PERFORMANCE ENHANCEMENT OF WATER SUPPLYDISTRIBUTION IN MINNA METROPOLIS

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY ZARIA IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF SCIENCE IN WATER RESOURCE AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING
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July, 2014

DECLARATION

I declare that the work in this thesis entitled **'PERFORMANCE ENHANCEMENT OF WATER SUPPLY DISTRIBUTION IN MINNA METROPOLIS'** has been carried out by me in theDepartment of Water Resources and Environmental Engineeringunder the supervision of Dr. J A Otun andDr. D.B Adie.

The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

.....	.....	.....
MUSA MUHAMMAD	Signature	Date

CERTIFICATION

This thesis entitled **PERFORMANCE ENHANCEMENT OF WATER SUPPLY DISTRIBUTION IN MINNA METROPOLIS** by **Musa Muhammad** has meets the regulation governing the award of Masters of Science of Ahmadu Bello University, Zaria and is approve for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my wife HabibaKitabuYahaya for her love and sincerity and my wonderful children AishaHanifa, Amaturrahman, Abdullah Aslim and Abdurrahman Mahbub. Together we make one big family.

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All praises and thanks are due to Allah SubhanahuWataalathe lord of the creation. May His peace and blessings be upon the last messenger Prophet Muhammad SallalahuAlaihimWaaliyi Was Salam.

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ABSTRACT

In this thesis, a diagnostic assessment of the entire water supply distribution network was carried out in order to evaluate problems associated with water supply in Minna. This assessment was carried out by conducting inventory of all the facilities in the entire water supply distribution network by onsite, physical and visual inspection of all the elements in the distribution system during operation. Qualitative assessment of equipment/facilities physical conditions and functionality was conducted using numeric rating of 0-4. The situational analysis of the system was also carried out using performance indicators such as SPEM, SERA and SWOT analyses. Detailed evaluation of overall operation and maintenance and pumping schedule plan was looked into. The results clearly shows that the transmission pipes, service reservoirs, pumping stations and valves in the distribution system are in good physical condition and are functioning properly. However, most of leakages and burst occur in asbestos pipe in the distribution system and valves in the transmission system. The system has 56% operation and 70% human resources capacity with the total evaluation capacity using SPEM as 60%. While the performance evaluation using SERAwas 39%. The type of maintenance carried out is simple reactive rehabilitation approach any time there is failure. A suggestion of proactive rehabilitation was made which is better than reactive rehabilitation approach. Thus, it will be appropriate to pump water from 0000 to 0600 hours and 1200 to 1800 hours to meet the water demand and minimised cost of operation. The sum of Nineteen Million Two Hundred and Nineteen Thousand naira (N19,219,000:00) would be required to repair the pumps and replaced the valves that are in bad condition.

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ABBREVATIONS

AC	Asbestos Cement
AWS	Assistant Work superintendent
AWWA	America Water Works Association
B.Eng	Bachelor of Engineering
DI	Ductile Iron
DMA	District Metered Areas
EPA	Environmental Protection Agency
GI	Galvanized Iron
HND	Higher National diploma
HRC	Human Resources Capacity
IWA	International Water Association
KPI	Key Performance Indicators
MTTR	Minimum Time to Resolve Maintenance
ND	National Diploma
NRW	Non Revenue Water
NSWB	Niger State Water Board
O&M	Operation and Maintenance
OPS	Operational Capacity
PRV	Pressure Regulating Valves
PVC	Polyvinyl Chloride
SERA	Sustainable Effectiveness Ranking Approach
SPEM	Service Performance Evaluation Matrix
SWOT	Strength, Weakness, Opportunities and Threats
VSD	Variable Speed Drive

WSS	Water Supply System

CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

Water is a primary life-giving resource. Its availability is an essential component in socio-economic development and poverty reduction. Water is fundamental to our way of life at whatever point in the socio-economic spectrum a community may be situated.

The essential paradox of water supply in developing countries is that, in one sense, everyone has a water supply, in another sense, most people have not. Water is essential for life and all human communities must have some kind of water source. It may be dirty, it may be in adequate in volume and it may be several hours walk away but, nevertheless some water must be available. However, if reasonable criterion of adequacy- in term of the quantity, quality and availability of water- then most people in developing countries do not have an adequate supply (Cairncrossand Feachem, 1988)

More so, delivery of safe reliable supply of drinking water to consumers tap depends on the integrity of the distribution system. The pipe networks, extending over large areasencompasses multiple connections and points of access typically constituting the bulk of water utility assets. Propermanagement of water system is crucial for ensuring sustainability of a given water resource, maintaining high quality water resources, and maximizing the utility's ability to respond to profound operating conditions.

1.2 STATEMENT OF THE PROBLEM

Minna water distribution network consists of the pumping station, distribution piping which comprises of transmission mains and distribution mains, valves, hydrants and service reservoirs. Mays (2004) opined that a water distribution system operates as a system of

dependent and independent components. The hydraulics of each component depend directly on each other as aresult it affects performance of other components. The distribution system comprises of several service reservoirs which distribute water directly to the consumers.

Despite the fact that the system was properly designed and constructed, some of the facilities are functional but are working below the installed capacity. The people of Minna have come to rely heavily on water vendors, hand dug wells, boreholes and rainwater harvesting which may not necessarily be safe. The consumption of water from these doubtful sources often results in the spread of water borne and water based diseases such as diarrhoea, cholera, typhoid fever, paratyphoid fever, hepatitis,ameobiasis among others.

More so the major problem that the populace of Minna are facing is that of intermittent water supply. Majority of people in Minna get pipe borne water for 4 – 6 hours twice a week based on the schedule time table prepared by the Niger State Water Board. This situation is not satisfactory because of the following reasons:

1. The system does not operate as designed
2. The capacity of the service reservoirs are grossly under utilized
3. Water from intermittent water supply systems may not be safe to drink, because under vacuum conditions foul water can drain into the pipes.
4. There is frequent wear and tear on the valves.

1.3 AIM AND OBJECTIVES

The aim of this study is to enhance the effectiveness of water supply distribution in Minna.

The specific objectives of this research are to:

i. Carry out diagnostic assessment of the entire water distribution network, so as to evaluate the problems in the entire network.

ii. Review and evaluate the means of improving the capacity utilization of the distribution network.

iii. Determine the optimum pumping schedule required to improve the water supply in Minna.

iv. Developan operation and maintenance (0&M) plan and operation and maintenance procedure for the distribution system.

1.4JUSTIFICATION OF THE STUDY

Various efforts have been made by the State Government and Niger State Water Board to provide potable water to the people of Minna metropolis, despite that the water supply is not adequate. The resultant effect of pipe borne water is having adverse effects on the poor citizenry of Minna. In Minna metropolis ajerry-can of 25 litres of water is selling between ₦25.00 to ₦100.00.

A thorough evaluation of the distribution system will be carried out and appropriate pumping schedule would be suggested to the Niger State Water Board in order to find a lasting solution to the problem of inadequate water supply in Minna.

1.5 LIMITATIONS

While distribution systems may affect drinking water quality and water quality may affect health, this research does not address these possible effects. This research is limited to the physical integrity of the components of the distribution system.

CHAPTER TWO

LITERATURE REVIEW

2.1 WATER DISTRIBUTION SYSTEM

The term distribution system is used to describe collectively the facilities used to supply water from its source to the point of usage (Peavy*et al*,. 1985). Mays (2006) explained that the purpose of water distribution network is to supply the systems users with the amount of water demanded and to supply this water with adequate pressure under various loading conditions. He further explained that the loading condition is defined as a time pattern of demands. A number of different loading conditions, which a municipal water supply may be subjected to include fire demands at different nodes, peak daily demands, and series of patterns varying throughout a day; or a critical load when one or more pipes are broken. The ability of the system to operate under a variety of load patterns is required of a reliable network. Also, American Water Works Association AWWA (2007) described the purpose of water distribution system infrastructure in simple terms to be supply of water to all customers at sufficient pressure and volume to provide for their need as well as for fire suppression (water quantity aspect), while also protecting the quality of water as prescribed by various standards (water quality aspect). It is important that the distribution system delivers water reliably and protect the quality of the water that is delivered. These water distribution systems involve complex networks of infrastructural components consisting of pipes, joints, valves and other appurtenances.

Water distribution systems have three major components; pumping stations, distribution storage and distributing piping. Depending on the topographical relationship between the source of supply and the consumer, water can be transported by canals, flumes, tunnels and

pipelines. Gravity,pumping or a combination of both pumpingand gravity may be used to supply water to the consumer with adequate pressure (Peavy*et al,*. 1985). Gravity supply is used where the source of supply is at a sufficient elevation above the consumer so that the desiredpressurecan be maintained. In the gravity system of water supply it is often possible to supply water to one or more storage reservoirs within the system. This system is proven to be quite economical where it can be used.

In pumped supply, pumps are used to develop the necessary pressure head todistribute water to the consumers and storage reservoirs.Punmia*et al.,* (2001) opined that such a system is not desirable, because pumping is required first to pump raw water from source to the treatment work and then pump purified water directly into the distribution mains. The pumps have to be run at varying speeds according to the variations in the consumption. Whereas,if there is power failure the entire water distribution system isdisturbed. Also, the system requires constant attendance.

The third system which is pumped-storage supply, storage reservoirs are used to maintain adequate pressures during periods of high consumers demand and under emergency conditions such as power or fire failures.During periods of low water consumption excess water is pumped and stored in the storage reservoirs.Since the storage reservoirare used to provide water during period of high or peak demand, the pumps can be operated at their rated capacity.

More so, thedistributing system networksare described as series of interconnected pipes used in supplying water to consumers.Peavy*etal.,* (1985) described the network configuration to include.

(i) Branching system – in the branching system of water distribution network, the structure of such a system is similar to a tree.Thetrunk line is the main source of

water supply. Services main are then connected to the trunk line and sub-mainsare connected to the service mains. In turns, building connection used to provide service to individuals residence and buildings are connected to the sub mains. Even though this type of system is simple to design and build, it is not favoured in modern water works practice due to the following reasons: (1) bacterial growths and sedimentation may occur in the branch ends due to stagnation; (2) it is difficult to maintain chlorine residual at the dead ends of the pipe; (3) when repairs must be made to an individual line, service connection beyond the point of repair will be without water until the repairs are made; and (4) the pressure at the end of the line may become undesirable low as additional extension are made.

(ii) Grid system – in this system all the pipes are inter-connected and there are no dead ends. In such a system, water can reach a given point of withdrawal from several directions.Thegrid system overcomes all the difficulties of the branching system. One disadvantage is that the determination of the pipe sizeis somewhat more complicated.

The principal components to the distribution network are: pipes; valves;fire hydrants; service connection; storage reservoirs and pumps.

Pipe section or links are the most abundant elements in the network. These sections are constant in diameter and may contain fittings and other appurtenances such as valves, storage facilities and pumps. Pipes are manufactured in different sizes and are composed of different materials such as steel, cast iron, ductile iron, reinforced concrete, prestressed concrete, asbestos cement, polyvinyl chloride, polyethylene, and fibre glass.

Control valves regulate the flow of pressure in water distribution systems. If condition exists for flow reversal the valve will close and no flow will pass. The most common type

ofcontrol valve is the pressure - reducing (pressure-regulating) valve (PRV), which is placed at pressure zone boundaries to reduce pressure. The PRV maintains a constant pressure at the downstream side of the valve for all flows with a pressure lower than the upstream head,when connecting high pressure and low pressure water distribution system. The PRV permits flow from the high pressure system if the pressure on the low side is not excessive (Mays, 2006). Peavy*et al,* (1985) stated that the principal function of a valve is to isolate subsection of the system for repair and maintenance. They itemised the commonly used valves to include gate valve, air-relief valves, check valves and drain valves. Drain valves are provided at low point in the system, while air-release or release valve are placed at high spots in the pipeline. Check valves are used to limit the flow of water to a single direction.

Pumps are used to increase the energy in a water distribution system (Mays, 2006). There are many different types of pumps. They include positive displacement pumps, kinetic pumps, turbine pumps, horizontal centrifugal pumps, vertical centrifugal pumps. However, the most commonly used type of pumps in water distribution system is the centrifugal pumps. This is because of their low cost, simplicity, and reliability in the range of flows and head encountered. Mays (2006) described centrifugal pump to be any pump in which fluid is energized by a rotating impeller, whether the flow is radial, axial or combination of both. In radial flow pumps the fluid is displaced axially in the pump while in mixed-flow pumps the fluid is displaced both radially and axially in the pump.

Punmia*et al.,* (2001) highlighted that pumps of small capacity can be operated in parallel in order to obtain maximum variable discharge at maximum efficiency. With parallel arrangement it is very possible to operate each pump near maximum efficiency. In series

operation, the same discharge passes through each pump while the pressure (or head) is boosted in doing so. Unlike pumps in parallel pumps in series are operated simultaneously. The following strategies where outlined by Feldman (2009) on how pump stations and other controlled facilities are usually operated.

1. Pressure control pumps are started according to variations in section pressure. Increase in demand would reduce the network pressure and for pump start up. A pump is stopped when pressure increase due to reduction in demand.
2. Level control pumps are started and stopped according to reservoir water level variations.
3. Time control pumps are started and stopped on fixed hours of the day.

2.2 STORAGE AND DISTRIBUTION RESERVOIRS

Punmia*et al.,* (2001) described storage and distribution reservoirs as important units in a modern distribution system. Clear water storage is required for storage of filtered water until it is pumped into the service reservoirs or distribution reservoirs. Bhargava and Gupta (2004) gave the functions and economic benefits of service reservoir to include: (i) the service reservoirs absorb the hourly fluctuation in and allow the pumps to operate at a constant rate. This improves the efficiency and reduces the cost of operation; (ii) The pumping of the water in shifts and in tune with power supply hour is made possible through the reservoirs without effecting the supply, 8 to 16 hours of pumping may easily pump the supply of the whole day; (iii) the reservoir help maintain a constant pressure in the distribution mains, otherwise the pressure would drop with increasing demand; (iv) the reservoir make economy by reducing the size of the pump; and (v) the reservoir could also

serve as storage for emergencies such asoutbreak of fire, failure of pumps or bursting of mains as started by (Punmia*et al.,* 2001).

Depending on the topography and local environmental conditions storage reservoir may be located above, on or below the ground surface. Underground reservoirs are usually constructed of reinforced concrete; small ground-level reservoirs are usually earth-lined with gunite, asphalt or some synthetic membrane. Large surface reservoirs are concrete lined.

In order to obtain the necessary head within the distribution system, water towers and elevated reservoirs are often used. Water tower, located at ground level can be constructed of prestressed concrete or steel. Elevated water-storage reservoirs are usually constructed of steel.

Otun and Abubakar (2009) gave the capacity of storage reservoir to be the required volume to contain the excess when the supply is more than the demand, and also to provide the deficit when the demand is more than the supply. Provision should also be for requirements and break down storage. They gave the equalizing volume of reservoir to be about 1/6 to 1/3 of the total demand.

2.3 SYSTEMS OF WATER SUPPLY

Water may be supplied to the consumer by any of the following two systems

1. Continuous system: - In this system water is available to the consumers for all the 24 hours. This is the best system since water is available when it is needed but this may lead to wasteful use of water.
2. Intermittent system: -in this type of system water is delivered to users for less than 24 hours in a day this is the type of service found in developing countries.

2.4 PUMPING SCHEDULE

Lucken, *et al.*, (2004) considered pumping schedulling problem having four objectives to be minimized – electrical energy cost, maintenance cost, maximum power peak, and level variation in a reservoir. Pumping schedule optimization has proven to be a practical and highly effective method to reduce pumping cost without making changes to the actual infrastructure of the whole system. Therefore, schedulling the pumps operation mean choosing the right combination of pumps that will be working at each time interval of schedulling period. While a pump schedule is the set of all pump combination chosen for every time interval of the schedule horizon. Luken*et al.*, (2004) described optimal pump schedule as pump schedule that optimizes particular objectives while fulfilling system constraints. They summarized the definition of multi objective pump scheduling problem considering pumps characteristics (pumping capacity) in order to satisfy water demand, while fulfiling other constraints such as the maximum and minimum levels in the reservoir; at the same time, electric energy, cost, pump maintenance cost, maximum power peak and level variation in the reservoir between the beginning and end of the optimization period.In any pumping system, the role of the pump is to provide sufficient pressure to overcome the operating pressure of the system to move water at a required flow rate. Milnes, 2007 assumed that the operating pressure of the system is a function of the flow through the system and the arrangement of the system in term of pipe length, fittings, pipe size, the change in liquid elevation, pressure on the liquid surface among others.

Proper management of water system is crucial for ensuring sustainability of a given resource and maintaining high-quality water resources and maximizing a utility to profound operating condition. By taking a system perspective water utilities can ensure must

effective overall management of operation,as such Jentgen,*et al.,* (2005) described a 'system's approach as a planned, comprehensive way to optimize operations and address the entire water system. True optimization is achieved only by considering the system as a whole. Boulos*et al.,* (2001) proposed model that make use of the latest advances in genetic algorithm to automatically determine the least-cost pump schedulling and operation policy for each pump station in a water distribution system while satisfying the target hydraulic performance requirements.

2.5 CONDITION ASSESSMENT

Water infrastructure systems represent a major capital investment: utilities must ensure they are getting the highest yield possible on their investment, both in terms of cost and water quality. Accurate information related to equipment, pipe characteristics, location, site condition, age,hydraulic rates and water quality is critical to industry and municipalities to enable the most cost-efficient operation, maintenance and rehabilitation of existing system (Stone *etal*., 2000).

Condition assessment encompasses the collection of data and information through direct inspection, observation and investigation and in-direct monitoring and reporting and the analysis of the data and information to make a determination of the structural, operational and performance status of the capital infrastructure assets (EPA 2007 and U.S.E.P.A 2007). Also, Agarwal (2010) confirmed that condition assessment process involves the assessment of the current performance of the system and continued monitoring of the performance in order to either manage the associated risk or take remedial action where necessary.

Condition assessment also includes the practice of failure analysis which seeks to determine the causes of infrastructure failure in other to prevent future failure.

Structural condition of the pipeline is narrowly defined as the presence/absence of holes, cracks, breaks, or conditions leading to their formation. Therefore, structural condition assessment involves: (1) development of a formal or informal structural-condition approach that links pipeline parameter data to the likelihood of structural failure; (that is, holes, cracks and breaks)for the time period of interest; (2) collection of data (such as physical, environmental, and operational characteristics; failure history, processers and associated indictors)by applicable direct and/or indirect methods, necessary to characterizethe pipeline current and structural integrity; and (3) analysis of the pipeline data and information to categorize pipe structural condition, based on the structural condition rating approach, as to its likelihood of failure for the pipeline sections and time periods of interest. The structural condition assessment results are used as input to an informal or formal decision-support system. The decision support system considers not only the conditions assessment result, but also other factors such as the consequences of failure, available options andtheir cost, level of service targets, and hydraulic and water quality conditions, among others, to determine whether, when, where, and/or how the pipeline should be inspected in greater detail, repaired, rehabilitated, replaced, or whether operating condition should be changed.

Misiunas (2008) gave two main approaches for the assessment of the condition of a pipe. The first approach is direct inspection and monitoring called non-destructive testing (NDT). The second condition assessment approach is based on using indirect indicator such as soil properties and historical pipe breakage rate. The Federation of Canadian Municipalities and National Research Council (2003) explained that the best practice for investigating the condition of a water distribution system is based on a two-phase approach. The first phase

involves a preliminary assessment of structural condition, hydraulic capacity, leakages andwater quality on a system- wide basis using data that should be collected by every municipality on a routine basis. A preliminary assessment of water and data or routine sampling and inspection which should be conducted each year will identify both trends and the need for detail investigations. The second phase involves a more detailed investigation of specific problems based on an evaluation of the level of service, economics, risk and benefits.

Theobjectives of condition assessment are not to manage asset condition but to manage failurerisk (EPA 2007).The purpose of condition assessment data is to make an assessment of the remaining life of the asset so that rehabilitation or replacement investment can be planned and implemented before failures occur that would cost the utility more than it would have if such failures were not avoided through asset management.An accurate assessment of the system condition is essential in order to develop an effective, efficient management plan and optimize operation and maintenance. The benefits of condition assessment within the overall asset management process are enlisted in order of preference as;

1. Rehabilitation decision - making
2. Future failure protection
3. Leakage reduction
4. Risk management
5. Asset valuation and
6. Reduction and operation expenditure cost.

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

Minna is acity (estimated population 304,113in 2006)in North Central Nigeria. It is the capital of Niger State and is the headquarters of ChanchangaLocal Government Area. Since becoming the capital of Niger State in 1976, Minna has developed as an administrative centre. Minna is made up of an area of about 324km^2. It is bounded by latitude $9^0 32^1$N and $9^0 42^1$N longitude $6^0 30^1$E and $6^0 40^1$E.

The climate of Minna is like much of West Africa. The daylight temperatures vary from about 24^0C at middle of wet season to above 35^oC at peak of dry season. The seasonal rainfall regime give rise to longer wet season of about seven months with average rainfall of 250 mm and dry season of five month with little or no rain.

More so, the climate of Minna usually alternate with dry and rainy season, with a total rainfall between 1270 mm and 1524 mm spread over the months of April to October. Fig 3.1 shows the map of Minna.

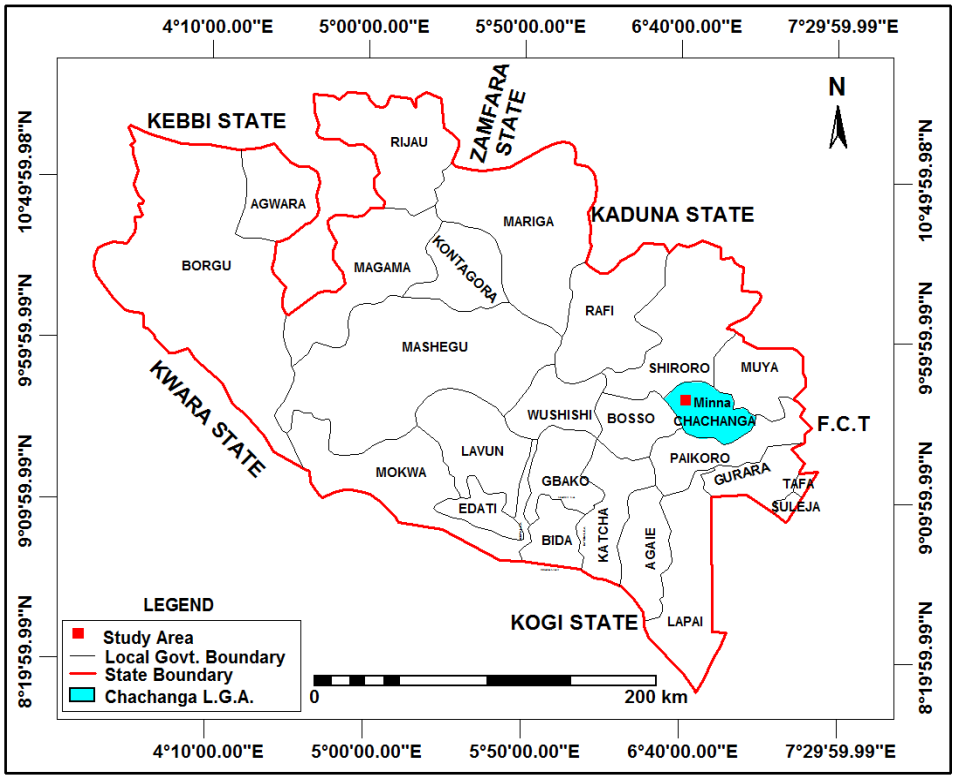

FIG.3.1a :NIGER STATE SHOWING MINNA :THE STUDY AREA

Source ;Adapted and modified from Adminstrative Map ofNiger State

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Fig3.1b: Land Used Map of Minna-Niger State (Source: Google, Earth Retrieved on 18-July-2014)

3.2 DESCRIPTION OF THE DISTRIBUTION SYSTEM

Minna and its environs are supplied with treated water from ChanchagaWater Works. The water works is made up of two independent water treatment plants named after the companies that constructed them. The first water work was constructed in 1979 by Costain International Engineering Construction Company. This water works was upgraded in 1982 by Biwater Holdings. It has a production capacity of 27,000m^3/day. Therefore, it is called Costain/Biwater water works. The second water works was constructed in 1995 by Impresit Construction Company. It has a total designed production capacity of 50,000m^3/day. The water works has a total design capacity 77,000m^3/day.

3.2.1 Pump Stations

The distribution system has two pump stations Costain/Biwater and Impresit pumping stations. The pumps in the two stations were arranged in parallel. Their data are shown in Table 3.1.

Table 3.1: Pumping Station

Pump station	Pump	Design flow Q m^3/h	Design head H(m)	Attributes of each pump				
				Type	**Speed n (RPM)**	**Power (kw)**	**Manufacturer**	**Date Installed**
Costain /Biwater	1	350	150.03	Centrifugal	1490	230	KSB	2010
	2	558	150	Centrifugal	1490	335	KSB	2000
	3	558	150	Centrifugal	1490	355	KSB	2000
	4	350	150.3	Centrifugal	1490	230	KSB	2010
	5	350	160	Centrifugal	2900	230	Overman	2010
	6	350	150.3	Centrifugal	1490	230	KSB	2010
Impresit	1	490	190	Centrifugal	1470	300	Weir pump	Reinstall 2012
	2	475	160	Centrifugal	2900	315	Mass Daft	2010
	3	608	180	Centrifugal	1490	315	Overman	2010
	4	475	160	Centrifugal	2900	315	Weir pump	2010

(Source: fieldwork, 2013)

3.2.2 Pipelines

The water system piping consists of the transmission system which are the raising mains and the distribution system which are the distribution mains. The transmission system consists of components that are designed to convey large quantity of water over a great distance from water works to the service reservoirs. The diameter of pipes in the transmission system ranges from 300 to 900 mm with a total length of 43,125 m.Water is then transported from service reservoirs and transmission pipe through the distribution pipe to the consumers. The distribution system consists of 100 to 400mm diameter pipelines and

a total length of 94,625 m. The materials the pipelines are made of ductile iron, galvanized iron, asbestos cement and polyvinyl chloride (PVC) pipes. The diagram of Minna water distribution network is shown in Fig 3.2.

3.2.3 Storage Facilities/Booster Pump Station

There are seven service reservoirs in the distribution system. The reservoirs are located on topographical high areas within the town. Water is pumped directly from pumping station through the transmission line to the reservoirs. Water is then supplied to the consumers through the distribution mains from the reservoirs by gravity. Table 3.2 shows the service reservoirs and the areas they serve.

Table 3.2: Service Reservoirs

Reservoir name	Material	Shape	Vol (m^3)	Year of construction	Areas served
Biwater tank	Bolted steel	Rectangular	4,500	1984	Shango, Barikin sale, Army Barrack New Secretariat
Shiroro Tank	Reinforced concrete	Rectangular	2,000	1982	Tunga, TungaLowcost, Shiroro Road
Tunga East Tank	Reinforced concrete	Rectangular	2,000	1995	Tunga, David Mark road, Tunga market, Top Medical road
INEC Tank	Reinforced concrete	Trapezoidal	1,000	1964	Police barracks, Bay clinic road, School of midwifery, Tunga-Dan boyi rail-way quarters
Uphill tank	Reinforced concrete	Circular	7,000	2000	Minna central, Old airport road, Maitumbi, Bosso road, 123 quarters, commissioners quarters
Paida hill Tank	Reinforced concrete	Circular	4,000	1995	UnguwanDaji, UnguwanSarki, F-layout Zarumai, Abayi
Dutsen Kura Tank	Reinforced concrete	Circular	10,000	1995	DutsenKuraHausa,dutsen Kura Gwari,Bossolowcost,Bosso Estate, Police Secondary School, Shanu Village. London Street.

(Source: fieldwork, 2013)

3.2.4 Booster pump station

It is only DustenKura reservoir that has a booster pump station.Table 3.3 gives the attribute of the pumping station.

Table 3.3: Booster Pumping Station

Attribute of Each Pump					
Pump	**Design flow m^3/h**	**Design Head m**	**Type**	**Speed RPM**	**Power**
1	300	150	Centrifugal	-	-
2	220	100.5	Centrifugal	2900	-
3	Nil	Nil	Centrifugal	-	-

(Source: fieldwork, 2013)

3.3 METHODS

3.3.1 Condition Assessment

Condition assessment is the collection of data and information through direct inspection, observation and investigation and indirect monitoring and reporting, and the analysis of the data and information to make a determination of the current and/or future structural water quality and hydraulic status of the pipeline.

In order to assess the condition of the water distribution system, an inventory was carried out by onsite, physical and visual inspection of all the elements in the distribution system. The equipment and facilities were assessed during operation. The onsite inspection was carried out with theoperations staff of the facilities to provide information and documentation as needed. The elements in the distribution system inspected were;

i. Pumping stations

ii. Distribution reservoirs

iii. Transmission (raising) mains

iv. Distribution mains

v. Valves

vi. Fire hydrants

The inspection survey was performed at discrete time. This involves checking the whole or a part of the system to assess the level of leakage and find the leaks that are already present. The following were used as sign of underground leaks.

i. Unusual wet spots/water pooling on the ground surface

ii. An area that is green, muddy, soft or mossy surrounded by drier condition.

iii. A notable drop in water pressure/flow volume

Where visual inspection was not possible, interviews were conducted with the distribution staff to determine if there were any of these

i. Reduced hydraulic capacity

ii. High leakage rate and

iii. Frequent breaks

Qualitative assessment of equipment/facilities physical condition and functionality was also conducted. The physical condition relates to the appearance, including apparent wear and corrosion as well as operating characteristics such as noise, vibration and temperature. Functionality relates to the ability of the piece of equipment to accomplish its purpose. Both physical condition and functionality were given a numeric rating from 0 – 4. Description of these ratings is provided in Tables 3.4 and 3.5.

Table 3.4: Equipment Physical Condition Rating

Rating scale	Description
0	Not applicable
1	Equipment integrity severely compromised by corrosion and wear
2	Moderate to high risk of failure
3	Visible degradation of equipment, but acceptable
4	Well-maintained like new condition of equipment

(Source: Brown and Caldwell, 2007)

Table 3.5: Equipment Functionality Rating

Rating scale	Description
0	Not applicable (Not operational or abandoned)
1	Equipment is not currently functioning for its intended use
2	Equipment is in service but function is highly improved
3	Equipment function is intended maintenance frequency and tasks as expected for this asset class
4	Equipment function as intended by maintenance frequencies and task exceeded those expected for this asset class

(Source: Brown and Caldwell, 2007)

3.4 PERFORMANCE INDICATORS

The situational analysis of the distribution network was also carried out using performance indicators which were measured using key indicators.

3.4.1 Development of Evaluation Approach

A service performance evaluation metrics (SPEM) to adequately appraise the condition of the existing network viz-a-viz the level of service delivery was proposed in the research. It is a preliminary approach to get a rational benchmark tool for evaluating local Water

Supply Scheme (WSS). The key performance area evaluated by SPEM was operational, institutional and human resources capacities of the distribution system. A scoring matrix was developed for evaluating each of these performance areas using some key performance indicators (KPIs) as shown in table 3.6. A rating scale of 1-5 was used, with Excellent =5, Very Good =4, Good=3, Fair =2, Poor=1.

Table 3.6: Evaluation Aspect: Key Performance Areas

Evaluation Aspect: Key Performance Area	Key Performance Indicator (KPI)
Operational	Maintenance Frequency Maintenance Planning Spare Part Availability Duration of Supply (hr/d) Volume of Water Produced(m^2) System Capacity Capacity utilization
Human Resources	No. of Staff Training and Development Professionalism

(Source: Mani, 2011)

3.4.2 Operational Capacity Utilizations

The information gathered during the onsite, physical and visual and physical inspection together with consultation and interactions were used in the operational evaluation. The scoring matrix for the key performance indicators are shown in the Tables3.7 and 3.8.

Table 3.7: Scoring Matrix for Operational Capacity Evaluation

Key Performance Indicator	Key Performance Objective	Score
OPS.1: Maintenance Frequency	i. MTTR FAULT <24 hours ii. MTTR 24 hours iii. MTTR two days iv. MTTR three days v. MTTR seven day	5 4 3 2 1
OPS 2 Maintenance Planning	i. Monthly routine maintenance established ii. Routine maintenance carried out one day after the schedule date iii. Routine maintenance carried out two day after the schedule date. iv. Routine maintenance carried out one week after the schedule date. v. No routine maintenance schedule established	5 4 3 2 1
OPS 3 System Capacity Utilization	i. 90-100 ii. 70-89 iii. 50-69 iv. 30-49 v. 10-29	5 4 3 2 1
OPS 4 Duration of Supply	i. 20-24 hr/d ii. 15-19hhr/d iii. 10-14 hr/d iv. 9-13 hr/d v. 2- 8 hr/d	5 4 3 2 1
OPS 5 volume of water produced	i. Above 60 000 m^3 ii. 50000- 60000 m^3 iii. 40000-50000 m^3 iv. 30000-40000 m^3 V. <30000 m^3	5 4 3 2 1

(Source: Mani, 2011)

Table 3.8: Scoring Matrix for Human Resources Capacity Evaluation

Key Performance Indicator	Key Performance Objective	Score
H.R. 1 No. of staff	80-100 persons	5
	60-80 persons	4
	40-60 persons	3
	20-40 persons	2
	0-20 persons	1
H.R. 2 training and Development	Staff attend courses quarterly	5
	Staff attend courses thrice annually	4
	Staff attend courses twice annually	3
	Staff attend courses once in a year	2
	No training workshop or seminar attended	1

(Source: Mani, 2011)

3.4.3 Sustainable and Effectiveness Ranking Approach (SERA)

The sustainable and effectiveness approach (SERA) assesses the management, resources allocations, operation efficiency and technological indicators of a scheme with a view to providing a sound technical basis for auditing the organizations work. The following operational indicators were considered: policies and procedures, organizational structure, role and responsibility, inventories control and equipment management and work order system. A five point (5) rating scoring was used with 1 being poor and 5 being excellent. The scoring format is shown in Table 3.9.

Table 3.9: Scoring Format / Structure for SERA Evaluation

	Rating 1-poor, 2-fair, 3-good, 4-very good, and 5-excellent
A. SERA Indicator: Policies and Procedures	
Governing policies well defined Operating and maintenance procedures are well documented and controlled Key supporting document are kept current and readily available Procedure and work practices are implemented consistently Procedures are used routinely by staffs as a reference Procedures are in compliance with organizational and regulatory agency requirements Procedures incorporate achievable best practices Periodically reviewed and updated for continual improvement.	
B SERA Indicator: Organizational Structure	
Effective organizational structure to meet current and future demands Close relationship and information sharing among departments High adaptability for restructuring priorities Adequate and inter-communication channels from manager to supervisors and staffs Incentives to motivate dedicated and skilled staffs	
C. SERA Indicator: Inventory Control and Equipment Management	

Well define inventory control procedures Maintain a database containing types, ages and ours of operation Stock spares equipment and parts in well-organized manner Use historical data to plan the inventory Readily available materials, parts and supplies when needed.	
D. SERA Indicator: Work Order System	
Well documented work order system and process Document accountability for completion of work orders Uniform work order across the system Appropriate performance measures for each category of work Performance matrices are routinely monitored	

(Source: Mani, 2011)

3.4.4 Strengths Weaknesses Opportunities and Threats (SWOT) Analysis

A detailed SWOT analysis of present situation of the entire distribution was carried out in order to establish the basis for developing strategies for the development plan. The SWOT analysis identifies the strengths, weaknesses, opportunities, and threats of the utilities. Table 3.10 is the template used for the SWOT analysis.

Table 3.10: SWOT Analysis Template

Strengths	Weaknesses
Advantages of propositions? Capabilities? Competitive advantages? Resources, Assets, People? Experience, Knowledge, Data? Financial Reserves likely returns? Location and Geographical? Price, value, quality? Qualification, certifications? Processes systems IT communications? Cultural, attitudinal, behavioural? Management cover, succession?	Disadvantages of proposition? Gaps in capabilities? Lack of competitive strengths? Reputation, presence and reach? Financial? Timescale deadlines and pressure? Cash flow start-up cash drain? Continuity, supply chain robustness? Effect on core activities, distraction? Reliability of Data, plan predictability Morale commitment, Leadership? Processes and systems?
Opportunities	**Threats**
Market development? Competitor vulnerability? Industry or life style trends? Technology development and innovation? Global influences? New market, vertical and horizontal? Geographical, export, import? Business and product Development? Information and research? Partnerships, agencies, distribution Volumes, production economics?	Political effects? Legislative effects? Environmental effects? IT development? Competitors intentions- various? Market demand? New technologies services ideas? Vital contracts and partners? Sustaining internal capabilities? Obstacle facet? Insurmountable weaknesses? Loss of key staffs? Sustainable financial backing? Economy – home abroad?

(Source: Ajibeke, 2013)

3.5 OPERATION AND MAINTENANCE

In engineering parlance, operation refers to timely and daily operation of components of a water supply system such as headworks, treatment plant, machinery and equipment, conveying mains, service reservoirs, distribution systems among others, which is done by

an operator and/or his assistant. Maintenance is the art of keeping the plant, equipment, structures and other related facilities in optimum working order. Maintenance includes preventive or corrective maintenance, mechanical adjustments, repairs and corrective action and planned maintenance (CPHEED 2005). Also,Otun and Abubakar (2009) described operation as the actual running of a service and procedures and activities involved in actual delivery of services such as abstraction, treatment, pumping, transmission and distribution of water or waste water. Maintenance deals with the activities that keep the system in proper working condition including management, cost recovery, repairs and preventive maintenance. They further classified maintenance into crises maintenance or curative maintenance which is under-taken only in response to breakdown and/or public complaints, leading to poor services level, high operation and maintenance cost, faster wear and tear of equipment and user's dissatisfaction, and preventive maintenance which is the activities undertaken in response to prescheduled systematic inspection, repair and replacement, leading to continuity in service level.

The objective of an efficient operation and maintenance of a water supply system is to provide safe and clean drinking water in adequate quantity and desired quality, at adequate pressure at convenient location and time and as economically as possible on a sustainable basis.

The overall operation and maintenance plan of the water distribution system was determined. This was done by collecting operation and maintenance programme of the various units within the distribution system. The plan contains procedures for routine tasks, checks and inspection at intervals,viz, daily, weekly, quarterly, semi-annually and annually. More so, the number of personnel involved in the distribution system was determined together with the task and responsibility which they perform.

3.6 PUMPING SCHEDULE

Pumping schedule is an operational policy for a pumping station which represent a set of guide line that indicate when a particular area should be supplied with water over a given control period. Lucken*et al.* (2004) has proven that pumping schedule is a highly effective method to reduce pumping cost without making changes to the actual infrastructure of the whole system.

In any pumping system, the role of the pump is to provide sufficient pressure to overcome the operating pressure of the system to move water at a required flow rate. The operating pressure of the system is a function of the flow through the system and the arrangement of the system in term of pipe length, fittings, pipe size. The change in liquid elevation, pressure on the liquid surface among others, (Milnes, 2007)

Typically, pumping station consist of a set of pumps having different capacities. These pumps are used in combination to drive water to the reservoirs, thus at a particular point in time, some pumps would be working but others would not. Therefore, scheduling the pump operation mean choosing the right combination of pumps that will be working at each time interval of a scheduling period. That is to say pump schedule is the set of all pump combination chosen for every time interval of the scheduling horizon.

In order to design the pumping schedule plan of the water supply system the following parameters were assessed:

1. Length and diameter of the pipes.
2. Properties of pumps in each pumping station that is head versus discharge.
3. Geometry of the service reservoirs.
4. Water demand/consumption pattern of the populace.
5. Time required to fill each service reservoir.

Equations 3.1 to 3.3 were used to determine the time to fill each of the reservoirs in the distribution system;

$$t = \frac{D.A}{Q} \quad (3.1)$$

$$Q = \frac{Vol}{t} \quad (3.2)$$

$$t = \frac{V}{Q} \quad (3.3)$$

Where:

Q = design flow rate of the pump (m^3/s)

V = volume (m^3)

D = pipe diameter (m)

A = cross sectional area (m^2)

t = time (s)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 CONDITION OF THE DISTRIBUTION SYSTEM

4.1.1Pipes Properties

The transmission system is made up of 43125 m length of ductile iron pipes. Their diameter ranges from 300 to 900 mm. Generally the pipes are in good working condition with leakages only at the valves. The distribution mains is made up of about 940625 m of pipes of diameter ranging 100 to 400mm. which are made of different materials such as ductile iron, asbestos cement, polyvinyl chloride (PVC), and galvanized iron. Most of the leakages occur in asbestos cement pipes. These leakages are attributed to age of the pipes, high pressure in the system during the period of low water consumption, soil condition among others. However, the occurrence of leakage is low in PVC pipes and no leakage in ductile iron pipes.The diameter, length and materials of the pipes in the transmission and distribution systems are shownin Tables 4.1 and 4.2, respectively.

Table 4.1: Transmission system piping

Diameter (mm)	Length (m)	Material
900	5500	DI
700	3125	DI
600	1875	DI
500	6625	DI
450	18125	DI
300	7875	DI

Table 4.2: Distribution system piping

Diameter (mm)	Length (m)	Material
400	1500	DI
400	2875	AC
350	2062.5	DI
300	25125	AC
250	1937.5	AC
250	2250	PVC
225	1875	AC
200	2000	PVC
200	850	AC
150	36,725	AC
150	4875	PVC
100	6287.5	AC
100	4700	PVC
100	1000	GI

4.1.2 Valves

Valves are used for various purposes in water distribution systems, including isolation, air release, drainage, and checking and pressure reduction.

A total of 102 valves were inventoried. The valves were air release valves, sluice valve and butterfly valves. The sizes of the valves ranged from 300 to 900mm on the transmission pipelines and 100 to 400mm on the distribution pipe lines. Eight butterfly valves on the

transmission mains are found to be leaking. However, only one 300 mm sluice valve in the distribution system is leaking. The remaining valves inspected on the distribution mains were in good working condition. The eight butterfly valves leaking in the transmission mains are to be replaced since they cannot be repaired. The sluice valve leaking on the distribution mains need to be repaired.

Sluice and gate valves are extensively used in the distribution to shut off the supplies whenever desired. They also divide the water mains into suitable sections. The air valves were used to discharge air when the mains are being filled and to admit air when it is being emptied. The admission of air on empting the main is of great importance on steel mains which may flatten if the pressure falls below that of atmosphere (Jun, 2005). As such bad and inoperable valves result in loss of considerable quantity of water. Valves are said to be reliable if they can be found and identified under all-weather condition and can be operated and works properly. The conditions of valves in the transmission and distribution system with their rehabilitation measures are given in Tables 4.3 and 4.4, respectively.

Table 4.3: Transmission Mains Valves Data

Valve Type	Diameter(mm)	No	Condition	Rehabilitation measure
Air release	900	2	Good	_
Air release	700	2	Good	_
Air release	500	1	Good	_
Air release	450	6	Good	_
Butterfly	900	3	Leaking	Replaced
Butterfly	700	3	2 good 1 leaking	Replaced
Butterfly	500	4	3 good 1 leaking	Replaced
Butterfly	450	7	4 good 3 leaking	Replaced
Butterfly	300	2	Good	_

Table 4.4: Distribution Mains Valves Data

Valve Type	Diameter(mm)	No	Condition
Sluice	400	2	Good
Sluice	350	2	Good
Sluice	300	22	21 good 1 bad
Sluice	250	3	Good
Sluice	225	2	Good
Sluice	200	7	Good
Sluice	150	19	Good
Sluice	100	13	Good
Gate	200	2	Good

4.1.3 Pumps

Most of the pumps in the pumping station have good physical condition and functional rating. It is only pump 1 in the Impresit pump station and pumps 2 and 3 in the booster pump station that are in bad condition. At the time of carrying out this research these pumps were not functioning. The pumps that are in bad conditions need to be repaired for the water supply system to function efficiently and optimally. The condition assessment and functionality rating of the pumps in the pumping stations is shown in Table 4.5.

Table 4.5: Pumping Station Condition Assessment

Pump station	Equipment Number	Rating									
		Physical condition					Functionality				
		0	1	2	3	4	0	1	2	3	4
Costain /Biwater	Pump 1					X				X	
	Pump 2					X				X	
	Pump 3					X				X	
	Pump 4					X				X	
	Pump 5				X				X		
	Pump 6				X				X		
Impresit	Pump 1	X					X				
	Pump 2					X				X	
	Pump 3					X				X	
	Pump 4					X				X	
Booster pumping station	Pump 1					X			X		
	Pump 2	X					X				
	Pump 3	X					X				

4.1.4 Service Reservoirs

The entire service reservoirs in the distribution system have good physical condition and functionality rating. Theoretically, it is most appropriate to pump water into the distribution mains as per demand pattern of the area, and in that case there will not be need for reservoir, but this is very tedious to manage apart from being uneconomical. Thus, the service reservoirs which are still in good working condition could still absorb the hourly fluctuations in demand and allow the pumps to operate at constant rate thereby reducing operating cost and improving their efficiency. It will also allow the pumping of water in shifts and in tune with power supply hours without affecting water supply. Also, the reservoir could help in maintaining constant pressure in the distribution mains during periods of increase in demand. Since, they are located in topographically high area within the city. The condition assessment and functionality rating of the service reservoirs is shown in Table 4.6.

Table 4.6: Services Reservoir Condition Assessment

Reservoir	Rating									
	Physical condition					Functionality				
	0	1	2	3	4	0	1	2	3	4
Biwater tank					X					X
Shiroro tank			X						X	
Dutsenkura tank					X					X
Tunga east Tank				X						X
INEC tank				X						X
Uphill tank					X					X
Paida hill tank					X					X

4.1.5 Hydrants

There is only one functional hydrant throughout the distribution system. A fire hydrant which is an active protection measure and a source of water provided in most urban, suburban and rural areas with municipal water service to enable firefighters to tap into the municipal water supply to assist in extinguishing a fire. Looking at the importance of fire hydrant, there is the need for the Water Board to install more fire hydrants at strategic positions in the water distribution system.

4.2 PERFORMANCE EVALUATION ANALYSIS

Data collected during the onsite, physical and visual inspection of the entire element in the distribution system was analysed and used for the performance evaluation using the SPEM and SERA approaches. The outcome of the evaluation analysis using SPEM and SERA is shown in Tables 4.7 – 4.10.

Table 4.7: Performance Evaluation Using SPEM

Operational capacity	Sub-categories	Scores
Maintenance frequency	OPS1	4
Maintenance planning	OPS 2	3
System capacity utilization	OPS 3	3
Duration of supply	OPS 4	1
Volume of water production	OPS 5	3
Human Resources Capacity		
No. of staff	HR 1	5
Training and development	HR2	2

Table 4.8: Summary of Performance Evaluation Using SPEM

Item	Operational capacity	Human resources capacity	Total
Score	14	7	21
Score in %	56	70	60

Table 4.9: Performance evaluation using SERA

SERA Evaluation Criteria	Scores 1-Poor, 2-Fair, 3-Good, 4-very good 5-Excellent
A. SERA Indicator: Policies and Procedures	
Governing policies well defined.	3
Operating and maintenance procedures well documented and control	2
Key supporting documents are kept current and are readily available	1
Procedure and work practices are implemented consistently	2
Procedures are used routinely by staff as reference	2
Procedure are in compliance with organizational and regulatory agency requirements	2
Procedure incorporate achievable best practice	2
Periodically reviewed and updated for continual improvement.	1
Sub-total	15

B. SERA Indicator Organizational Structure	
Sub-total	12
C. SERA Indicator: inventory control and equipment management	
Well defined inventory procedures Maintain a database containing type, ages and hour of operations Stock spare equipment and parts in well-organized manner Use historical data to plan the inventory Readily available materials, parts and supplies when needed	1 1 3 1 3
Sub-total	9
D. SERA Indicator: work order system	
Well documented order system and process Document accountability for completion of work orders Uniform work order system across the system Appropriate performance measures for each category of work Performance metrics are routinely monitored	2 2 2 2 1
Sub-total	9

Table 4.10: Summary of Performance Evaluation Using SERA

Item	Policies and procedures	Organizational structure	Inventory control and equipment management	Work order system	Total
Scores	15	12	9	9	45
Scores in %	37.5	48	36	36	39

4.2.1 Discussion of results of Performance Evaluation Analysis

The results shown in Table 4.8 shows that the system has 56% operation capacity and 70% human resources capacity and total evaluation capacity using SPEM as 60%. The score is above average but there is need to improve on training and development of staff in charge of operation and maintenance of the distribution system. Also, the result in Table 4.10 shows the summary of performance evaluation using SERA. This indicates that the system has poor policies and procedures, inventories and equipment management and work order system. However, the organizational structure of the system is fair. Therefore there is need for serious improvement. The capabilities of human resources management of water supply system can be improved through standardised vocational training approach and continuous education on the job training. Effective training can be beneficial to the organization in many ways. It can enhance compliance with policy, specification and applicable regulatory requirements, thereby reducing liability and cost. From management perspective, it can empower the employees to make decisions and provide skilled labour. The training course should include planning and implementation, waste minimization practices, water leakage monitoring technologies and techniques concerned with handling water in environmentally sound manner, emergency repairs, data collection and analysis.

The Water Board should devote at least 5% of the annual personal and overhead cost of water supply to human development. The Board should liaise with the National Water ResourcesInstitute and other training institutions in water and sanitation to access human resources requirement for optimum performance and appropriate capacity building interventions as stipulated in Niger State Government Draft on Water and Sanitation Policy (2009).

4.3SWOT ANALYSIS

A detailed SWOT analysis of the present situation was carried out to identify the strengths, weaknesses, opportunities and threats of the existing network. Table 4.11 shows the SWOT analysis of water supply distribution of Minna.

The SWOT analysis shows the the Water Board has good functional and adequate infrastructures with good objective oriental planning. The weaknesses were: high leakages on the transmission mains which may contaminate the water before getting to the reservoirs; frequent breaks and burst on the distribution mains- thislead to increase in cost of maintenance and an additional indirect cost on consumers; lack of constant power supply make the system to rely more on generator thereby increasing the cost of water production; lack of properly planned pumping schedule which make the facilities to be grossly under-utilized.

Some of the threats identify include high cost of maintenance, illegal connection, cost of diesel, corrupt operating environment, low technological and innovative capacity. The available opportunities include motivation of staff through training and retraining; reorganization of network operation team and duties should be assigned to staff;

establishment of monitoring mechanism to ensure that all leaks and burst are reported and recorded and;development of preventive maintenance programme which should be implemented.

Table 4.11: SWOT Analysis of Water Supply Distribution in Minna

Strength	Weakness
Well laid infrastructure Limited leakages in transmission mains Skilled operation and maintenance staff Good objective oriental planning Adequate Service Reservoirs	High valve leakages on the transmission mains Frequent pipe break and burst on the distribution mains Aged distribution pipes Lack of proper pumping schedule Lack of facilities to measure the impulse of the supply system Staffs not motivated There is no proper record keeping The system is not metered No constant and low power supply
Opportunities	**Threats**
Service expansion opportunities Private public participation Staff willingness to change Automation of the system Capacity building Research and development	Illegal connection High cost of maintenance High cost of diesel Political interference Corrupt operating environment Low technological and innovative capacity Lack of local available spare parts

4.4 OPERATION AND MAINTENANCE

The objective of an efficient operation and maintenance of the water supply system is to provide safe and clean drinking water in adequate quantity and desired quality at adequate pressure at convenient location and time and as economically as possible on a sustainable basis. In order to attain this objective there is supposed to be an operating procedure to ensure that the system can operate satisfactorily, function efficiently and continuously and as far as possible at lowest cost.

Conceptually operating the distribution system is not that difficult. All that is needed is to keep an eye on measurement of the system performance, whether the measurements are in the form of pressure, flow, or reservoir level.

The normal operations in transmission mains, distribution mains and service reservoirs are valves operation during the fixed hours of water supply. The activities of valve operation usually match the prevailing conditions. All the pipe breaks and burst usually occur at the distribution mains. The bust or break could occur at any time. When a break or burst is identified the position is located then a decision is taken as to which valve is to be closed to isolate the section where the break has occurred. After the closure of the valve, dewatering /mud pump is used to drain the pipe break point. The damaged pipe is then removed and accumulated silt is also removed from inside the pipe and the damage pipe is replaced.

Generally the type of maintenance carried out is referred to as simple reactive rehabilitation approach. The pipes are being repaired only after it fails to meet its performance requirement such as hydraulic carrying capacity (i.e. breaks, bursts, blockage, low pressure and excessive leakage) and water quality (excessive rust in distributed water). The benefit of this approach is that a pipe section realizes its full economic life. However, the disadvantage of this approach is that cost of fixing a pipe after it fails is more than fixing it

prior to failure. In addition to the potential for increased and unplanned direct rehabilitation cost, there may be the additional indirect cost due to customer service interruptions, damages to co-located utilities, damages to properties and traffic interruptions.

However, Stone *et al.,* (2000) comprehensively explained that in a proactive approach pipe sections rehabilitation is carried out prior to its failure. Although there are many variations to proactive rehabilitation approach management, they made suggestion of the following steps:

1. Identify performance indicator for the entire network and each pipe section. These indicators include hydraulic capacity, water quality, customer service, cost effectiveness and environmental impact.
2. Assess the network characteristics (pipe length, material, age, operational conditions and environmental conditions) functional capabilities (hydraulic capacity and water quality) and structural condition.
3. Prioritize the pipe rehabilitation based on estimated date on or about which pipe will fail. The prioritization process can also involve predicting future benefits and implications of different rehabilitation strategies.
4. Selection of potential options for corrective action or rehabilitation that is most effective rehabilitative option by the use of economic models.
5. Implement rehabilitation option and reassess system performance.

4.4.1 Pumps and Pumping Station

Pumping machines and pumping station are very important components in a water supply system. Pumping machines are subject to wear, tear, erosion and corrosion done to their nature of functioning and therefore vulnerable to failures. Correct operation and timely

maintenance and up keep of pumping stations and pumping machines are of vital importance to ensure uninterrupted water supply.

The pumps operation involves the following

1. Starting and stopping the pumps. Two pumps are operated at a schedule period of 6 hours.
2. There is continuous monitoring of voltage which should be within the range of 370v- 415v
3. The delivery valves are operated gradually to avoid sudden change in flow velocity which can cause water hammer.
4. There is continuous monitoring of over load relay – this check the temperature and noise of the pump.
5. Before the pumps are stated the water levels in sumps are checked to ensure that they are above low water level.
6. Before the pumps are switched off the delivery valves are gradually closed.

In case of power failure, stand by pumps are started and previous pumps working would be put on standby.

4.4.2 Maintenance of Pumping Machines

Lack of preventive and timely maintenance or poor maintenance can cause under wear of fast moving parts and premature failure of the equipment. Such premature failure or break down cause immense hardship to consumers and staffs and avoidable increase in repair cost. The shortcoming in maintenance can also result in increase in hydraulic and power losses and low efficiency. The daily maintenance of pumps were

a. Cleaning of the pumps, motor and other accessories
b. Checking of coupling bushes and rubber spider

c. Checking of stuffing box

The following irregularities were observed on routine basis and appropriate action were taken

a. Changes in sound of running pump and motor
b. Abrupt changes in temperature
c. Oil leakage from bearings
d. Leakages from mechanical seal
e. Changes in temperature
f. Overheating of motor, starter etc.

The monthly maintenance were

a. Changes of the bearings
b. Greasing of the bearings
c. Changes of bolts and nuts

At the time of carrying out this research there was no log book for recording operation and maintenance activities.

4.5 STAFFING

Even the best designed and constructed facility will not operate at its full capacity without adequate number of qualified staff. Basically there are two units in charge of Minna water distribution system. The first unit is the Distribution Department of Niger State Water Board. The department is headed by an Assistant General Manager (AGM) assisted by Deputy Assistant General Manager (DAGM). The department comprises of permanent and casual staff.Table 4.12 below shows the numbers of staff with their designations.

Table 4.12: Staff of Distribution Department

Designation	No	Qualification
AGM	1	B. Eng.
D.AGM	1	HND
Coordinator	1	ND
Head valve operator	2	AWS
Valve Operators	8	AWS
Foremen	2	AWS
Plumbers	4	AWS
Labourers	10	Casual workers

The second unit is the plant unit which is under Operation and Maintenance Department. This unit is responsible for the operations and maintenance of the pumping stations.The unit is headed by a Plant Manager and assisted by Assistant Plant Manager. Table 4.13show the designation and qualification of staff in plant unit.

Table 4.13: Staff of Plant Unit

Designation	No	Qualification
Plant Manager	1	HND
Ass. Plant Manager	1	ND
Supervisors	8	ND/AWS
Operators	28	ND/AWS
Mechanics	6	ND/AWS
Electricians	9	ND/AWS

The operators work for eight hours shift. The mechanics and electricians are in charge of maintenance of the pumping machines. They work as a team any time there is any maintenance job to be done on the pumping machines.

From the performance evaluation conducted using the SPEM it was found that the distribution system have enough staff for its operation and maintenance.However, there is no any form of capacity development for the staff. Therefore, there is need for constant training and re-training for the staffs.

4.6 PUMPING SCHEDULE

4.6.1 Water Demand

Based on the survey conducted using structured interview, the per capita water demand for Minna ranges from 40 to 150 lpcd. But the water supply system was designed based on 120 lpcd. In most cases the peak demand occurs in the morning from 0530 to 1000 hours and in the evening from 1600 hour to 2000 hours. The average consumption is from 1200 to 1600 hours. During the night hours from 2000 hours to 0530 hours and late morning hours from 1000 to 1200 hours the consumption is below average. The water supply scheme should be able to meet this water demand pattern if it is properly managed.

4.6.2 Existing Pumping Schedule

Presently, the existing water supply system provides water for an average of 4 to 6 hours per day on an average of 2 days per week. Water is being pumped into various reservoirs on rotational bases on the rational time table as shown in Table 4.14.Table 4.15 shows the days which the reservoirs are fed after which water is release the following day as shown in Table 4.16.

Table 4.14: Reviewed Niger State Water Board Supply Rationing Time Table

PUMPING DAY	RESERVOIR TANK TO BE FED	RELEASE DATE & TIME	AREAS TO BENEFIT
SATURDAY	d. Up – Hill	Sunday 6am-10am	Central Minna, Abayi close/F-Layout, AnguwanDaji, Central Mosque, Kwangila (Part), Limawa, Yoruba Road, Old Airport Quarters
SUNDAY	e. Tunga East f. Biwater g. INEC	Monday 6am – 10am	Top Medical Area, Part of Aloe vera, TungaDanboyi, Police Barracks, Railway Quarters, Sauka – kahuta
MONDAY	h. Dutsen Kura	Tuesday 6am-10am	Dutsen Kura, Hausa and Gwari, Bosso Low-Cost & Estate, Shanu Village, London Street A&B, Police Secondary School
TUESDAY	i. Direct Pumping 'A' j. Shiroro Morning, Emir, Paida, Abayi, SAICO, Kuta Rd	Tuesday Night Wednesday 6am-10am	123 Quarters, KetarenGwari, Kpakungu, Kuta Road, SabonGari Morning Airport Quarters, TungaLowcost A & B, Niteco Road
WEDNESDAY	k. Biwater	Thursday 6am – 12 noon	Shango, Barracks, Chanchaga, Minna Central
THURSDAY	l. Dustenkura, Type B 3pmDkura	Friday 6am – 12noon	Dutsen Kura, Hausa and Gwari, Bosso Low-Cost & Estate, Shanu Village, London Street A&B, Police Secondary School
FRIDAY	m. Direct pumping 'B' n. Paida Hill	Saturday6am-10am	F/Layout, Tayi Village, Type 'B' Quarters, Lower part of Zarumai Quarters

Table 4.15: PumpingSchedule

Days	Reservoirs to be fed
Saturday	Uphill
Sunday	Tunga East, Biwater, INEC
Monday	Dusten Kura
Tuesday	Shiroro and Direct Pumping 'A'
Wednesday	Biwater
Thursday	Dutsen Kura
Friday	Paida Hill and Direct pumping B

Table 4.16: Release Schedule

Day	Reservoirs	Time
Sunday	Uphill	6 am- 10 am
Monday	Tunga East, Biwater, INEC	6 am- 10 am
Tuesday	Dusten Kura	6 am-10 am
Wednesday	Shiroro and Direct Pumping A	6 am -10 am
Thursday	Biwater	6 am-12 noon
Friday	Dutsen Kura	6 am- 12 noon
Saturday	Paida Hill and Direct pumping B	6 am- 10 am

4.6.3 Physically Feasible Operating Pumps Combination

Traditionally, the pumps are operated manually by the facilities operator. Tables 4.17 and Table 4.18 presents the possible combination of the various pumps for Coastain/Biwater and Impresit pumping station respectively.

Costain/Biwater pumping station pump water to the Biwater, INEC, Uphill and Paida Hill reservoirs while, Impresitpumping station pump water to DutsenKura, Shiroro and Tunga East reservoirs.

Table 4.17: Pump Combination for Costain/Biwater Pumping Station

Pumpcombination	Pumps in combination						Flow m^3/h
	Design flow Qm^3/h	1	2	3	4	5	6
		350	558	558	350	350	350
1		X		X		X	1258
2			X		X		X 1258

Table 4.18: Pump Combination Impresit Pumping Station

Pump combination	Pumps in combination					Flow m^3/h
	Design from Qm^3/h	1	2	3	4	
		490	475	608	475	
1		X	X			965
2				X	X	1083

4.6.4 Time Required to Fill Each Service Reservoir

The time required to fill each of the reservoir was determined using the Eqns 3.1, 3.2 and 3.3 and possible pump combinations for Coastan/Biwater and Impresitpumping stations is shown in Table 4.19 below;

Table 4.19: Time Required to Fill Each Service Reservoir

Reservoir Name	Capacity (m^3)	Length of pipe (m)	Equivalent diameter (mm)	Vol of water in pipe (m^3)	Time to fill pipe (H)*	Time to fill Pipe (H) +	Time to fill the reservoir (H)*	Time to fill the reservoir (H)+
Biwater	4,500	5375	0.300	380	0.30	0.30	3.58	3.58
Shiroro	2,000	7875	0.714	4413	4.57	4.07	2.07	1.85
Dutsenkura	10,000	15250	0.501	6002	6.22	5.54	10.36	9.23
Tunga East	2000	7750	0.601	3657	3.79	3.38	2.07	1.85
INEC	1000	9125	0.450	1451	1.15	1.15	0.79	0.79
Uphill	7000	9250	0.450	1471	1.17	1.17	5.56	5.56
Paida hill	4000	11125	0.229	2001	1.59	1.59	3.18	3.18

4.6.5 Total water consumption per day

The population of Minna is estimated to be 304113 based on 2006 population census with a growth rate factor of 2.37% the population is estimated using arithmetic growth method to be 358295 in the year 2013 (NPC 2006).

Per capita consumption = 120 lpcd

Water consumption = 120 x 358295

= 42,995,400 litres

Assuming 10% for leakage and 1/3 of total water demand for firefighting requirement

Total water consumption = 57,327,200 L

= 57,327.2 m^3

The present water demand is below the total design capacity of the water works which is 77,000 m^2/ day.

4.6.6 Required Storage Capacity

Using the analytical method, the required storage capacity for 24, 20, 18, 16, 14 and 12 hours of pumping is calculated and presented in the Appendix Tables A1- A21. The summary of the analysis is shown in Table 4.20.

Table 4.20: Summary of required capacity

Duration of pumping	Hour	Required reservoir capacity m^3
12	(0 – 12)	19268.60
12	(0 - 6), (18 - 24)	2212.44
12	(0 – 6), (12 – 18)	13648.59
12	(12 – 24)	19134.80
14	(0 – 7), (12 – 19)	10781.22
14	(0 - 7), (17 – 24)	10781.22
14	(0-14)	16057.17
14	(5 - 24)	9920.92
16	(0 – 16)	12845.73
16	(0 – 8), (12 – 20)	8530.58
16	(0-8), (16 – 24)	14852.88
16	(8-24)	12745.38
18	(0 – 6), (12 – 24)	13827.03
18	(0 -2), (18 – 24)	11106.18
18	(6-24)	8742.24
20	(0 – 10), (12 – 22)	6021.437
20	(0 – 10), (14 – 24)	92932.87
20	(0 – 20)	5218.580
20	(4 – 24)	5620.01
24	(0 - 24)	5820.72

4.6.7 Pumping Schedule Analysis

Presently, Minna has seven services reservoir located at different location within the town with a total storage of 30,500m^3 capacities. Table 4.20 shows the summary of

therequired storage for 12, 14, 16, 18, 20 and 24 hours pumping. Biwaterpumping station pumps water to Biwater, INEC, Uphill and Paida- Hill reservoirs. While the Impresit pumping station pumps water to DutsenKura, Shiroro and Tunga East resevoirs. The Biwater station can pump water of at the rate 1258m^3/h for the two possible combinations while, the Impresitstation can pump water at rate of 965m/h and 1083m^3/m for the two possible combinations shown in tables 4.17 and Table 4.18.

Table 4.19 show the time to fill each reservoir after satisfying the dead storage in pipe line. Assuming that there will be at least 10% leakage of the total water pumped into the reservoir, it will take about 53 minutes to fill the smallest reservoir which is 1000m^3 and it will take about 10 hours 30 minutes to fill the largest reservoir of 10,000m^3 – the remaining reservoir could be filled within six hours of pumping.

It will be appropriate to pump water twelve hours daily from 0000 hours to 0600 hours and from 1200 hour to 1800 hours with a required storage of 13648.58m^2,since the pumps are designed for eight hours continuous pumping. However, if there is constant monitoring of the water consumption rate which may varies from time to time,there may be need to put only one pump during off peak periods.

This pumping schedule is an interesting proposal and highly effective method to achieve cost reduction in pumping station without making changes in the actual infrastructure of the whole system.The decision of operating the pumps at the prescribed time period of 0000 hours to 0600 hours and 1200 hours to 1800 hours, the demand will be met, pressure conditions satisfied and total operating cost minimized. Also, with the pumping schedule it will minimize pump start and off, these will reduce transient and pressure variation, which are the main course of pipe breaks and increase of water loss and energy consumption.

4.7 OPERATION AND MAINTENANCE PLAN

4.7.1 Transmission Mains.

Normally the operation involves transmission of required water within the available head or within pumping head. Operations of pumps from which the transmission mains start are the routine operations.

A record should be kept at the transmitting and receiving reservoirs about the valve operations, water level and flows. Flow meters should be installed at the start and end points of the transmission pipe for proper monitoring of the flows. Water level in sumps from which water is being pumped should be measured. Critical points should be selected in the transmission system for monitoring of pressures by recorders and gauges. In the pumping systems, whenever water pressures in the pumping station drop below the designed system pressure, the operators should be alerted to search for possible leaks in the pumping system. Also, at the receiving end, if the required water levels are not building up at the storage reservoir, it indicates that the required quantity is either not pumped or there may be leakages en route.

For continuity the operators would be required to check that the transmission of water takes place continuously and as per the requirement. The flow meter readings, water levels in reservoir and pressures in the transmission main should be recorded and transmitted to the control room. The operators must ensure the accuracy of instruments for flows, pressures and levels so as to perform the operation properly.

4.7.2 Maintenance Schedules

The maintenance schedule is to improve the level of maintenance of water transmission system through improved co-ordination and planning of administrative and field work and through the use of adequate techniques, equipment and materials for field

maintenance. There should be a daily surveillance for leaks in pipeline, pipe joints and valves. Vales, joints and valve chamber should be checked and serviced every six months. The flushing of the transmission line should be done in every six to twelve months, so as to remove sediments that may be present in pipes.

4.7.3 Service Reservoirs

A water usage curve over a 24 hour period should be prepared for each service reservoir. It can be seen from the usage curve the pattern of variation during the different days of the week especially on weekends, holidays and festivals.

Water levels in the service reservoirs should be read and recorded at the same time each day. There should be a direct communication to the pumping station whenever service reservoir reaches the maximum water level, so as to stop pumping.

A spot map showing the location of pipes and valves should be prepared for each service reservoir. Also there should be a record sheet for each valve showing the direction of turning, number of turns, inspections, repairs whether open or closed.

The service reservoirs should be inspected regularly to determine if there is any leakage. Pressure grouting should be resorted to in order to arrest any leaks form the structure. Also, the service reservoir should be cleaned at least once in year during the period of the lowest water consumption.

4.7.4 Distribution System

Normally, the operations are intended to maintain the required supply and pressure throughout the distribution system. Critical points are to be selected in the distribution system for monitoring of pressures by installation of pressure recorders and gauges. Whenever water pressures in the distribution system or water levels in the service reservoir drops below the minimum required levels, pumps should be started.

The maintenance schedule should be the same as that of the transmission system.

4.7.5 Pumps

Pumping machinery and pumping station are very important components in water supply system. The pumps are subjected to wear, tear, and corrosion due to their nature of functioning and therefore are vulnerable to failures. Generally more number of failures or interruptions in water supply is attributed to pumping machinery and their components. Therefore, correct operation and timely maintenance and up keep of pumping stations and pumping machines are of vital importance to ensure uninterrupted water supply.

The following important points should be observed while operating the pumps

i. Dry running the pumps should be avoided

ii. The pumps should be primed before starting

iii. The pumps should be operated only within the recommended range of the head-discharge characteristics of the pump.

iv. Voltage during operation of pump-motor set should be within $\pm$ 10% of rated voltage.

v. The delivery valve should be operated gradually to avoid sudden change in flow velocity which can cause water hammer pressures.

Maintenance of pumps;

Daily maintenance

i. Cleaning of the pump, motor and other accessories

ii. Checkingof coupling bushes, rubbers spider

iii. Checking of stuffing box, gland etc.,

Routine observation or irregularities

The pump operators should be watchful and should take appropriate action on any irregularity noticed in the operation of the pumps. Particular attention should be paid to the following irregularities

i. Changes in sound of the running pump and motor

ii. Abrupt changes in bearing temperature

iii. Oil leakage from bearings

iv. Leakage from stuffing box and mechanical seal

v. Changes in voltage

vi. Changes in current

vii. Changes in vacuum gauge and pressure gauge readings

viii. Overheating of motor, starter, switch gear, cable among others.

There should be a log book to record all the above observations.

4.8 BILL OF ENGINEERING MEASUREMENT AND EVALUATION

If the water supply system will operate efficiently and optimally as proposed in this research, there is the need to carry out the rehabilitation of equipment and facilities that are in bad condition. Table 4.21 gives the Bill of Engineering Measurements and Evaluation of valves and pumps that need to be repaired and replaced.

Table 4.21: Bill of Engineering Measurement and Evaluation for Replacement and Repairs of Valves and Pumps

Item	Description	Qty	Unit	Rate	Amount N : K
A	Repairs of high lift centrifugal pump No 1 at impresit pumping station	1	No	902,000	902,000.00
B	Repairs of 2 pumps at Booster pumping station	2	No	902,000	1,804,000.00
C	Replacement of 3 unit of butterfly 900mm valve on the transmission main	3	No	3,500,000	10,500,000.00
D	Replacement of 1 unit of butterfly 700mm valve on the transmission main	1	No	2,300,000	2,300,000.00
E	Replacement of 1 unit of butterfly 500mm valve on the transmission main	1	No	1,000,000	1,000,000.00
F	Replacement of 3 units of butterfly 450mm valve on the transmission mains	3	No	850,000	2,550,000.00
G	Repair of 1 unit of sluice valve on the distribution main	1	No	163,000	163,000.00
	Total				**N19,219,000.00**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research is an effort to enhance the effectiveness of water supply distribution in Minna. A diagnostic assessment of the entire components in the distribution system was carried out.

The system has two independent pumping station located at the water works. The stations are Costain/Biwater and Impresit pumping stations. Most of the pumps are in good working condition and have good functional rating. It was only pump 1 in the Impresit pumping station and pumps 2 and 3 in the booster pumping stations that are in bad condition.

The pipelines in the system were inventoried and evaluated based on subjective factor. There was no any record to show the ages of the pipes and their repair history. The system has nearly 43,125m of pipes which serves as transmission mains. The pipe sizes ranges from 300mm to 900mm diameter. These pipes were made of ductile iron. These pipes in good working condition and they are serving the intended purpose. The leakages that occurred at transmission lines were on valve fittings.

The distribution mains were made up of about 94,062.5m of pipe lines of diameter ranging from 100mm to 400mm. The pipe materials were ductile iron, asbestos cement, polyvinyl chloride (PVC) and galvanized iron. Most of the leakage occurs in asbestos cement pipes. These leakages may be due to the pipe age, high pressure in pipes during direct pumping, soil condition etc. However, the PVC pipes and ductile iron pipes are in good condition.

The system has seven service reservoirs located at different topographical high places within the city. The capacity of the reservoirs ranges from 1000m^3 to 10,000m^3 with a

total capacity of 30,500m^3. All the reservoirs supply water to the consumer through the distribution line via gravity. However, Bosso Low cost and Bosso Estate get their water with the help of booster pumps at the Dutsen Kura Reservoir. All the reservoirs are in good working condition and have good functional rating. With twelve hours of pumping from 0000 hours to 0600 hours and 1200 hour to 1800 hours it is possible to provide twenty four hours water supply.

The normal operations in transmission mains, distribution main and service reservoirs was valve operations during fixed hours of water supply in accordance with the supply schedule. The maintenance activities carried out is pipe replacement if break or burst occur in the pipe line and also, servicing of valves in the distribution network. However, there is proper daily and routine operation and maintenance of pumps in the pumping station.

The sum of nineteen million two hundred and nineteen thousand naira would be required to repair the pumps in bad conditions and to install new butterfly valves on the transmission mains.

The following conclusion have been derived from these studies

1. The system facilities have good physical condition and functionality rating
2. The performance evaluation using SPEM show that the distribution system has enough staff for its operation and maintenance. However, there is the need for constant training and retraining of staff.
3. The total evaluation capacity using SPEM was found to be 60% and, the performance evaluation using SERA was found to be 39%.
4. It will be appropriate to pump water from 0000 to 0600 hours and from 1200 to 1800 hours in order to meet the current water demand.

5.2 RECOMMENDATIONS

1. Flow and pressure measuring gauges should be installed at the pumping stations to test pump normal operation and to evaluate the performance of the pumps. Data from the gauges can be used for calibration and numerical simulation.
2. Most of failures are associated with asbestos cement pipes. These failures occurred in pipes of old age installation. The water Board should look at possibilities of replacing the old AC pipes in the system.
3. The water Board should look into possibilities of installing variable speed drives (VSD) for pumps. VSD for pumps provide significant flexibility and improve operation efficiency. VSD for centrifugal pumps enables maintaining fixed pressure vs. changing flow condition or inversely, flow vs. pressure. This flexibility reduces the number of pump starts and stops and the number of pipe breaks.
4. District Metered Areas (DMAs) should be created and flow entering and leaving the (DMAs) should be metered. This will enable the execution of water balance and analysis of flows to quantify the level of leakages.
5. Flow meter should be installed in each reservoir for monitoring the reservoir behaviour. The parameters to be measured are inflow, outflow and water level.
6. Water level in each service reservoir should be read and recorded every hour.
7. Water usage curve over a 24 hours period should be prepared for each service reservoir. It can be seen from the curve the variation pattern during the different times of day and also during different day of the week.
8. The water board should prepared a routine procedure for preparing and updating map and inventory of pipes, valves and consumers connection

9. There should be continuous surveillance of the whole system. Any activity or situation that might endanger the facility or water quality should be investigated and corrective action should be taken.
10. Log books should be provided for all the units in the distribution system for proper recording of all the activities in the distribution system.
11. There should be constant training and retraining of staff.
12. Mathematical simulation model of the system should be developed from the basic data of the network.
13. A mechanism by which the situational analysis approach can be automated should be developed.

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APPENDICES

Table A-1: Twenty four Hours of Pumping

Time	draft in %max daily requirement	cum draft	inflow in %of max daily requirement	inflow-draft	∑(5)in % of max daily requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	4.1667	2.1667	2.1667
1-2	2	4	4.1667	2.1667	4.3334
2-3	2	6	4.1667	2.1667	6.5
3-4	3	9	4.1667	1.1667	7.6667
4-5	3	12	4.1667	1.1667	8.8334
5-6	6	18	4.1667	-1.8333	7
6-7	7	25	4.1667	-2.8333	4.1667
7-8	7	32	4.1667	-2.8333	1.3334
8-9	6	38	4.1667	-1.8333	-0.5
9-10	6	44	4.1667	-1.8333	-2.3333
1011	4	48	4.1667	0.1667	-2.1666
1112	4	52	4.1667	0.1667	-2
1213	4	56	4.1667	0.1667	-1.8333
1314	4	60	4.1667	0.1667	-1.6666
1415	4	64	4.1667	0.1667	-1.5
1516	4	68	4.1667	0.1667	-1.3333
1617	6	74	4.1667	-1.8333	-3.1666
1718	5	79	4.1667	-0.8333	-4
1819	5	84	4.1667	-0.8333	-4.8333
1920	5	89	4.1667	-0.8333	-5.6666
2021	3	92	4.1667	1.1667	-4.5
2122	3	95	4.1667	1.1667	-3.3333
2223	3	98	4.1667	1.1667	-2.1666
2324	2	100	4.1667	2.1667	3.1E-10

Storage capacity required $= \frac{8.8333+5.667}{100} \times 4014.961 = 5820.722m^3$

Table A-2: Twelve Hours of Pumping

Time	Draft in %of max daily requirement	cum draft	inflow in % of max daily requirement	inflow - draft	∑(5)in % of max daily requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	8.3333	6.3333	6.3333
1-2	2	4	8.3333	6.3333	12.6667
2-3	2	6	8.3333	6.3333	19
3-4	3	9	8.3333	5.3333	24.3333
4-5	3	12	8.3333	5.3333	29.6667
5-6	6	18	8.3333	2.3333	32
6-7	7	25	0	-7	25
7-8	7	32	0	-7	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	0	-4	-6
13-14	4	60	0	-4	-10
14-15	4	64	0	-4	-14
15-16	4	68	0	-4	-18
16-17	6	74	0	-6	-24
17-18	5	79	0	-5	-29
18-19	5	84	8.3333	3.3333	-25.6667
19-20	5	89	8.3333	3.3333	-22.3333
20-21	3	92	8.3333	5.3333	-17
21-22	3	95	8.3333	5.3333	-11.6667
22-23	3	98	8.3333	5.3333	-6.3333
23-24	2	100	8.3333	6.3333	1.5E-14

Storage capacity required $= \frac{32+25.6667}{100} \times 4014.961 = 23149.095 m^3$

Table A -3: Twelve Hours of Pumping

time	draft in %max daily requirement	cum draft	inflow in %of max daily requirement	inflow-draft	∑(5)in % of max daily requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	8.3333	6.3333	6.33333
1-2	2	4	8.3333	6.3333	12.6667
2-3	2	6	8.3333	6.3333	19
3-4	3	9	8.3333	5.3333	24.3333
4-5	3	12	8.3333	5.3333	29.6667
5-6	6	18	8.3333	2.3333	32
6-7	7	25	8.3333	1.3333	33.3333
7-8	7	32	8.3333	1.3333	34.6667
8-9	6	38	8.3333	2.3333	37
9-10	6	44	8.3333	2.3333	39.3333
10-11	4	48	8.3333	4.3333	43.6667
11-12	4	52	8.3333	4.3333	48
12-13	4	56		-4	44
13-14	4	60		-4	40
14-15	4	64		-4	36
15-16	4	68		-4	32
16-17	6	74		-6	26
17-18	5	79		-5	21
18-19	5	84		-5	16
19-20	5	89		-5	11
20-21	3	92		-3	8
21-22	3	95		-3	5
22-23	3	98		-3	2
23-24	2	100		-2	2.1E-14

Storage capacity required $= \frac{48+0}{100} \times 4014.961 = 19268.600 m^3$

Table A-4: Eighteen Hours of Pumping

time	draft in %max daily requirement	cum draft	inflow in %of max daily requirement	inflow-draft	∑(5)in % of max daily requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
1-2	2	4	5.5556	3.5556	7.1111
2-3	2	6	5.5556	3.5556	10.6667
3-4	3	9	5.5556	2.5556	13.2222
4-5	3	12	5.5556	2.5556	15.7778
5-6	6	18	5.5556	-0.4444	15.3333
6-7	7	25	5.5556	-1.4444	13.8889
7-8	7	32	5.5556	-1.4444	12.4444
8-9	6	38	5.5556	-0.4444	12
9-10	6	44	5.5556	-0.4444	11.5556
10-11	4	48	5.5556	1.5556	13.1111
11-12	4	52	5.5556	1.5556	14.6667
12-13	4	56	0	-4	10.6667
13-14	4	60	0	-4	6.6667
14-15	4	64	0	-4	2.6667
15-16	4	68	0	-4	-1.3333
16-17	6	74	0	-6	-7.3333
17-18	5	79	0	-5	-12.3333
18-19	5	84	5.5556	0.5556	-11.7778
19-20	5	89	5.5556	0.5556	-11.2222
20-21	3	92	5.5556	2.5556	-8.6667
21-22	3	95	5.5556	2.5556	-6.1111
22-23	3	98	5.5556	2.5556	-3.5556
23-24	2	100	5.5556	3.5556	-3.E-15

Storage capacity required $= \frac{15.7778+12.3333}{100} \times 4014.961 = 112846.152 m^3$

Table A-5: Twelve Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	8.3333	6.3333	6.3333
1-2	2	4	8.3333	6.3333	12.6667
2-3	2	6	8.3333	6.3333	19
3-4	3	9	8.3333	5.3333	24.3333
4-5	3	12	8.3333	5.3333	29.6667
5-6	6	18	8.3333	2.3333	32
6-7	7	25	0	-7	25
7-8	7	32	0	-7	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	8.3333	4.3333	2.3333
13-14	4	60	8.3333	4.3333	6.6667
14-15	4	64	8.3333	4.3333	11
15-16	4	68	8.3333	4.3333	15.3333
16-17	6	74	8.3333	2.3333	17.6667
17-18	5	79	8.3333	3.3333	21
18-19	5	84	0	-5	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	1.4E-14

Storage capacity required $= \frac{25+2}{100} \times 4014.961 = 10838.587 m^3$

Table A-6: Twelve Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	0	-2	-2
1-2	2	4	0	-2	-4
2-3	2	6	0	-2	-6
3-4	3	9	0	-3	-9
4-5	3	12	0	-3	-12
5-6	6	18	0	-6	-18
6-7	7	25	0	-7	-25
7-8	7	32	0	-7	-32
8-9	6	38	0	-6	-38
9-10	6	44	0	-6	-44
10-11	4	48	0	-4	-48
11-12	4	52	0	-4	-52
12-13	4	56	8.3333	4.3333	-47.6667
13-14	4	60	8.3333	4.3333	-43.3333
14-15	4	64	8.3333	4.3333	-39
15-16	4	68	8.3333	4.3333	-34.6667
16-17	6	74	8.3333	2.3333	-32.3333
17-18	5	79	8.3333	3.3333	-29
18-19	5	84	8.3333	3.3333	-25.6667
19-20	5	89	8.3333	3.3333	-22.3333
20-21	3	92	8.3333	5.3333	-17
21-22	3	95	8.3333	5.3333	-11.6667
22-23	3	98	8.3333	5.3333	-6.3333
23-24	2	100	8.3333	6.3333	2.3E-14

Storage capacity required $= \frac{0+47.6667}{100} \times 4014.961 = 19134.803 m^3$

Table A-7: Eighteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	5.5556	3.5556	3.5556
1-2	2	4	5.5556	3.5556	7.1111
2-3	2	6	5.5556	3.5556	10.6667
3-4	3	9	5.5556	2.5556	13.2222
4-5	3	12	5.5556	2.5556	15.7778
5-6	6	18	5.5556	-0.4444	15.3333
6-7	7	25	5.5556	-1.4444	13.8889
7-8	7	32	5.5556	-1.4444	12.4444
8-9	6	38	5.5556	-0.4444	12
9-10	6	44	5.5556	-0.4444	11.5556
10-11	4	48	5.5556	1.5556	13.1111
11-12	4	52	5.5556	1.5556	14.6667
12-13	4	56	5.5556	1.5556	16.2222
13-14	4	60	5.5556	1.5556	17.7778
14-15	4	64	5.5556	1.5556	19.3333
15-16	4	68	5.5556	1.5556	20.8889
16-17	6	74	5.5556	-0.4444	20.4444
17-18	5	79	5.5556	0.5556	21
18-19	5	84	0	-5	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	7.1E-15

Storage capacity required == $\frac{20.889+0}{100} \times 4014.961 = 8385.414m^3$

Table A-8: Eighteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	5.5556	3.5556	3.5556
1-2	2	4	5.5556	3.5556	7.1111
2-3	2	6	5.5556	3.5556	10.6667
3-4	3	9	5.5556	2.5556	13.2222
4-5	3	12	5.5556	2.5556	15.7778
5-6	6	18	5.5556	-0.4444	15.3333
6-7	7	25	0	-7	8.3333
7-8	7	32	0	-7	1.3333
8-9	6	38	0	-6	-4.6667
9-10	6	44	0	-6	-10.6667
10-11	4	48	0	-4	-14.6667
11-12	4	52	0	-4	-18.6667
12-13	4	56	5.5556	1.5556	-17.1111
13-14	4	60	5.5556	1.5556	-15.5556
14-15	4	64	5.5556	1.5556	-14
15-16	4	68	5.5556	1.5556	-12.4444
16-17	6	74	5.5556	-0.4444	-12.8889
17-18	5	79	5.5556	0.5556	-12.3333
18-19	5	84	5.5556	0.5556	-11.7778
19-20	5	89	5.5556	0.5556	-11.2222
20-21	3	92	5.5556	2.5556	-8.6667
21-22	3	95	5.5556	2.5556	-6.1111
22-23	3	98	5.5556	2.5556	-3.5556
23-24	2	100	5.5556	3.5556	-5.3E-15

Storage capacity required $== \frac{15.7778+18.6667}{100} \times 4014.961 = 13827.027m^3$

Table A-8 Eighteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	0	-2	-2
1-2	2	4	0	-2	-4
2-3	2	6	0	-2	-6
3-4	3	9	0	-3	-9
4-5	3	12	0	-3	-12
5-6	6	18	0	-6	-18
6-7	7	25	5.5556	-1.4444	-19.4444
7-8	7	32	5.5556	-1.4444	-20.8889
8-9	6	38	5.5556	-0.4444	-21.3333
9-10	6	44	5.5556	-0.4444	-21.7778
10-11	4	48	5.5556	1.5556	-20.2222
11-12	4	52	5.5556	1.5556	-18.6667
12-13	4	56	5.5556	1.5556	-17.1111
13-14	4	60	5.5556	1.5556	-15.5556
14-15	4	64	5.5556	1.5556	-14
15-16	4	68	5.5556	1.5556	-12.4444
16-17	6	74	5.5556	-0.4444	-12.8889
17-18	5	79	5.5556	0.5556	-12.3333
18-19	5	84	5.5556	0.5556	-11.7778
19-20	5	89	5.5556	0.5556	-11.2222
20-21	3	92	5.5556	2.5556	-8.6667
21-22	3	95	5.5556	2.5556	-6.1111
22-23	3	98	5.5556	2.5556	-3.5556
23-24	2	100	5.5556	3.5556	8.8E-15

Storage capacity required $= \frac{0+21.7778}{100} \times 4014.961 = 8742.244 m^3$

Table A -10: Twenty Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow - Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) =(4)- (2)	(6) = ∑(5)
0-1	2	2	5	3	3
1-2	2	4	5	3	6
2-3	2	6	5	3	9
3-4	3	9	5	2	11
4-5	3	12	5	2	13
5-6	6	18	5	-1	12
6-7	7	25	5	-2	10
7-8	7	32	5	-2	8
8-9	6	38	5	-1	7
9-10	6	44	5	-1	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	0	-4	-6
13-14	4	60	0	-4	-10
14-15	4	64	5	1	-9
15-16	4	68	5	1	-8
16-17	6	74	5	-1	-9
17-18	5	79	5	0	-9
18-19	5	84	5	0	-9
19-20	5	89	5	0	-9
20-21	3	92	5	2	-7
21-22	3	95	5	2	-5
22-23	3	98	5	2	-3
23-24	2	100	5	3	0

Storage capacity required $= \frac{13+10}{100} \times 4014.961 = 9232.871 m^3$

Table A-11: Twenty Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow - Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) (2)	(6) = ∑(5)
0-1	2	2	5	3	3
1-2	2	4	5	3	6
2-3	2	6	5	3	9
3-4	3	9	5	2	11
4-5	3	12	5	2	13
5-6	6	18	5	-1	12
6-7	7	25	5	-2	10
7-8	7	32	5	-2	8
8-9	6	38	5	-1	7
9-10	6	44	5	-1	6
10-11	4	48	5	1	7
11-12	4	52	5	1	8
12-13	4	56	5	1	9
13-14	4	60	5	1	10
14-15	4	64	5	1	11
15-16	4	68	5	1	12
16-17	6	74	5	-1	11
17-18	5	79	5	0	11
18-19	5	84	5	0	11
19-20	5	89	5	0	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $= \frac{13+0}{100} \times 4014.961 = 5218.579 m^3$

Table A-12: Twenty Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow - Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	5	3	3
1-2	2	4	5	3	6
2-3	2	6	5	3	9
3-4	3	9	5	2	11
4-5	3	12	5	2	13
5-6	6	18	5	-1	12
6-7	7	25	5	-2	10
7-8	7	32	5	-2	8
8-9	6	38	5	-1	7
9-10	6	44	5	-1	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	5	1	-1
13-14	4	60	5	1	0
14-15	4	64	5	1	1
15-16	4	68	5	1	2
16-17	6	74	5	-1	1
17-18	5	79	5	0	1
18-19	5	84	5	0	1
19-20	5	89	5	0	1
20-21	3	92	5	2	3
21-22	3	95	5	2	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $= \frac{13+2}{100} \times 4014.961 = 6024.437 m^3$

Table A-13Twenty Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) (2)	(6) = ∑(5)
0-1	2	2	0	-2	-2
1-2	2	4	0	-2	-4
2-3	2	6	0	-2	-6
3-4	3	9	0	-3	-9
4-5	3	12	5	2	-7
5-6	6	18	5	-1	-8
6-7	7	25	5	-2	-10
7-8	7	32	5	-2	-12
8-9	6	38	5	-1	-13
9-10	6	44	5	-1	-14
10-11	4	48	5	1	-13
11-12	4	52	5	1	-12
12-13	4	56	5	1	-11
13-14	4	60	5	1	-10
14-15	4	64	5	1	-9
15-16	4	68	5	1	-8
16-17	6	74	5	-1	-9
17-18	5	79	5	0	-9
18-19	5	84	5	0	-9
19-20	5	89	5	0	-9
20-21	3	92	5	2	-7
21-22	3	95	5	2	-5
22-23	3	98	5	2	-3
23-24	2	100	5	3	0

Storage capacity required $= \frac{0+14}{100} \times 4014.961 = 5620.008 m^3$

Table A-15: Fourteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow –Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) ∑(2)	(4)	(5) = (4) (2)	(6) = ∑(5)
0-1	2	2	7.1428	5.1428	5.1428
1-2	2	4	7.1428	5.1428	10.2857
2-3	2	6	7.1428	5.1428	15.4285
3-4	3	9	7.1428	4.1428	19.5714
4-5	3	12	7.1428	4.1428	23.7142
5-6	6	18	7.1428	1.1428	24.8571
6-7	7	25	7.1428	0.1428	25
7-8	7	32	0	-7	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	0	-4	-6
13-14	4	60	0	-4	-10
14-15	4	64	0	-4	-14
15-16	4	68	0	-4	-18
16-17	6	74	0	-6	-24
17-18	5	79	7.1428	2.1428	-21.8571
18-19	5	84	7.1428	2.1428	-19.7142
19-20	5	89	7.1428	2.1428	-17.5714
20-21	3	92	7.1428	4.1428	-13.4285
21-22	3	95	7.1428	4.1428	-9.2857
22-23	3	98	7.1428	4.1428	-5.142857143
23-24	2	100	7.1428	5.1428	0

Storage capacity required $= \frac{25+24}{100} \times 4014.961 = 19670.029 m^3$

Table A-15: Fourteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	7.1428	5.1428	5.1428
1-2	2	4	7.1428	5.1428	10.2857
2-3	2	6	7.1428	5.1428	15.4285
3-4	3	9	7.1428	4.1428	19.5714
4-5	3	12	7.1428	4.1428	23.7142
5-6	6	18	7.1428	1.1428	24.8571
6-7	7	25	7.1428	0.1428	25
7-8	7	32	0	-7	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	7.1428	3.1428	1.1428
13-14	4	60	7.1428	3.1428	4.2857
14-15	4	64	7.1428	3.1428	7.4285
15-16	4	68	7.1428	3.1428	10.5714
16-17	6	74	7.1428	1.1428	11.7142
17-18	5	79	7.1428	2.1428	13.85714286
18-19	5	84	7.1428	2.1428	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $= \frac{25+2}{100} \times 4014.961 = 10838.587 m^3$

Table A-16Fourteen Hour of Pumping

Time (Hour) (1)	Draft in % of Max. Daily Requirement (2)	Cum. Draft (3) =∑(2)	Inflow in % of Max. Daily Requirement (4)	Inflow -Draft % (5) = (4) - (2)	∑(5) in % of Max Daily Requirement (6) = ∑(5)
0-1	2	2	7.1428	5.1428	5.1428
1-2	2	4	7.1428	5.1428	10.2857
2-3	2	6	7.1428	5.1428	15.4285
3-4	3	9	7.1428	4.1428	19.5714
4-5	3	12	7.1428	4.1428	23.7142
5-6	6	18	7.1428	1.1428	24.8571
6-7	7	25	7.1428	0.1428	25
7-8	7	32	7.1428	0.1428	25.1428
8-9	6	38	7.1428	1.1428	26.2857
9-10	6	44	7.1428	1.1428	27.4285
10-11	4	48	7.1428	3.1428	30.5714
11-12	4	52	7.1428	3.1428	33.7142
12-13	4	56	7.1428	3.1428	36.8571
13-14	4	60	7.1428	3.1428	40
14-15	4	64	0	-4	36
15-16	4	68	0	-4	32
16-17	6	74	0	-6	26
17-18	5	79	0	-5	21
18-19	5	84	0	-5	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	7.1E-15

Storage capacity required $= \frac{40+0}{100} \times 4014.961 = 16057.166 m^3$

Table A-17:Fourteen Hours Of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) (2)	(6) = ∑(5)
0-1	2	2	0	-2	-2
1-2	2	4	0	-2	-4
2-3	2	6	0	-2	-6
3-4	3	9	0	-3	-9
4-5	3	12	0	-3	-12
5-6	6	18	7.1428	1.1428	-10.8571
6-7	7	25	7.1428	0.1428	-10.7142
7-8	7	32	7.1428	0.1428	-10.5714
8-9	6	38	7.1428	1.1428	-9.4285
9-10	6	44	7.1428	1.1428	-8.2857
10-11	4	48	7.1428	3.1428	-5.1428
11-12	4	52	7.1428	3.1428	-2
12-13	4	56	7.1428	3.1428	1.1428
13-14	4	60	7.1428	3.1428	4.2857
14-15	4	64	7.1428	3.1428	7.4285
15-16	4	68	7.1428	3.1428	10.5714
16-17	6	74	7.1428	1.1428	11.7142
17-18	5	79	7.1428	2.1428	13.85714286
18-19	5	84	7.1428	2.1428	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $= \frac{12+16}{100} \times 4014.961 = 11240.016 m^3$

Table A-18:Sixteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	6.25	4.25	4.25
1-2	2	4	6.25	4.25	8.5
2-3	2	6	6.25	4.25	12.75
3-4	3	9	6.25	3.25	16
4-5	3	12	6.25	3.25	19.25
5-6	6	18	6.25	0.25	19.5
6-7	7	25	6.25	-0.75	18.75
7-8	7	32	6.25	-0.75	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	0	-4	-6
13-14	4	60	0	-4	-10
14-15	4	64	0	-4	-14
15-16	4	68	0	-4	-18
16-17	6	74	6.25	0.25	-17.75
17-18	5	79	6.25	1.25	-16.5
18-19	5	84	6.25	1.25	-15.25
19-20	5	89	6.25	1.25	-14
20-21	3	92	6.25	3.25	-10.75
21-22	3	95	6.25	3.25	-7.5
22-23	3	98	6.25	3.25	-4.25
23-24	2	100	6.25	4.25	0

Storage capacity required $= \frac{19.5+18}{100} \times 4014.961 = 15053.594 m^3$

Table A-19: Sixteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) (2)	(6) = ∑(5)
0-1	2	2	6.25	4.25	4.25
1-2	2	4	6.25	4.25	8.5
2-3	2	6	6.25	4.25	12.75
3-4	3	9	6.25	3.25	16
4-5	3	12	6.25	3.25	19.25
5-6	6	18	6.25	0.25	19.5
6-7	7	25	6.25	-0.75	18.75
7-8	7	32	6.25	-0.75	18
8-9	6	38	0	-6	12
9-10	6	44	0	-6	6
10-11	4	48	0	-4	2
11-12	4	52	0	-4	-2
12-13	4	56	6.25	2.25	0.25
13-14	4	60	6.25	2.25	2.5
14-15	4	64	6.25	2.25	4.75
15-16	4	68	6.25	2.25	7
16-17	6	74	6.25	0.25	7.25
17-18	5	79	6.25	1.25	8.5
18-19	5	84	6.25	1.25	9.75
19-20	5	89	6.25	1.25	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $=\frac{19.5+2}{100} \times 4014.961 = 8630.727 m^3$

Table A-20: Sixteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) =∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	6.25	4.25	4.25
1-2	2	4	6.25	4.25	8.5
2-3	2	6	6.25	4.25	12.75
3-4	3	9	6.25	3.25	16
4-5	3	12	6.25	3.25	19.25
5-6	6	18	6.25	0.25	19.5
6-7	7	25	6.25	-0.75	18.75
7-8	7	32	6.25	-0.75	18
8-9	6	38	6.25	0.25	18.25
9-10	6	44	6.25	0.25	18.5
10-11	4	48	6.25	2.25	20.75
11-12	4	52	6.25	2.25	23
12-13	4	56	6.25	2.25	25.25
13-14	4	60	6.25	2.25	27.5
14-15	4	64	6.25	2.25	29.75
15-16	4	68	6.25	2.25	32
16-17	6	74	0	-6	26
17-18	5	79	0	-5	21
18-19	5	84	0	-5	16
19-20	5	89	0	-5	11
20-21	3	92	0	-3	8
21-22	3	95	0	-3	5
22-23	3	98	0	-3	2
23-24	2	100	0	-2	0

Storage capacity required $= \frac{32+0}{100} \times 4014.961 = 12845.733 m^3$

Table A-21: Sixteen Hours of Pumping

Time (Hour)	Draft in % of Max. Daily Requirement	Cum. Draft	Inflow in % of Max. Daily Requirement	Inflow -Draft %	∑(5) in % of Max Daily Requirement
(1)	(2)	(3) = ∑(2)	(4)	(5) = (4) - (2)	(6) = ∑(5)
0-1	2	2	0	-2	-2
1-2	2	4	0	-2	-4
2-3	2	6	0	-2	-6
3-4	3	9	0	-3	-9
4-5	3	12	0	-3	-12
5-6	6	18	0	-6	-18
6-7	7	25	0	-7	-25
7-8	7	32	0	-7	-32
8-9	6	38	6.25	0.25	-31.75
9-10	6	44	6.25	0.25	-31.5
10-11	4	48	6.25	2.25	-29.25
11-12	4	52	6.25	2.25	-27
12-13	4	56	6.25	2.25	-24.75
13-14	4	60	6.25	2.25	-22.5
14-15	4	64	6.25	2.25	-20.25
15-16	4	68	6.25	2.25	-18
16-17	6	74	6.25	0.25	-17.75
17-18	5	79	6.25	1.25	-16.5
18-19	5	84	6.25	1.25	-15.25
19-20	5	89	6.25	1.25	-14
20-21	3	92	6.25	3.25	-10.75
21-22	3	95	6.25	3.25	-7.5
22-23	3	98	6.25	3.25	-4.25
23-24	2	100	6.25	4.25	0

Storage capacity required $= \frac{0+32}{100} \times 4014.961 = 12845.733 m^3$