.160 |
| PIPE | 69 | 69 | 68 | 75 | 440 | 125 | 0 | OPEN | OPEN | 0.720 | 0.160 |
| PIPE | 70 | 70 | 69 | 75 | 625 | 125 | 0 | OPEN | OPEN | 0.720 | 0.160 |
| PIPE | 71 | 22 | 70 | 75 | 245 | 125 | 0 | OPEN | OPEN | 0.720 | 0.160 |

Results of abstraction rate at pipe size of 100 mm

Demand rate = 1253 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 100 | 210 | 125 | 0 | OPEN | OPEN | 3.310 | 0.420 |
| PIPE | 2 | 2 | 3 | 100 | 85 | 125 | 0 | OPEN | OPEN | 0.100 | 0.010 |
| PIPE | 5 | 3 | 6 | 100 | 175 | 125 | 0 | OPEN | OPEN | 0.100 | 0.010 |
| PIPE | 6 | 6 | 10 | 100 | 1350 | 125 | 0 | OPEN | OPEN | 0.100 | 0.010 |
| PIPE | 10 | 10 | 11 | 100 | 1085 | 125 | 0 | OPEN | OPEN | 0.100 | 0.010 |
| PIPE | 11 | 2 | 14 | 100 | 2790 | 125 | 0 | OPEN | OPEN | 3.210 | 0.410 |
| PIPE | 14 | 14 | 15 | 100 | 195 | 125 | 0 | OPEN | OPEN | 0.400 | 0.050 |
| PIPE | 15 | 14 | 18 | 100 | 1955 | 125 | 0 | OPEN | OPEN | 2.800 | 0.360 |
| PIPE | 18 | 18 | 22 | 100 | 1140 | 125 | 0 | OPEN | OPEN | 2.800 | 0.360 |
| PIPE | 22 | 22 | 23 | 100 | 640 | 125 | 0 | OPEN | OPEN | 1.260 | 0.160 |
| PIPE | 23 | 23 | 24 | 100 | 380 | 125 | 0 | OPEN | OPEN | 0.2000 | 0.030 |
| PIPE | 24 | 23 | 26 | 100 | 805 | 125 | 0 | OPEN | OPEN | 1.060 | 0.140 |
| PIPE | 26 | 26 | 27 | 100 | 565 | 125 | 0 | OPEN | OPEN | 0.250 | 0.030 |
| PIPE | 27 | 26 | 28 | 100 | 340 | 125 | 0 | OPEN | OPEN | 0.810 | 0.100 |
| PIPE | 28 | 28 | 29 | 100 | 455 | 125 | 0 | OPEN | OPEN | 0.050 | 0.010 |
| PIPE | 29 | 28 | 32 | 100 | 1695 | 125 | 0 | OPEN | OPEN | 0.760 | 0.100 |
| PIPE | 32 | 32 | 33 | 100 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 100 | 1065 | 125 | 0 | OPEN | OPEN | 0.760 | 0.10 |
| PIPE | 34 | 34 | 36 | 100 | 1560 | 125 | 0 | OPEN | OPEN | 0.710 | 0.090 |
| PIPE | 36 | 36 | 40 | 100 | 2590 | 125 | 0 | OPEN | OPEN | 0.660 | 0.080 |
| PIPE | 40 | 40 | 71 | 100 | 2950 | 125 | 0 | OPEN | OPEN | 0.660 | 0.080 |
| PIPE | 42 | 71 | 42 | 100 | 770 | 125 | 0 | OPEN | OPEN | 0.200 | 0.030 |
| PIPE | 43 | 71 | 43 | 100 | 765 | 125 | 0 | OPEN | OPEN | 0.150 | 0.020 |
| PIPE | 44 | 71 | 46 | 100 | 2270 | 125 | 0 | OPEN | OPEN | 0.310 | 0.040 |
| PIPE | 45 | 46 | 45 | 100 | 205 | 125 | 0 | OPEN | OPEN | 0.150 | 0.020 |
| PIPE | 47 | 46 | 49 | 100 | 1900 | 125 | 0 | OPEN | OPEN | 0.350 | 0.050 |
| PIPE | 50 | 50 | 46 | 100 | 1175 | 125 | 0 | OPEN | OPEN | 0.190 | 0.020 |
| PIPE | 51 | 50 | 51 | 100 | 340 | 125 | 0 | OPEN | OPEN | 0.150 | 0.020 |
| PIPE | 52 | 52 | 50 | 100 | 2815 | 125 | 0 | OPEN | OPEN | 0.340 | 0.040 |
| PIPE | 53 | 52 | 53 | 100 | 305 | 125 | 0 | OPEN | OPEN | 0.350 | 0.050 |
| PIPE | 54 | 54 | 52 | 100 | 750 | 125 | 0 | OPEN | OPEN | 0.690 | 0.090 |
| PIPE | 55 | 54 | 57 | 100 | 855 | 125 | 0 | OPEN | OPEN | 0.100 | 0.010 |
| PIPE | 58 | 59 | 54 | 100 | 2250 | 125 | 0 | OPEN | OPEN | 0.790 | 0.100 |
| **PIPE** | **60** | **59** | **60** | **100** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.050** | **0.010** |
| PIPE | 61 | 63 | 59 | 100 | 1030 | 125 | 0 | OPEN | OPEN | 0.840 | 0.110 |
| PIPE | 64 | 63 | 67 | 100 | 1935 | 125 | 0 | OPEN | OPEN | 0.200 | 0.030 |
| PIPE | 68 | 68 | 63 | 100 | 645 | 125 | 0 | OPEN | OPEN | 1.540 | 0.200 |
| PIPE | 69 | 69 | 68 | 100 | 440 | 125 | 0 | OPEN | OPEN | 1.540 | 0.200 |
| PIPE | 70 | 70 | 69 | 100 | 625 | 125 | 0 | OPEN | OPEN | 1.540 | 0.200 |
| PIPE | 71 | 22 | 70 | 100 | 245 | 125 | 0 | OPEN | OPEN | 1.540 | 0.200 |

Results of abstraction rate at pipe size of 150 mm

Demand rate = 3637 l/c/day

| TYPE | No | From Node | To Node | Diameter ( mm ) | C. Length | Coeff | Minor Loss | Open/ Closed | Balanced Status | Flow ( l/s) | Velocity ( m/s ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE | 1 | 1 | 2 | 150 | 210 | 125 | 0 | OPEN | OPEN | 9.600 | 0.540 |
| PIPE | 2 | 2 | 3 | 150 | 85 | 125 | 0 | OPEN | OPEN | 0.290 | 0.020 |
| PIPE | 5 | 3 | 6 | 150 | 175 | 125 | 0 | OPEN | OPEN | 0.290 | 0.020 |
| PIPE | 6 | 6 | 10 | 150 | 1350 | 125 | 0 | OPEN | OPEN | 0.290 | 0.020 |
| PIPE | 10 | 10 | 11 | 150 | 1085 | 125 | 0 | OPEN | OPEN | 0.290 | 0.020 |
| PIPE | 11 | 2 | 14 | 150 | 2790 | 125 | 0 | OPEN | OPEN | 9.310 | 0.530 |
| PIPE | 14 | 14 | 15 | 150 | 195 | 125 | 0 | OPEN | OPEN | 1.160 | 0.070 |
| PIPE | 15 | 14 | 18 | 150 | 1955 | 125 | 0 | OPEN | OPEN | 8.140 | 0.460 |
| PIPE | 18 | 18 | 22 | 150 | 1140 | 125 | 0 | OPEN | OPEN | 8.140 | 0.460 |
| PIPE | 22 | 22 | 23 | 150 | 640 | 125 | 0 | OPEN | OPEN | 3.660 | 0.210 |
| PIPE | 23 | 23 | 24 | 150 | 380 | 125 | 0 | OPEN | OPEN | 0.580 | 0.030 |
| PIPE | 24 | 23 | 26 | 150 | 805 | 125 | 0 | OPEN | OPEN | 3.080 | 0.170 |
| PIPE | 26 | 26 | 27 | 150 | 565 | 125 | 0 | OPEN | OPEN | 0.730 | 0.040 |
| PIPE | 27 | 26 | 28 | 150 | 340 | 125 | 0 | OPEN | OPEN | 2.350 | 0.130 |
| PIPE | 28 | 28 | 29 | 150 | 455 | 125 | 0 | OPEN | OPEN | 0.150 | 0.010 |
| PIPE | 29 | 28 | 32 | 150 | 1695 | 125 | 0 | OPEN | OPEN | 2.200 | 0.130 |
| PIPE | 32 | 32 | 33 | 150 | 425 | 125 | 0 | OPEN | OPEN | 0.000 | 0.000 |
| PIPE | 33 | 32 | 34 | 150 | 1065 | 125 | 0 | OPEN | OPEN | 2.200 | 0.130 |
| PIPE | 34 | 34 | 36 | 150 | 1560 | 125 | 0 | OPEN | OPEN | 2.060 | 0.120 |
| PIPE | 36 | 36 | 40 | 150 | 2590 | 125 | 0 | OPEN | OPEN | 1.910 | 0.110 |
| PIPE | 40 | 40 | 71 | 150 | 2950 | 125 | 0 | OPEN | OPEN | 1.910 | 0.110 |
| PIPE | 42 | 71 | 42 | 150 | 770 | 125 | 0 | OPEN | OPEN | 0.580 | 0.030 |
| PIPE | 43 | 71 | 43 | 150 | 765 | 125 | 0 | OPEN | OPEN | 0.440 | 0.030 |
| PIPE | 44 | 71 | 46 | 150 | 2270 | 125 | 0 | OPEN | OPEN | 0.900 | 0.050 |
| PIPE | 45 | 46 | 45 | 150 | 205 | 125 | 0 | OPEN | OPEN | 0.440 | 0.030 |
| PIPE | 47 | 46 | 49 | 150 | 1900 | 125 | 0 | OPEN | OPEN | 1.020 | 0.060 |
| PIPE | 50 | 50 | 46 | 150 | 1175 | 125 | 0 | OPEN | OPEN | 0.560 | 0.030 |
| PIPE | 51 | 50 | 51 | 150 | 340 | 125 | 0 | OPEN | OPEN | 0.440 | 0.030 |
| PIPE | 52 | 52 | 50 | 150 | 2815 | 125 | 0 | OPEN | OPEN | 0.990 | 0.060 |
| PIPE | 53 | 52 | 53 | 150 | 305 | 125 | 0 | OPEN | OPEN | 1.020 | 0.060 |
| PIPE | 54 | 54 | 52 | 150 | 750 | 125 | 0 | OPEN | OPEN | 2.010 | 0.110 |
| PIPE | 55 | 54 | 57 | 150 | 855 | 125 | 0 | OPEN | OPEN | 0.290 | 0.020 |
| PIPE | 58 | 59 | 54 | 150 | 2250 | 125 | 0 | OPEN | OPEN | 2.300 | 0.13 |
| **PIPE** | **60** | **59** | **60** | **150** | **865** | **125** | **0** | **OPEN** | **OPEN** | **0.145** | **0.010** |
| PIPE | 61 | 63 | 59 | 150 | 1030 | 125 | 0 | OPEN | OPEN | 2.450 | 0.140 |
| PIPE | 64 | 63 | 67 | 150 | 1935 | 125 | 0 | OPEN | OPEN | 0.580 | 0.030 |
| PIPE | 68 | 68 | 63 | 150 | 645 | 125 | 0 | OPEN | OPEN | 4.490 | 0.250 |
| PIPE | 69 | 69 | 68 | 150 | 440 | 125 | 0 | OPEN | OPEN | 4.490 | 0.250 |
| PIPE | 70 | 70 | 69 | 150 | 625 | 125 | 0 | OPEN | OPEN | 4.490 | 0.250 |
| PIPE | 71 | 22 | 70 | 150 | 245 | 125 | 0 | OPEN | OPEN | 4.490 | 0.250 |

# APPENDIX K

## RESULTS OF SENSITIVITY ANALYSIS ON ECONOMIC FACTORS TO THE NET PRESENT COST OF WATER SUPPLY SYSTEMS

Maintenance cost decrease by 30%

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | Note: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 21 480 | 22 984 | 24 593 | 26 314 | 28 156 | 30 127 | 32 236 | 34 492 | 36 907 | 39 490 | 42 255 |
| **Cash flow ( R )** | | **1 555 779** | **22 984** | **24 593** | **26 314** | **28 156** | **30 127** | **32 236** | **34 492** | **36 907** | **39 490** | **42 255** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 740 859** | | | | | | | | | | | |

Maintenance costs decrease by 20%

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 24 549 | 26 267 | 28 106 | 30 073 | 32 178 | 34 431 | 36 841 | 39 420 | 42 179 | 45 132 | 48 291 |
| **Cash flow ( R )** | | **1 558 848** | **26 267** | **28 106** | **30 073** | **32 178** | **34 431** | **36 841** | **39 420** | **42 179** | **45 132** | **48 291** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 770 367** | | | | | | | | | | | |

Maintenance cost decrease by 10%

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 27 617 | 29 551 | 31 619 | 33 832 | 36 201 | 38 735 | 41 446 | 44 347 | 47 452 | 50 773 | 54 328 |
| **Cash flow ( R )** | | **1 561 916** | **29 551** | **31 619** | **33 832** | **36 201** | **38 735** | **41 446** | **44 347** | **47 452** | **50 773** | **54 328** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 799 876** | | | | | | | | | | | |

Maintenance cost increase by 10%

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | | Interest on Capital Redemption | | 10% | | | | | | | | |
| | | Annual Pipe Maintenance Costs | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | Note: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 33 755 | 36 117 | 38 646 | 41 351 | 44 245 | 47 343 | 50 657 | 54 202 | 57 997 | 62 056 | 66 400 |
| **Cash flow ( R )** | | **1 568 054** | **36 117** | **38 646** | **41 351** | **44 245** | **47 343** | **50 657** | **54 202** | **57 997** | **62 056** | **66 400** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 858 893** | | | | | | | | | | | |

Maintenance cost increase by 20%

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | Pipeline | | R 1 480 770 | | | | | | | | | |
| | Reservoir | | R 53 529 | | | | | | | | | |
| | **Total** | | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | Reservoir | | R 1 071 | | | | | | | | | |
| | pipeline | | R 29 615 | | | | | | | | | |
| | Total | | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 36 823 | 39 401 | 42 159 | 45 110 | 48 268 | 51 646 | 55 262 | 59 130 | 63 269 | 67 698 | 72 437 |
| **Cash flow ( R )** | | **1 571 122** | **39 401** | **42 159** | **45 110** | **48 268** | **51 646** | **55 262** | **59 130** | **63 269** | **67 698** | **72 437** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 888 401** | | | | | | | | | | | |

Maintenance cost increase by 30%

| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | Note: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 39 892 | 42 684 | 45 672 | 48 869 | 52 290 | 55 950 | 59 867 | 64 057 | 68 541 | 73 339 | 78 473 |
| **Cash flow ( R )** | | **1 574 191** | **42 684** | **45 672** | **48 869** | **52 290** | **55 950** | **59 867** | **64 057** | **68 541** | **73 339** | **78 473** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 917 910** | | | | | | | | | | | |

Cost of capital decrease by 30% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 7% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 871 845** | | | | | | | | | | | |

Cost of capital decrease by 20% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 8% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 856 644** | | | | | | | | | | | |

Cost of capital decrease by 10% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 9% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 842 521** | | | | | | | | | | | |

Cost of capital increase by 10% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 11% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 817 150** | | | | | | | | | | | |

Cost of capital increase by 20% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 12% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | Note: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 805 743** | | | | | | | | | | | |

Cost of capital increase by 30% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | Inflation rate | | 7% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 13% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | Pipeline | | R 1 480 770 | | | | | | | | | |
| | Reservoir | | R 53 529 | | | | | | | | | |
| | **Total** | | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | Reservoir | | R 1 071 | | | | | | | | | |
| | pipeline | | R 29 615 | | | | | | | | | |
| | Total | | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 834 | 35 132 | 37 592 | 40 223 | 43 039 | 46 051 | 49 275 | 52 724 | 56 415 | 60 364 |
| **Cash flow ( R )** | | **1 564 985** | **32 834** | **35 132** | **37 592** | **40 223** | **43 039** | **46 051** | **49 275** | **52 724** | **56 415** | **60 364** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 795 097** | | | | | | | | | | | |

Inflation decrease by 30% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 5% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 190 | 33 767 | 35 421 | 37 157 | 38 978 | 40 888 | 42 891 | 44 993 | 47 198 | 49 510 |
| **Cash flow ( R )** | | **1 564 985** | **32 190** | **33 767** | **35 421** | **37 157** | **38 978** | **40 888** | **42 891** | **44 993** | **47 198** | **49 510** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 803 533** | | | | | | | | | | | |

Inflation decrease by 20% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 5.6% | per annum | | | | | | | |
| | | | Interest on Capital Redemption | 10% | | | | | | | | |
| | | | Annual Pipe Maintenance Costs | 2% | of Pipeline Capital Costs | | | | | | | |
| | | | Annual Reservoir maintenance costs | 2% | of Reservoir Capital Costs | | | | | | | |
| | Note: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 404 | 34 219 | 36 135 | 38 159 | 40 296 | 42 552 | 44 935 | 47 452 | 50 109 | 52 915 |
| **Cash flow ( R )** | | **1 564 985** | **32 404** | **34 219** | **36 135** | **38 159** | **40 296** | **42 552** | **44 935** | **47 452** | **50 109** | **52 915** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 811 824** | | | | | | | | | | | |

Inflation decrease by 10% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 6.3% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 32 619 | 34 674 | 36 859 | 39 181 | 41 649 | 44 273 | 47 062 | 50 027 | 53 179 | 56 529 |
| **Cash flow ( R )** | | **1 564 985** | **32 619** | **34 674** | **36 859** | **39 181** | **41 649** | **44 273** | **47 062** | **50 027** | **53 179** | **56 529** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 820 436** | | | | | | | | | | | |

Inflation increase by 10% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 7.7% | per annum | | | | | | | |
| | | | Interest on Capital Redemption | 10% | | | | | | | | |
| | | | Annual Pipe Maintenance Costs | 2% | of Pipeline Capital Costs | | | | | | | |
| | | | Annual Reservoir maintenance costs | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 33 049 | 35 594 | 38 334 | 41 286 | 44 465 | 47 889 | 51 576 | 55 548 | 59 825 | 64 431 |
| **Cash flow ( R )** | | **1 564 985** | **33 049** | **35 594** | **38 334** | **41 286** | **44 465** | **47 889** | **51 576** | **55 548** | **59 825** | **64 431** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 838 680** | | | | | | | | | | | |

Inflation increase by 20% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 8.4% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | Pipeline | | R 1 480 770 | | | | | | | | | |
| | Reservoir | | R 53 529 | | | | | | | | | |
| | **Total** | | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | Reservoir | | R 1 071 | | | | | | | | | |
| | pipeline | | R 29 615 | | | | | | | | | |
| | Total | | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 33 264 | 36 058 | 39 087 | 42 370 | 45 929 | 49 787 | 53 969 | 58 502 | 63 417 | 68 744 |
| **Cash flow ( R )** | | **1 564 985** | **33 264** | **36 058** | **39 087** | **42 370** | **45 929** | **49 787** | **53 969** | **58 502** | **63 417** | **68 744** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 848 337** | | | | | | | | | | | |

Inflation increase by 30% for pipeline option

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **CONVENTIONAL PIPED WATER SUPPLY SYSTEM** | | | | | | | |
| | | | | | | | | | | | | |
| **GENERAL DATA (Assumed)** | | | | | | | | | | | | |
| | | | Inflation rate | 9.1% | per annum | | | | | | | |
| | Interest on Capital Redemption | | | 10% | | | | | | | | |
| | Annual Pipe Maintenance Costs | | | 2% | of Pipeline Capital Costs | | | | | | | |
| | Annual Reservoir maintenance costs | | | 2% | of Reservoir Capital Costs | | | | | | | |
| | ote: Maintenance and Operation Costs (M & O) will also increase by 7% per annum from the first yea | | | | | | | | | | | |
| **Capital costs** | | | | | | | | | | | | |
| | | Pipeline | R 1 480 770 | | | | | | | | | |
| | | Reservoir | R 53 529 | | | | | | | | | |
| | | **Total** | **R 1 534 299** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Annual Maintenace and operation costs (M & O)** | | | | | | | | | | | | |
| | | Reservoir | R 1 071 | | | | | | | | | |
| | | pipeline | R 29 615 | | | | | | | | | |
| | | Total | **R 30 686** | | | | | | | | | |
| | | | | | | | | | | | | |
| **Calculations** | | | | | | | | | | | | |
| | | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year | Year |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Capital costs ( R )** | | 1 534 299 | | | | | | | | | | |
| **M & O ( R )** | | 30 686 | 33 478 | 36 525 | 39 849 | 43 475 | 47 431 | 51 747 | 56 456 | 61 594 | 67 199 | 73 314 |
| **Cash flow ( R )** | | **1 564 985** | **33 478** | **36 525** | **39 849** | **43 475** | **47 431** | **51 747** | **56 456** | **61 594** | **67 199** | **73 314** |
| | | | | | | | | | | | | |
| **NPV** | **R 1 858 370** | | | | | | | | | | | |