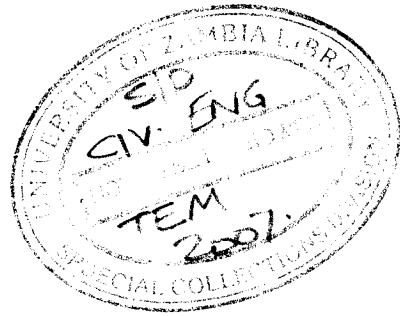
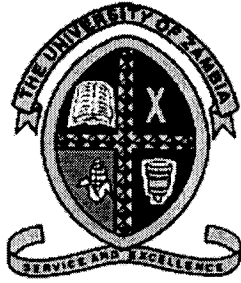




THE UNIVERSITY OF ZAMBIA

SCHOOL OF ENGINEERING

**DEPARTMENT OF CIVIL AND ENVIROMENTAL
ENGINEERING**

**EVALUATION OF KAFUE WATER TREATMENT PLANT
AND TOWN WATER DEMAND**

BY: PATRICK BALAMANI TEMBO

@ 2007

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EVALUATION OF KAFUE WATER TREATMENT PLANT AND TOWN
WATER DEMAND

BY: PATRICK TEMBO

COMPUTOR: 99012740

REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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ZAMBIA

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DEDICATION

All that I've been, all that I aim and all that I will possibly be, I owe it to my dearest daddy Balamani Tembo who left me with a legacy of hard work and determination. Never to fear the mountains for their tops, he inferred, one sees the beautiful scenery behind and wonders.....I will ever love you daddy wherever you are.

ACKNOWLEDGEMENT

My profound gratitude I confer to Mr.J.M.Tembo my project supervisor for guiding me ably throughout the execution of this project. Without his guidance, this project would not have come to its logical completion.

I am sincerely grateful to the director of works of Kafue District Council for providing me an opportunity of working on a water treatment plant. I really relish the challenges you exposed me to.

My acknowledgement will not be complete if I do not extend it to the lecturers of civil and environmental engineering department, the following Messer of ministry of agriculture irrigation section, G.Sikuleka, M.Phiri, M.Stali, and indeed the school of engineering at large for their tireless effort in shaping me into an engineer.

I further extend my thanks to my classmates who for their moral support and encouragement throughout the execution of this project.

Many thanks still go to my wife Gloria as well as my little ones, Clara and Kuzwayo for their unwavering moral and material support throughout my school life at UNZA .Thanks pals for being a family for me.

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DESCRIPTION OF ABBREVIATIONS

WHO	-World Health Organization
ZS	- Zambian Standard
LWSC	- Lusaka Water and Sewerage Company
TC	- Total Coliforms
FC	- Feacal Coliforms
ADD	- Average daily water demand

SUMMARY

Despite being so near to one of Zambia's biggest rivers, the Kafue River, Kafue residents especially those living at the heart of the town, do not enjoy an ample and continuous supply of water. The treatment plant capacity is inadequate such that every customer has a complaint about the quality and quantity.

A new company (LWSC) has just taken over the reins of water service provision from the local authority and is very eager to improve the water supply- of course as a self-sustaining business. To help solve many water blues in Kafue is what this project is all about. This report begins with a brief description of Kafue as a town and then opens on technical details of treatment of water and before zeroing on water demands.

Before explaining how the population and water demand for the town was projected to the design year (2021) the project dealt with how to estimate how much water people would need if they had no constraints to water access. It was part of this project's aim to come up with suggestions regarding both quality and quantity.

After a careful analysis of the treatment plant and water consumption habits, it was concluded that water problems were main due to being partially treated at the plant and the plant capacity falling way below the town water demand.

CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL

Water is an essential part of our day to day life and off course social-economic development. As a result of increasing urbanization and industrialization, populations in towns over years have increased significantly causing pressure on safe and secure water supplies to these locations. This has not just brought about a scenario where water has to be transported, treated and distributed but the need for a supply which will provide safe water in quantities sufficient for drinking, domestic and other household purposes so as to make possible the basic hygiene of all members of the households. A sufficient quantity should be available on a reliable basis all year round near to or within the household where the water is to be used. These services are provided usually by municipalities. As regards to Kafue these services are provided by the district council.

1.2 RATIONALE

Kafue District Council seeks to improve water quality delivery to its residents so as to reduce many costumer complaints arising from erratic supply which is characterized by rationing of water, unpalatable drinking water with low pressure and very inadequate supply. Solutions both in the short and long term ought to be found to improve the council's revenue base and restore costumer confidence in its clients.

1.3 MAIN OBJECTIVE

Evaluating the effectiveness of the Kafue town water treatment plant and determination of its adequacy to meet the current and future water town demand. (2006 and 2021)

1.4 SPECIFIC OBJECTIVES

- (a) Quantify the current town water demand and forecast it to the next 15 year period.
- (b) Relate both current water demand and forecasted demand to the capacity of the treatment plant.
- (c) Analyze the quality of both treated and raw water as well as make comparison with the stipulated Zambian standard.
- (d) Propose modifications to be made on the treatment plant to meet Zambia standard for drinking water,

1.5 SCOPE

The project focuses on the treatment processes employed at the plant and the adequacy of the plant to meet the current (2006) and future water demands.

With regards to treatment, attention is paid to factors such as Faecal coliforms, total Coliforms, chlorine water demand, residue chlorine, turbidity levels, quantifying chemical dosages and modes of application.

1.6 METHODOLOGY

The methods of engineering will be used to assess the implementation and usefulness of water treatment interventions. This type of research is called evaluation research. Evaluation research aims at testing interventions to see how effective they are and therefore represent an important means of linking action and research in a constructive manner.

Three of the most important advantages of evaluation research to water treatment interventions are listed below.

1. Evaluation research used as a diagnostic tool helps the people implementing an intervention to identify neglected areas of need, neglected target group and problems within organizations and programs.
2. A comparison of a program's progress with its original aims is another of the function of evaluation research this saves to adjust the program to the particular

needs and resources of the community within which it is situated. Evaluation designed to promote the effectiveness of the program is called formative evaluation.

Further, evaluation research furnishes evidence of the usefulness of a program. In this way a program gains credibility with funding organization, as well as the community within which it is operating. This is known as summative research. The methods to used can be summarized as below

(a) Review literature on water treatment and water demand projections

Treatment processes of water, various methods of population projections shall be looked at.

(b) Collect as much information as possible from the water treatment plant regarding

- dosing of chemicals
- components which are malfunctioning or disconnected

(c) Collect latest population distribution map for Kafue town from central statistics office and one reflecting the residential distribution from the local council:

- quantifying the population in each of the three housing categories.

(d) Collect samples of raw and treated water at various points on the water reticulation system

- for quality analysis both at field and laboratory levels.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 PREAMBLE

This chapter reflects on the basic units and treatment processes of a water treatment plant with particular reference to Kafue town as well as the parameters necessary for population forecasting over a certain number of years.

2.2 WATER BODIES

The body from which water is extracted can be a well, borehole, river, dam, rain, or a spring. However, streams, rivers and lakes have larger quantities of water but the quality of such waters depends upon the nature of soil through which they traverse and the existing human and natural activities. Usually surface waters are polluted due to large amounts of organic and inorganic matter such as sticks leaves dead animals. Decaying vegetable matter, clay or silt collect as water flows through plains, lowlands, mountains, villages and towns. Sometimes industrial effluent, domestic sewage and direct human and animal excreta are discharged into these bodies of water. This renders them unsafe for human consumption without purification.

2.3 WATERBORNE DISEASES

Generally contaminated or polluted water causes disease. For instance the decaying organic matter present in water causes dyspepsia [indigestion] and constipation. Similarly lead may cause poisoning. Pathogenic bacteria, viruses, protozoa, worms and other organisms present in water also cause disease. The following is a list of diseases communicable through water. The modes can be:-

FAECAL –ORAL ROUTE

A water-borne transmission occurs when a pathogen in water is drunk by a person who may be infected. All of the diseases in this category can be transmitted by any route which permits Faecal material to pass into the mouth. Some of these diseases include:-

- (a) **CHOLERA** Caused by the bacteria *Vibrio cholerae*. Infection is usually by drinking sewage contaminated water but may be contracted directly from contaminated food. It is prevalent in many parts of Africa.

- (b) **TYPHOID** Caused by the bacteria *Salmonella Typhi*.
Infection is usually through sewage contaminated water.

- (c) **Dysentery** Caused by bacteria *Shigella Sonnei*; *Shigella Flexner* *Shigella Shigae*. The first being the most common.
Infection may be by sewage contaminated water but more usually, by contaminated food. The disease is commonly spread by flies, particularly in tropics where disease is locally widespread. The disease is in two parts: bacterial and amoebic. Bacteria is caused as above, but amoeba is caused by the protozoon *Entamoeba histolytica*.

2.4 WATER CONTACT DISEASES

A water based disease is one in which the pathogen spends a part of its life cycle in another water organism such as the snail or an aquatic animal. These diseases are due to infections by parasitic worms that live in the body as opposed to those worms in the intestines. These include:-

- (d) **WORMS** Caused by a variety of round or flat worms
Infection is by drinking or coming in contact with

Sewage contaminated water.

(e) FLUKES

This is caused as above and infection is by bathing or washing in contaminated water.e.g schistomiasis and bilharziasis

2.5 WATER VECTOR HABITAT

This category of diseases is spread by biting insects which either breed in water or bite near water. The best known water breeding insect that transmits a disease while biting is anopheles mosquito. However, river blindness and yellow fever are some of them.

2.6 WATER-HYGIENE DISEASES

Water can play a great role in keeping our bodies and the human environment clean. Some infections thrive well when the human skin and the clothes are dirty. Fungal infection of the skin and eye infections are common

2.7 CHEMICAL CONTAMINATION

It is permissible for drinking water to contain many different chemicals, but to a limited and controlled extent. Certain chemical properties in water must be controlled within specified limits to preserve the wholesomeness and palatability of the water. Some of the chemical substances and properties which mostly of great concern to the environmental Engineer are:

Calcium

Iron

Zinc

Nitrates

Nitrites

Arsenic

2.8 TREATMENT PLANT

This is part of the water supply system where levels of contamination and pollution are controlled from. It consists of processing units such as, chemical coagulation/flocculation; settling tank, mixed-media filtration and water conditioning

units. The aim is to achieve the acceptable standards as stipulated in the Zambian standards for drinking water. Below are the targeted objectionable substances the treatment of water aims at.

- (a) Removal of all pathogenic bacteria contained in the untreated water;
- (b) Removal of unpleasant tastes and odours;
- (c) Removal of objectionable colors and;
- (d) Removal of corrosiveness.

2.9 METHODS OF TREATMENT

These methods of treating water may be classified according to the nature of impurities to be removed. These methods include;

- (1) Methods of removing suspended impurities

SCREENING

This is the prevention of leaves, sticks, fish, aquatic vegetation and large objects from entering the pumps or intake works.

PLAIN SEDIMENTATION

This is a process of letting the suspended solids in water to fall out of the body of water by gravity alone. No chemicals are used. The aim in plain sedimentation is to pass the water through a tank in a manner that the flow is smooth, even, slow, and allow the suspended solids to fall out by gravity. This is mostly used as a preliminary treatment for fast flowing river waters liable to carry a high content of mineral matter in suspension such as in the case of intake works on water transfer scheme where it is desirable to minimize the amount of suspended material passing into the system.

Sedimentation in the sedimentation cells is the removal by gravitational settling of suspended particles heavier than water. The efficiency of this process has a direct effect on the rapid sand filter length of run. The amount of suspended matter removed with respect to the total suspended matter in water is called removal ratio. With the settling velocity and settling characteristics known, the removal ratio can be ascertained. A decision can be made as whether there is need for additives to improve the coagulation/flocculation process or not.

This is the surface loading or overflow rate and shows the volume that can flow through the tank per m^2 surface in order to remove particles with the settling velocity V_o or greater.

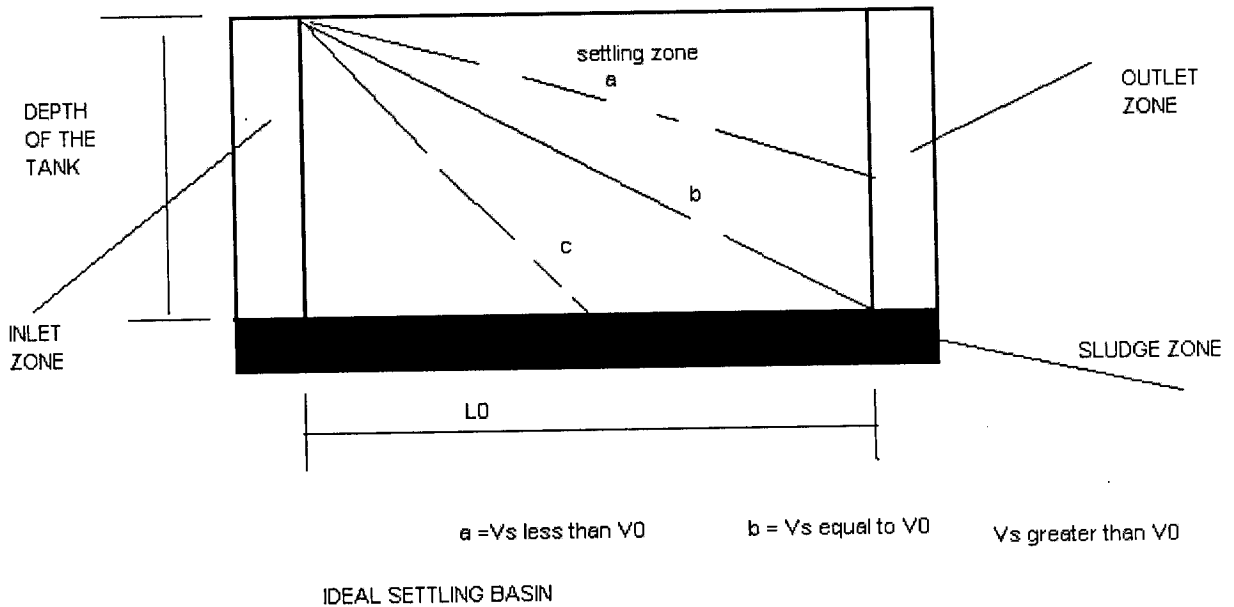


Figure 2.1 sedimentation cell (Robert L.Sanks)

The following assumptions were taken into consideration when making the above calculations:

- within the settling zone there are quiescent conditions (no turbulences, no currents)
- The flow is steady and uniform across the settling zone
- The concentration of the suspended particles is uniform throughout the cross section when water enters the settling zone.
- Once the particles have reached the bottom zone they stay there and are not re-suspended.

However, very often the pumps at the intake point experience a lot of break downs and as such the flow to the sedimentation cells is in most cases less than $1000\text{m}^3/\text{hr}$. This implies that the settling velocity will be less than the designed one and as such the surface loading rate will be low. Matters are further worsened by the fact that no chemical dosage administered to foster coagulation /flocculation process.

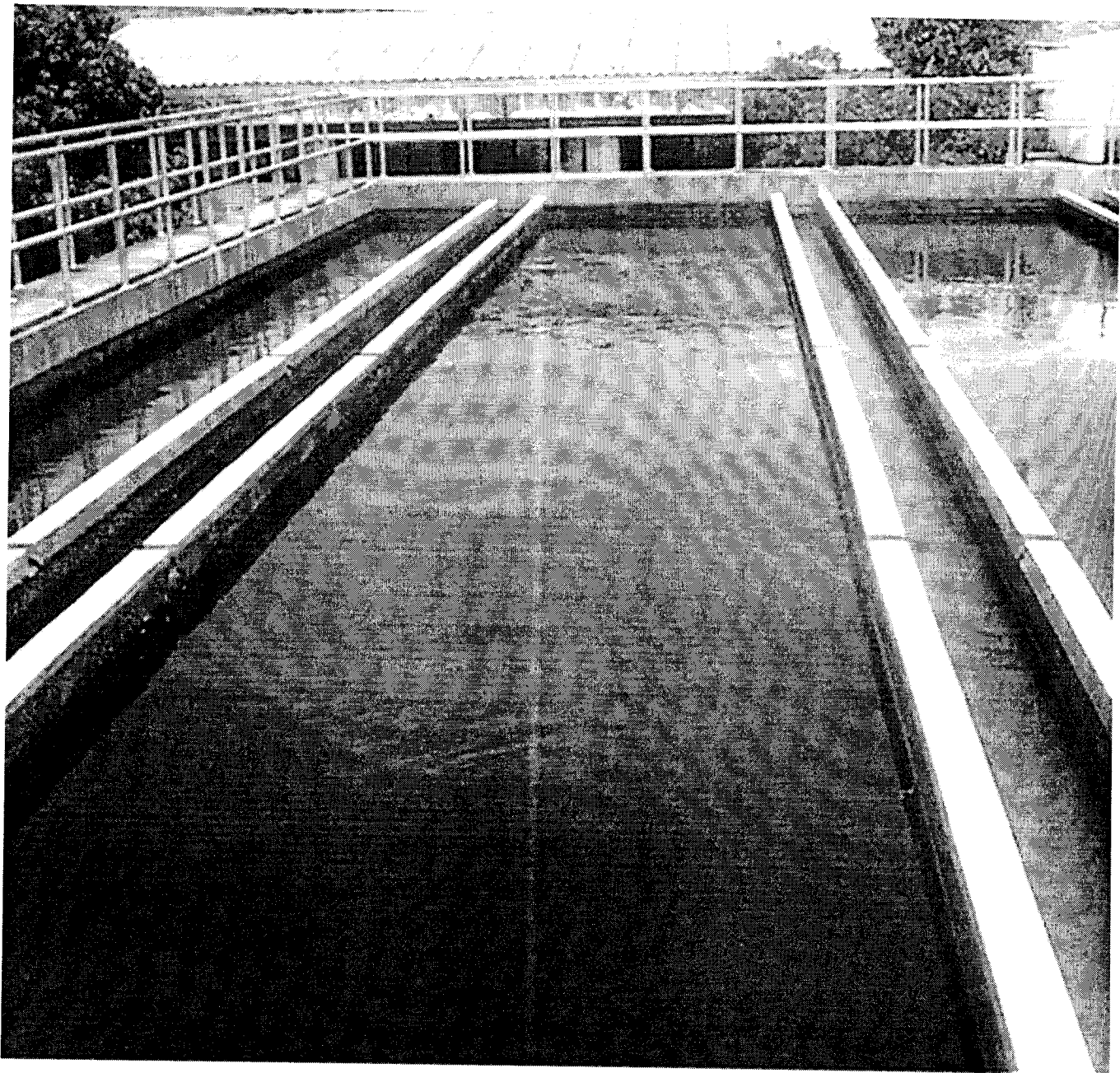


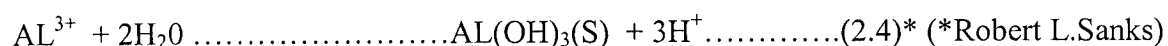
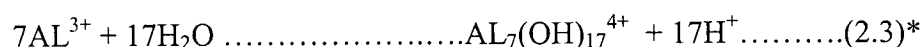
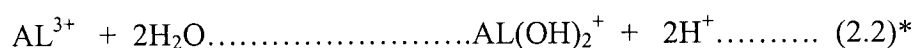
Figure 2.2 pictorial view of the sedimentation cell

HYDROLYSING METAL IONS

This process is associated with coagulation where before suspended matter in water can amass, the stabilization forces must be neutralized. The only useful method for

destabilizing suspended particles is the addition of chemicals. The chemicals normally employed for this purpose are inorganic salts of iron or aluminum.

Aluminum sulphate, $\text{Al}(\text{SO}_4)_3$, when added to water dissolves readily. The sulphate ions disperse throughout the liquid simply as SO_4^- ion. The Aluminum ion reacts with water or hydrolyses. In this simplest form the Aluminum ion is completely surrounded by six molecules and has three positive charges. This ion is represented as $\text{Al}(\text{H}_2\text{O})_6^{3+}$. However, under the PH conditions used in all water treatment processes the trivalent Aluminum ions react (hydrolyze) immediately to form many different species such as the following:



The hydrolysis of AL and Fe salts liberates H-ions as shown above. Acid is formed, the PH is lowered.

COAGULANT AIDS

Bentonite clays

Clays are used in conjunction with iron or aluminum salts in the following

- raw water turbidities of less than 50 TU
- color removal
- treating waters with low mineral content

In the first situation, the addition of the clay particles increases the probability of collision among the floc particles. This helps build larger, more settleable floc. In the second and third examples, the inorganic salts tend to form a light floc that does not settle rapidly. The clay combines with floc particles and adds weight to them, which results in an increased settling rate.

COLOR

Color in water is due to primarily to the presence of natural organic matter. This in turn is composed largely of humic and fulvic acids. Humic a strong acid is that component which is soluble in a strong base but insoluble in a strong acid. Humic acids have

molecular weights ranging from several hundred to a few thousands. They can aggregate naturally into colloidal particles with much higher apparent molecular weights. They are composed primarily of aromatic compounds with carboxyl, phenol and quinoid groups'. Fulvic acids are similar in structure to humic acids but have lower molecular weights. Due to their carboxylic and phenol groups, humic substances have high cation exchange capacities and can concentrate or bind metal ions. Because of their organic character, they can also accumulate hydrophobic organic compounds, including several pesticides

Humic substances react with positively charged monomeric and polymeric aluminum hydrolysis products to form colloidal precipitates. These are then aggregated further into larger flocs by additional aluminum species that act as destabilizing agent. Because of the stoichiometry involved in precipitation and coagulation by adsorption, the alum dose required is normally dependant on the concentration of the color.

There are three forms in which particles settle in the sedimentations tanks.

SETTLING OF DISCRETE PARTICLES.

This occurs to particles that do not change in size, shape or mass during settling and which do not influence each other by being too close to each other. For a spherical particle and for the condition of laminar flow we have the following terminal velocity.

$$V_s = \frac{g d^2 (s-1)}{18n} \dots\dots\dots (2.5)$$

Where d =diameter of the particle

s = specific gravity of the particle

n = kinematics viscosity (function of temperature)

g = gravitational constant

V_s = terminal velocity

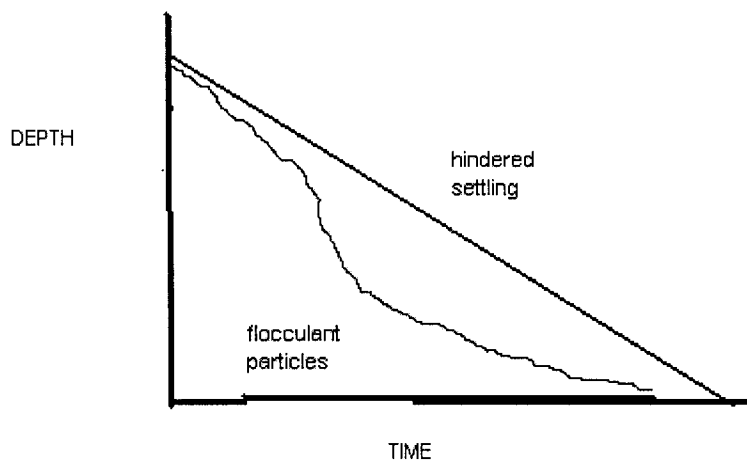
A discrete particle that is freely falling through a quiescent liquid of lower density will accelerate until the friction resistance or drag of the fluid equals the gravitational force

acting on the particle. From there on the particle settles with a uniform velocity which is called velocity.

HINDERED VELOCITY

The liquid displaced by the particles can thus move upward undisturbed. However, when the particles are spaced very close to each other, the displaced liquid is confined as a pipe and additional friction is caused. This reduces settling velocities. Hindered settling becomes noticeable in the river water after heavy rains.

FLOCCULANT VELOCITY: The shape, size and mass of a particle are not constant. The shape and size change as flocculation takes place. This makes the particle to increase in weight making it heavier than that of water and as such settles to the bottom of the sedimentation tanks.



SETTLING OF FLOCCULANT SUSPENSIONS

Figure 2.3 diagrammatic representation of settling velocity

When the PH gets too low the flocculation will not be good enough or simply will not take place at all. If there is enough alkalinity in water, the H-ions will react with the alkalinity and the change in PH will not be significant. As such a buffer solution is needed. Lime is normally used for this purpose

The figure below summarizes in schematic form the predominant mechanisms in coagulation. An analysis of the kinematics of the reactions is especially important. Coagulation in water treatment occurs predominantly by two mechanisms:

- (a) Adsorption of the soluble hydrolysis species on the colloid and destabilization
- (b) Sweep coagulation where the colloid is trapped within the precipitating aluminum hydroxide.

The reactions in adsorption-destabilization are extremely fast and occur within microseconds without formations of polymers and within 1 second if polymers are formed. Sweep coagulation is slower and occurs in the range of 1-7 seconds.

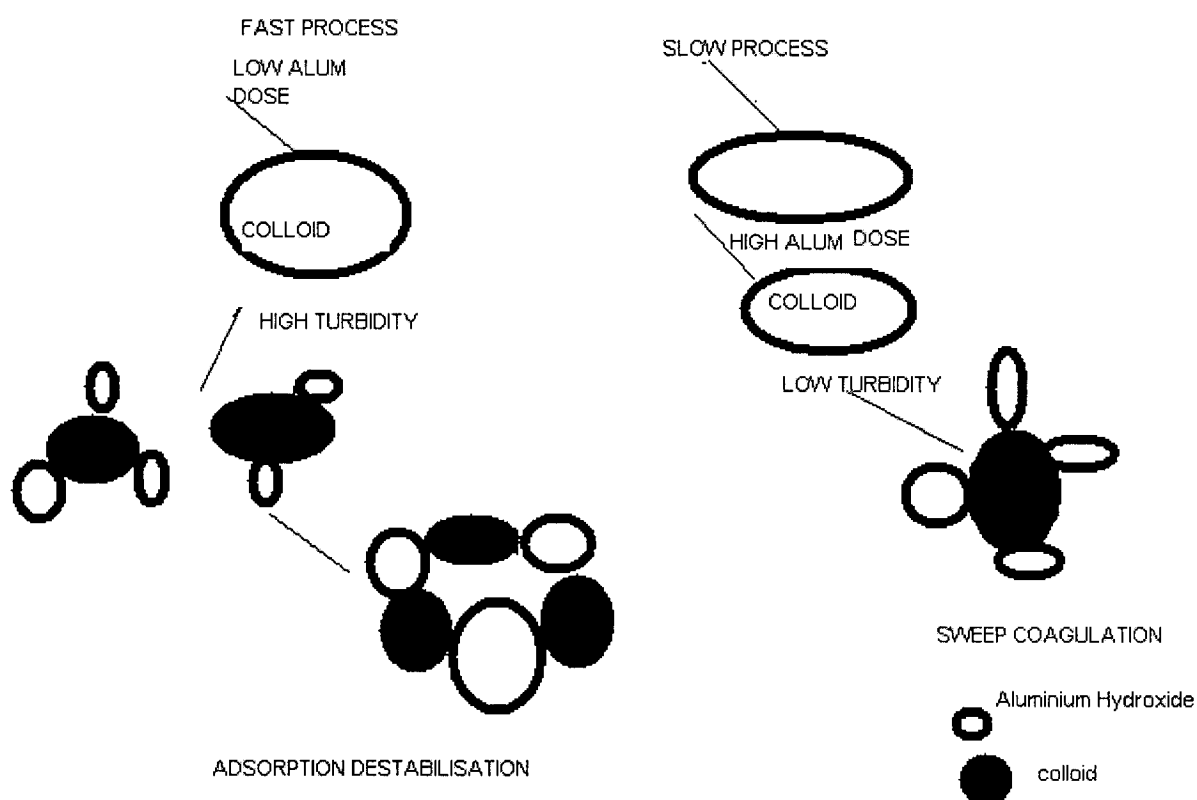
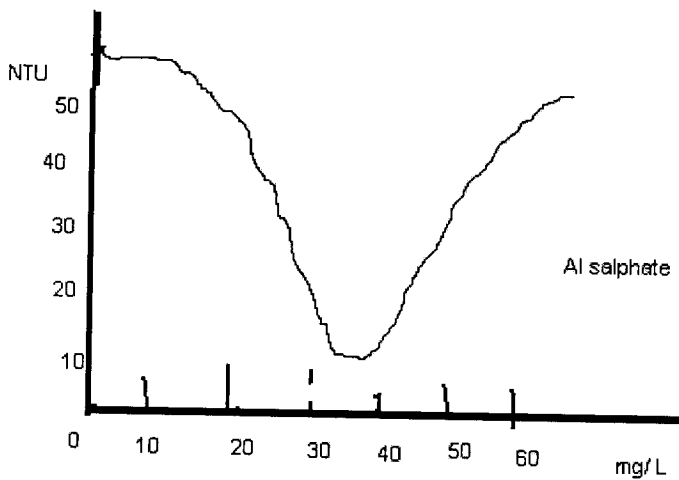


Figure 2.4 diagrammatic representation of coagulation (A.C.Twort)

FLOCCULATION TANKS

Flocculation tanks are designed to produce collisions between particles. Generally these collisions occur by fluid motion. Differences in velocities occur from point to point in all flowing or stirred water. Due to these velocity gradients particles suspended in water also have different velocities and hence can come into contact. Velocity gradients are induced by mechanical or hydraulic mixing.

COAGULATION TEST.



JAR TEST RESULTS: OPTIMUM COAGULATION DOSE

Figure 2.5 (Robert L.Sanks)

The amount of coagulation necessary to clarify a given raw water cannot be predicted theoretically, nor can the exact value of the optimum PH. The data have to be found by tests called jar tests. (Robert L.Sanks)

(2) Methods of removing dissolved impurities

FILTRATION

Filtration is a unit operation for the removal of suspended solids and under certain conditions, also of colloids and microorganisms from water.

Three basic filtration units commonly used are, vacuum, pressure and gravity filters.

Gravity filters are divided into two main categories. The slow and rapid sand filters. However, it is the rapid sand filter that attention shall be focused on as this is the one in use at Kafue treatment plant. Its layer depth varies between 1.8 to 2.5m at top and 75mm gravel of 13 to 6mm grain size.

When water containing suspended solids is passed through a layer of porous media, some of the suspended materials are partially or completely remove. The rate of flow through a media is directly proportional to the driving force and inversely proportional to the resistance of the filter media and the solids retained therein. The driving force is measured by the water head available to overcome the filter resistance.

The head available is measured by the difference in water level above the filter media and in the clear well to which the filter effluent discharges. If the effluent water discharge elevation is higher than the media surface the pressure in media is always higher than the atmospheric pressure. If the effluent water discharge location is below surface media elevation a condition of negative head can develop in which the pressure whin the media filter can be less than the atmospheric.

The overall removal of suspended matter is by a combination of different phenomena which include

- mechanical straining
- sedimentation
- adsorption
- chemical and biological activities

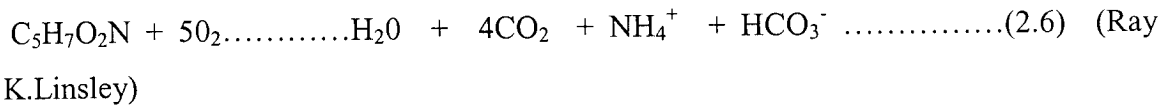
Mechanical straining: This is the removal of suspended matter larger than the pores between sand grains. It takes place at the surface of filter bed and is independent of the rate of filtration.

Sedimentation: This is the removal of particulate suspended matter of finer sizes than pore openings. These particulate matter precipitate upon the sides of the sand grains

Adsorption: This process removes colloidal and molecular dissolved impurities. These adhere to the sticky gelatinous coating formed on the filtering material by previously deposited bacteria and colloidal matter.

Chemical activity: In this process dissolved impurities are either broken down into simpler, less harmful substances or converted into insoluble compounds after which

straining, sedimentation and adsorption may remove them from the flowing water. For instance, in the presence of oxygen organic matter can be aerobically degraded as follows



The carbon dioxide formed stays in the solution to be discharged in the effluent.

Biological activity: This is brought about by micro-organisms living on and in the filter bed. Bacteria in water are adsorbed on the sand grain where they multiply.

2.1.0 HEAD LOSS

If the filter does clarify suspensions that flow through them, it follows that the pores of the media accumulate deposits that can cause either a loss of permeability or an increased flow resistance. The head loss development equations indicate first that for a specific media and flow rate head loss depends only on the volume of the floc retained by the filter and secondly that the time to reach a fixed head loss depends only on the volume of the formed suspended solids in the raw water and the added chemicals.

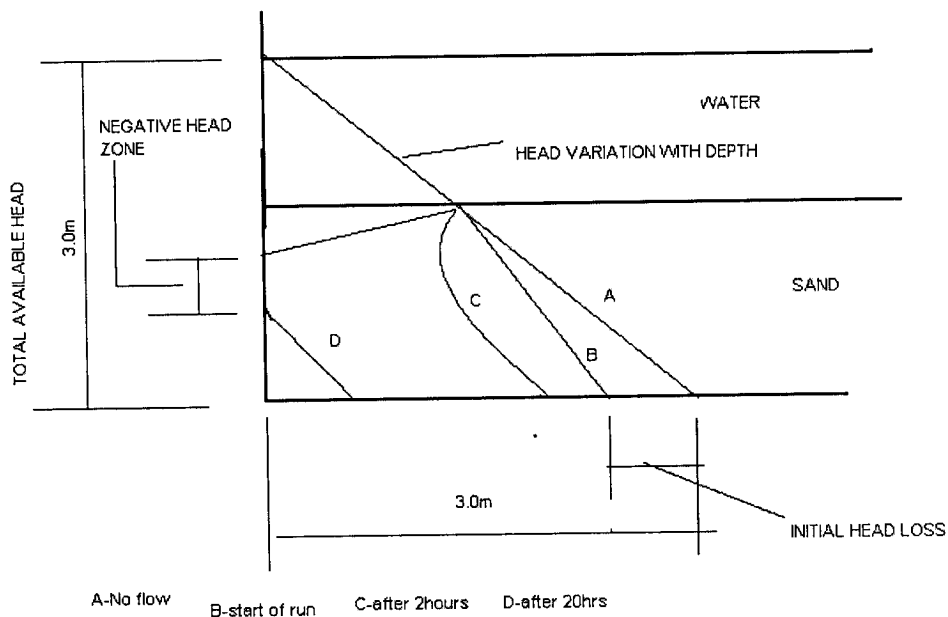


Figure 2.6 NEGATIVE PRESSURE HEAD

As filtration progresses the suspended solids removed are retained in the filter pores and the flow resistance increases which in turn decreases the pressure (driving force) available for maintaining the flow rate. The pressure distribution within the media of a typical gravity filter at various stages of a filter run is illustrated above. Negative head (less than atmospheric) can occur in a gravity filter when summation of the head loss from the sand surface downwards exceeds the pressure available. The objection of negative pressure is the danger of forming air pockets in the zone of negative pressure. Air pockets reduce effective filtering area; increase the local flow rate and head loss, and might result in serious degradation of filtrate quality.

MEDIA BACKWASHING

The principal problems in filter operations are associated with maintaining the filter bed in good condition. Inadequate cleaning leaves a thin layer of compressible dirt or floc around each grain of the media. Because pressure drop across the filter media increases during the subsequent filter run, the grains are squeezed together and cracks may form in the surface of the media, usually along the walls first. The heavier deposits of solids near the surface of the media break into pieces during the backwash. These pieces called mud balls may not disintegrate during the backwash. If small enough and of low density, they float on the surface of the fluidized media. If large or heavier they may sink into the filter to the bottom.

2.1.1 FACTORS AFFECTING SAND FILTER PERFORMANCE

Pretreatment: most of the suspended solids in water must be removed to prevent them from clogging the filter. Screens and other pretreatment units must be designed and operated properly and receive regular maintenance.

Media: Composition, size, uniformity and depth of the media all affect sand filter performance. Characteristics of the media's composition such as its solubility, acidity and hardness must be considered. The size and uniformity of the grains are measured through a series of mechanical sieves. The grains must be relatively uniform in size to prevent clogging

Organic loading: organic rate depends on the strength of water. High strength implies water containing high levels of organic material and can reduce the filter performance over time and increase the need for maintenance

Hydraulic loading rate: this is the amount of water applied to a filter surface in one day. Sand filters are less effective at removing certain pathogens from water at high hydraulic loading rates.

(3) Methods of removing disease producing bacteria (disinfection)

-Treatment with chlorine or its compounds

TREATMENT WITH CHLORINE

The primary objectives of the chlorination processes are-

2.1.2 DESINFECTION

The problem of delivering palatable and safe water to the consumer does not end as the water leaves the treatment plant. There are multitudes of difficulties in maintaining water quality in transmission conduits and distribution systems. The problems of water quality control in distribution are of two types. Probably the most prevalent is complaints about taste, odour and dirty water. The other is deterioration of bacteriological quality.

Chlorination is a unit operation for the disinfection of water. Disinfection means the destruction or inactivation of pathogenic microorganisms. Disinfected water is free from microorganisms whilst sterile water does not contain any microorganisms. This is not required for drinking water.

Chlorine for water treatment is applied in two forms, as gaseous elemental chlorine or as a salt of hypochlorous acid (hypo chlorites). The latter is restricted to small supplies of water whilst the former is best suited for huge water supplies like towns.

In general any chlorine gas installation will consist of the following essential parts.

- Chlorine gas supply- gas cylinder
- Metering and control system
- Injection system

Adequate residence time for a chlorine residual in a potable water is readily achieved both in long transmission lines and treatment plant processes. This is not true in small systems where water is pumped directly into the distribution system. Contact time should be consistent with the requirements for enteric virus inactivation.

BACTERICIDAL ACTION OF CHLORINE

Very small amounts of chlorine dissolve in water (less than 1mg\L) are already effective as a disinfectant. These concentrations are not toxic for man or other animals, they are also not corrosive. At concentrations greater than 0.3mg\L a characteristic taste and smell of water may be detectable. Chlorine kills bacteria by diffusion through the walls of the cell and reacting with important enzymes. Thus it inhibits the metabolism of the cell. The disinfection is a function of the following;

- concentration time (the longer the better)

- concentration of chlorine (the higher the better)

- PH of the water (the lower the faster)

- Temperature of the water (the higher the faster)

The effect of contact time is such that the number of organisms destroyed per unit time is proportional to the number of organisms remaining alive. In other words the more the number decreases the slower the die away. The exponential relation ship which describes this phenomenon is

$$N_t = N_0 e^{-kt} \dots\dots\dots (2.7)$$

N_t = number of survivors

N_0 = Original number of organisms

K = reaction constant depending on variables

When chlorine gas is dissolved in water the following happens

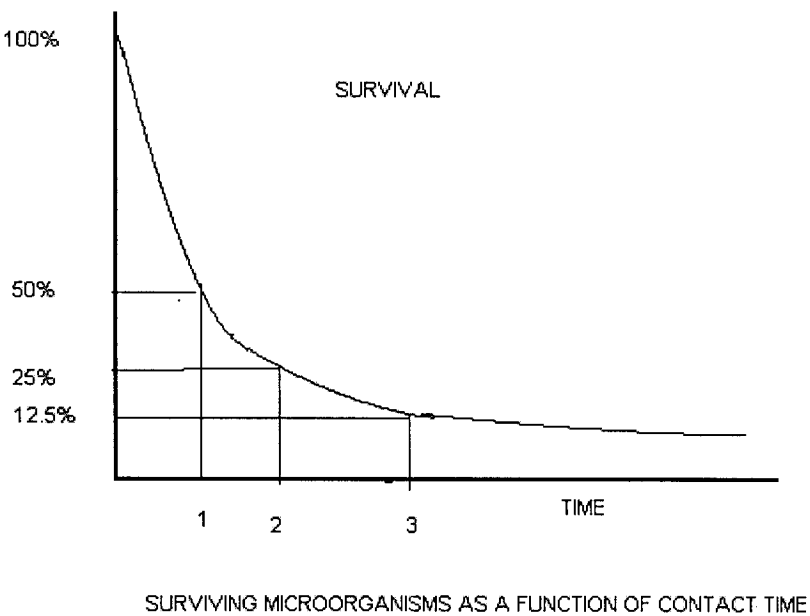
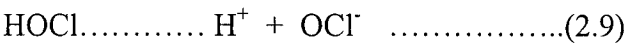


Figure 2.7



This reaction is known as hydrolysis. If the chlorine is small the reaction is almost complete. All elemental Cl_2 is converted into HOCL, the hypochlorous acid and HCL. HOCL is the actual disinfectant in water (hypochlorous acid)
The amount of HOCL is the FREE AVAILABLE CHLORINE in water.
The HOCL is a weak acid and partially ionizes in water.



The hypochlorite ion OCl^- is much less effective in destroying bacteria than the HOCL molecule. At higher PH values the species OCl^- prevails and only little of HOCL is available. The amount of chlorine consumed by various substances reacting with it is known as CHLORINE

DEMAND. A particular chlorine dosage produces a particular chlorine residue after a given contact time.

$$CL_{\text{dose}} - CL_{\text{residue}} = CL_{\text{demand}} \dots \dots \dots (2.20)$$

The goal of chlorination is not only to destroy bacteria from water source but also to maintain a free residue amount throughout the distribution system. Secondary pollution that may enter the system should be counteracted. At the end of the distribution system a concentration of 0.2-0.5mg/l should be present.

2.1.3 POPULATION AND WATER DEMAND FORECASTING

Whether a water distribution is being designed or improved, one of the most important aspects to consider is the expected rise in population of the community to be supplied and subsequently the corresponding rise in water demand. This entails determination of the number of people to be served and their per capital water consumption. The amount of water consumed by a community is usually expressed as consumption per capital.

$$\text{Consumption} = \frac{\text{daily water consumption}}{\text{Population to be served}}$$

Nonetheless, it is convenient for many purposes to use the average daily consumption

$$\text{Average daily consumption} = \frac{\text{Total daily average water demand for a year}}{\text{Population to be served}}$$

If anyone has a private water supply, incorporating such an individual in the above calculations will result in gross inaccuracies. The daily consumption per person served would in this case be more accurate.

POPULATION FORCASING

The water demand for any given population will increase as its population increases. Water supply systems are designed in such a way that they are able to service a given community for a given period (projected period). From the fore gone discussing, it is clear the design engineer for any water undertaking should be able to forecast as accurately as population of a given community to a design year.

Estimating the population at some given year can be difficult in that the engineer should exercise a lot of judgment of the factors that may affect population growth. The engineer's judgment is also required in deciding which of the available methods for population forecasting should be used. It is important that the environment of the community for which population is to be forecasted be known because factors such as the community's trade territory, industrial activity and growth, state of development in the surrounding country side, the positioning of the community with respect to other communities especially metropolitans, the location of the community with respect to other rail lines will all enter the fore casing process.

No matter how accurate the population forecasting process may be, the future still remains unknown for certainty because of the possibility of extraordinary events that can happen. A discovery of mines, oil fields or sudden change in the economy of a community can change the pattern of population growth of that particular community. The forecasted population should therefore be taken as indicative and not as absolute.

Of the methods available for population forecasting, the following are going to be considered.

(a) ARITHMETIC METHOD

This is arguably the simplest of all methods. It is based on the assumption that the population of a given community increases at a constant rate.

$$\frac{dP}{dt} = K = \text{rate of change of population with time} \dots\dots\dots(2.11)$$

K = constant can be determined graphically or from actual successive population figures

Examining the population growth of a community for equal increments can test the constant growth assumption. The population at a future time t can then be estimated from

$$P_t = P_o + Kt \dots\dots\dots (2.12)$$

Where P_t = population at a future time t

P_o = present population

t = period of the projection

K = constant

(b) UNIFORM PERCENTAGE METHOD

This method assumes a rate of growth which is proportional to the population

$$\frac{dp}{dt} = K'P \dots\dots\dots (2.13)$$

$$K' = \frac{\ln P - \ln P_o}{\Delta t} \dots\dots\dots (2.14)$$

P and P_o are populations separated by time interval Δt

K' can also be determined by plotting recorded growth on a semi-log graph from the best fit-line K' can be determined as the slope of the graph.

(C) CURVILINEAR METHOD

This method is based on the basis of comparison of the population growth of a given community to larger communities that are very similar in a lot or respects to the community being considered. The similarities can be in aspects such as geographical proximity, economic base, transportation systems and other factors. The assumption is that the community under consideration will grow in a similar fashion as the larger communities that it resembles.

(d) LOGISTIC METHOD

The hypothesis of logistic growth is based on the assumption that the community has a limiting saturation population and the population P at time t can be given by

$$P = \frac{P_{sat}}{1 + e^{a + b \Delta t}} \dots\dots\dots (2.15)$$

Where P_{sat} = saturation population of the community

$a, b = \text{constant}$

Plotting recorded population figures on a logistic paper can test the hypothesis of the logistic growth. If a straight line is produced, the hypothesis is valid for that particular population growth. Saturation population , the constants a and b can be determined from three successive census figures.

$$P_{sat} = \frac{2P_1P_2P_3 - P_2^2(P_1 + P_3)}{P_1P_3 - P_2^2} \dots\dots\dots (2.16)$$

$$a = \text{Ln} \frac{P_{sat} - P_1}{P_1} \dots\dots\dots (2.17)$$

$$b = \frac{1}{n} \text{Ln} \frac{P_1(P_{sat} - P_2)}{P_2 (P_{sat} - P_1)} \dots\dots\dots (2.18)$$

Where n is the time interval between successive census counts.

(e) DECLINING GROWTH METHOD

This method is based on the assumption that the community has a limiting population and that its rate of growth is a function of its population deficit to the saturation population.

$$\frac{dP}{dt} = K''(P_{sat} - P) \dots\dots\dots(2.19)$$

The saturation population is estimated from some rational basis as remaining land for development (industrial and residential) and the existing population density.

$$K'' = - \frac{1}{n} \text{Ln} \frac{P_{sat} - P}{P_{sat} - P_o} \dots\dots\dots(2.20)$$

$$P = P_o + (P_{sat} - P_o)(1 - e^{K''\Delta t}) \dots\dots\dots(2.21)$$

Where P and Po are population figures recorded at interval of n years apart.

(f) RATIO METHOD

This particular method is based on the hypothesis that population growth will maintain a specific trend in the change of the ratio of its population to that globe entity (country) to which it belongs. For this method to be used calculations of the ratio of the community population to the country in a series of census counts have to be made and a trend line produced from the calculated ratios. From the produced trend line, the ratio in the year of interest can be obtained.

For short-term period forecasting methods may most likely prove to be right as the line of extrapolation represents both the current rate of growth of the population and also the increase of consumption per capital. The other two methods involve making assumptions about both the population and per capital consumption and so errors can multiply. If a forecast is to be made for a very long time or if large increases of population due to migration and other factors are involved, one of the paramount factors to consider is the per capital consumption for different classes of population over the years ahead. If there

will be changes in the pricing policy of water, these should be taken into account as the cost of water as a bearing on its demand.

Whatever method is used, the projection of population is of importance in the design of any water supply undertaking. If the population is grossly under estimated, the supply system can soon become inadequate (before the projected period). On the other hand, if the population is grossly over estimated, an extremely over sized water supply will mean unwarranted high unit costs on the community and this cost can be so high that it can even stifle the development of the much needed water supply system.

WATER DEMAND

Water demand can simply be defined as the amount of water asked for by a given community within certain periods of time under given conditions. It is usually expressed as a flow e.g. m^3/sec or l/c/d . Water demand should be differentiated from water consumption which is the amount of water that is actually drawn off the system. Water demand can be classified into the following categories

- (A) Domestic:-This is the water used for all purposes such as
drinking, washing, bathing, cooking and other uses.
car washing.
- (B) Commercial and Industrial:-This water used in industries and commercial plants.
- (C) Public: - This is water used for public purposes such as fire fighting, street watering, public gardens flushing and other uses of public nature.
- (D) Loss and Wastage:-Under this category falls water that is lost in leakages from the mains and connections, leakages and outflows from service Reservoirs-uncounted for water.

It is difficult to accurately get measurements of consumption because standards of water of supply and maintenance vary considerably throughout the world. Water losses can range from 5% to as high as 55%. Factors that affect water supply includes

- (1) **The purpose for which water is used:-**The purpose for which water is used distinguishes it as domestic, industrial public etc.
- (2) **The type of users: -** Water consumption can vary according to the type of people that use the water. The differences can be based on culture, region, education, age, climate, technological advancement and other factors.

(3) **The value the consumer attaches to water:-**The circumstances under which water is used can also affect its demand. The circumstances include :-

- quality and quantity
- accessibility to water source
- i.e. Connection, public standpipe,
- distance for fetching and the cost of water

The above factors determine when and how water will be used.

WATER DELIVERY

The loss and waste category makes it necessary to produce or abstract more water than is required. The excess goes to serve the losses and waste. The amount pumped to satisfy demand, losses and waste is called WATER DELIVERY (Q_d).

It is given by

$$Q_d = Q_a / (1 - L/100) \dots\dots\dots(2.22)$$

Where Q_d = Water delivery

Q_a = Water demand

L = Losses and wastage (%)

DEMAND PROJECTION

The amount of water that will be required at a certain stage in future is very important parameter in the design of a new network or in improving an existing system so that it meets a future demand. Various methods can be used to forecast water demand. Several assessments must be taken into account whilst estimations for future demand are being made. These can be classified into the following groups.

- Projections of total consumption based on historical growth trends.
- Projections based on per capital consumption and population growth trends for domestic category
- Forecast based on assessment of growth trends of other main consumer categories (industries, commercial)

- Forecast based on developmental plans and programs.

Two models commonly used in calculation of demand trends.

- Linear model $Q_{i+n} = Q_i (1 + an/100) \dots\dots\dots(2.23)$

- Exponential model $Q_{i+n} = Q_i (1 + a/100)^n \dots\dots\dots(2.24)$

Where Q_i = Water demand at year “i”

Q^{i+n} = forecasted water demand after n years

n = design period in years

a = average annual growth rate during the design period.

CHAPTER TREE

3.0 CRITIQUES OF KAFUE TREATMENT PLANT

3.1 GENERAL

Kafue town water reticulation system abstracts its water from Kafue River. This river passes through the mining area of copper belt of Zambia where de-watering activities of the mines discharge their effluent into the river. In addition there is also the discharge of waste water into the river by Kafubu waste water treatment plant.

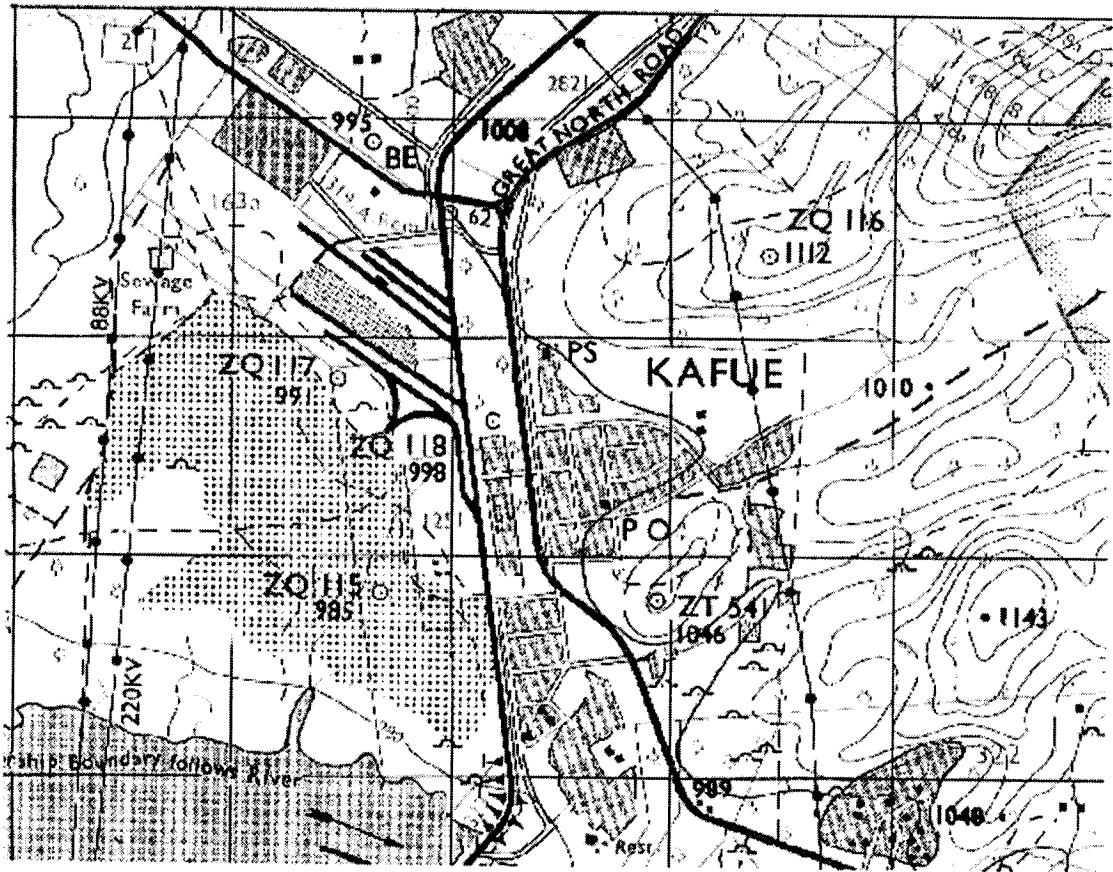


Figure 3.1 Shows location of Kafue town :(source: survey department)

Constituents are added to the flow. The river meanders its way through the flood plains such that at different stages of the river several mineral constituents are added to the flow. The need for this water to be treated before supplying it to the community cannot be overemphasized.

The town is situated in Lusaka province of Zambia and lies 50km south of Lusaka town. It lies on an altitude between 1030 and 1090m above sea level. However, for the past 15years or so the town has been experiencing erratic water supply whose appearance leaves much to be desired at times. The water works operation units were examined and notable short comings tabulated as below

3.2 NOTABLE SHORT COMINGS AND CORRESPONDING CURATIVE MEASURES

- (1) The sand in the filter has mud-mud balls
- (2) No laboratory
- (3) Pressure gauges for the filter beds disconnected
- (4) Sodium hypochlorite is administered to the filtrate in
under drain pipe system through the contact tank observation hole
by pouring five two grams of this chemical after one
hour.
- (5) Algae is seen in both sedimentation and sand filter
cells.
- (6) Alum and lime dosing pumps are either missing or have
been disconnected.
- (7) Customers complain of brown or black water.
- (8) Flooding of the pump house
- (9) The gas chlorinator unit has been disconnected.
- (10) Air bubbles in some of the filter cells
- (11) Various flow measuring meters are not functional
 - flow of raw water to the plant
 - flow to the balancing reservoir
- (12) At times the intake pumping rate is far much higher than the
treatment plant requirement

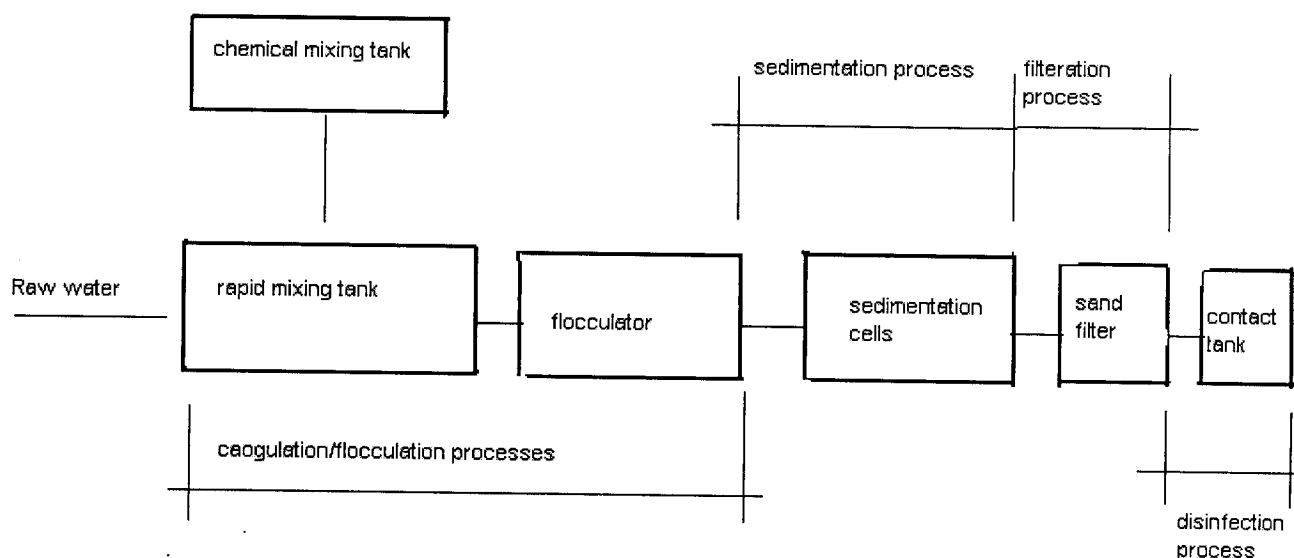


Figure 3.2 Layout of Kafue water treatment plant

MUD BALLS IN THE SAND FILTER

The principal problems in filter operation are associated with maintaining the filter beds in good condition. Inadequate cleaning of the filter leaves a thin layer of compressible dirt or floc around each grain of the media. Due to the pressure drop across the filter media which increases with subsequent filter runs, the grains are squeezed together and cracks may form in the surface of the media, usually along the walls first.

The heavier particles of solids are deposited near the surface of the media and eventually break into pieces during the backwash. These pieces, called mud balls, may not disintegrate during backwash. If small enough and of low density, they float on the surface of fluidized media. If larger or heavier, may sink into the filter to the bottom. Ultimately they must be broken up or removed from the filter because they will reduce filtration effectiveness or because shorter filter runs by dissipating available head loss.



Figure 3.3 shows a broken under drain nozzle

CURATIVE MEASURE

AIR SCOUR

This consists of the distribution of air over the entire area at the bottom of the filter media so that it flows upwards through the media. The air is used prior to the water backwash or concurrently with the water backwash. Air scour is introduced to the filter through a pipe system that is completely separate from the backwash water system. However air nozzles need replacement from time to time due to wear and tear caused by age and clogging. Apparently, air scouring is not very effective at Kafue water works.

NO LABORATORY

For efficient treatment and monitoring of the quality of water supply to the consumers the need for a laboratory can not be over emphasized. It is the diagnostic centre where prescriptions of what chemical and how much of it is to be added to make the water palatable for human consumption and indeed industrial use.

Emphasis is placed on the testing facilities for efficient treatment control and monitoring the more common water quality parameters rather than on performing routine chemical analyses.

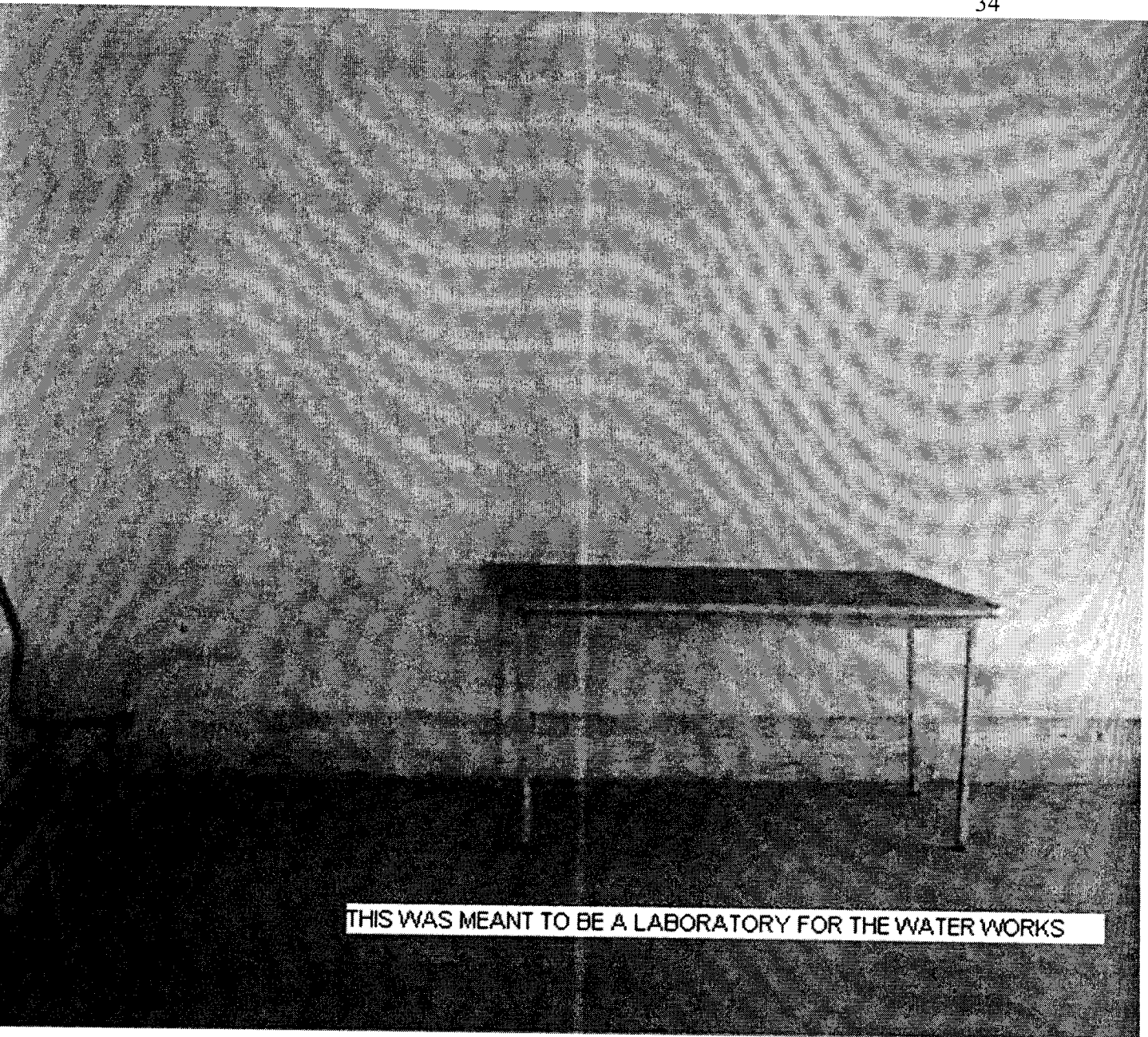


Figure 3.4

CURATIVE MEASURE

Although all water utilities should have fairly current chemical or mineral analyses available upon request, the small systems like Kafue plant should find it more economical to subcontract with a certified commercial laboratory of Lusaka Water and Sewerage Company.

PRESSURE GAUGES FOR THE FILTER CELLS

As filtration progresses, the suspended solids removed are retained in the filter pores and the flow resistance increases which in turn decreases the pressure available to maintain the flow rate. The pressure gauges will indicate at any given instance the pressure of the filter to ensure it does not reach the negative zones. Negative pressure is recorded when the summation of head loss from the sand surface downwards exceeds the available pressure. The objection of negative head is the danger of forming air pockets in the zone of negative pressure. Air pockets reduce the effective filtering area, increase the local flow rates and head loss, and might result in serious degradation of filtrate quality.

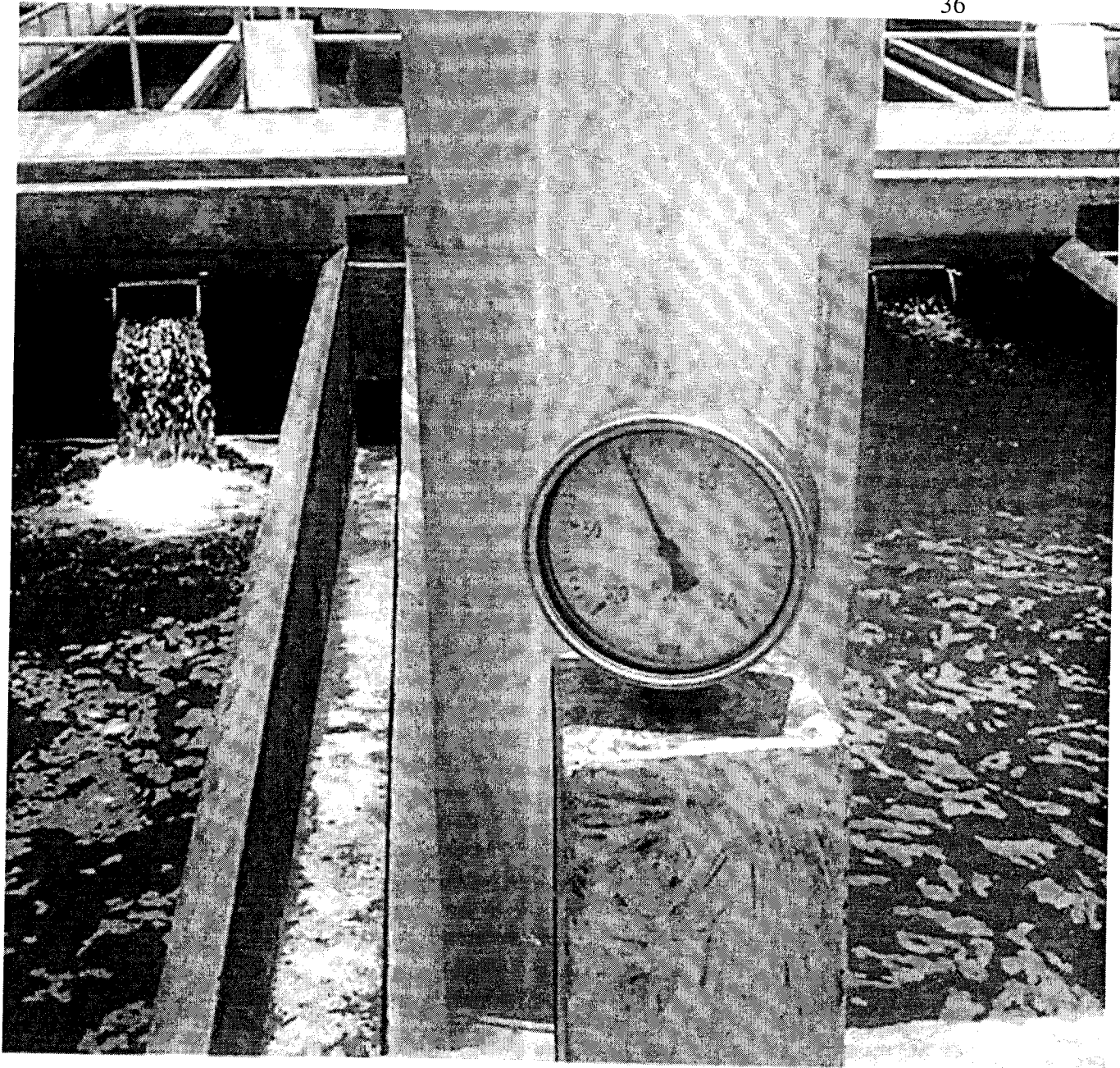


Figure 3.5 showing the sand filter pressure gauge

Replace or reconnect all the pressure gauges to the filter cells.

ADMINISTERING OF HYPOCHLORITE

Hypo chlorites are used in water chlorination particularly in small scale and emergency practice. They are salts of Hypochlorous acid and like acids, are stable when pure and are used therefore in an impure form. Decomposition of hypo chlorites is accelerated by the presence of acids and delayed by alkalis. Therefore stabilization is obtained by admixture with excess alkalis and hypo chlorites are more active in acids water than those which are alkaline. Common hypo chlorites in use in water chlorination include:-

- sodium solutions
- chlorides of lime

Hypochlorite solutions are caustic, corrosive and should be handled with care and splashing in the eye may cause serious injury. In water treatment, it is rubbed into suspension with a quantity of water, the solids allowed to settle and the supernatant solution then added to water to be treated. It should be borne in mind that the hypochlorite quantity to be added is done through calculations with reference to the characteristics of water to be treated. The characteristics of water to be treated vary from time to time and as such the idea of fixing it at five two grams of hypochlorite per hour does not hold in treatment of water. There is also the sludge that settles or because of administering it in the under drain system where the flow is turbulent is kept in suspension. This is likely to settle in the contact tank or pumped to the balancing reservoir where they will settle. A stream of water between one dosage of hypochlorite and the next has no chlorine whatsoever.

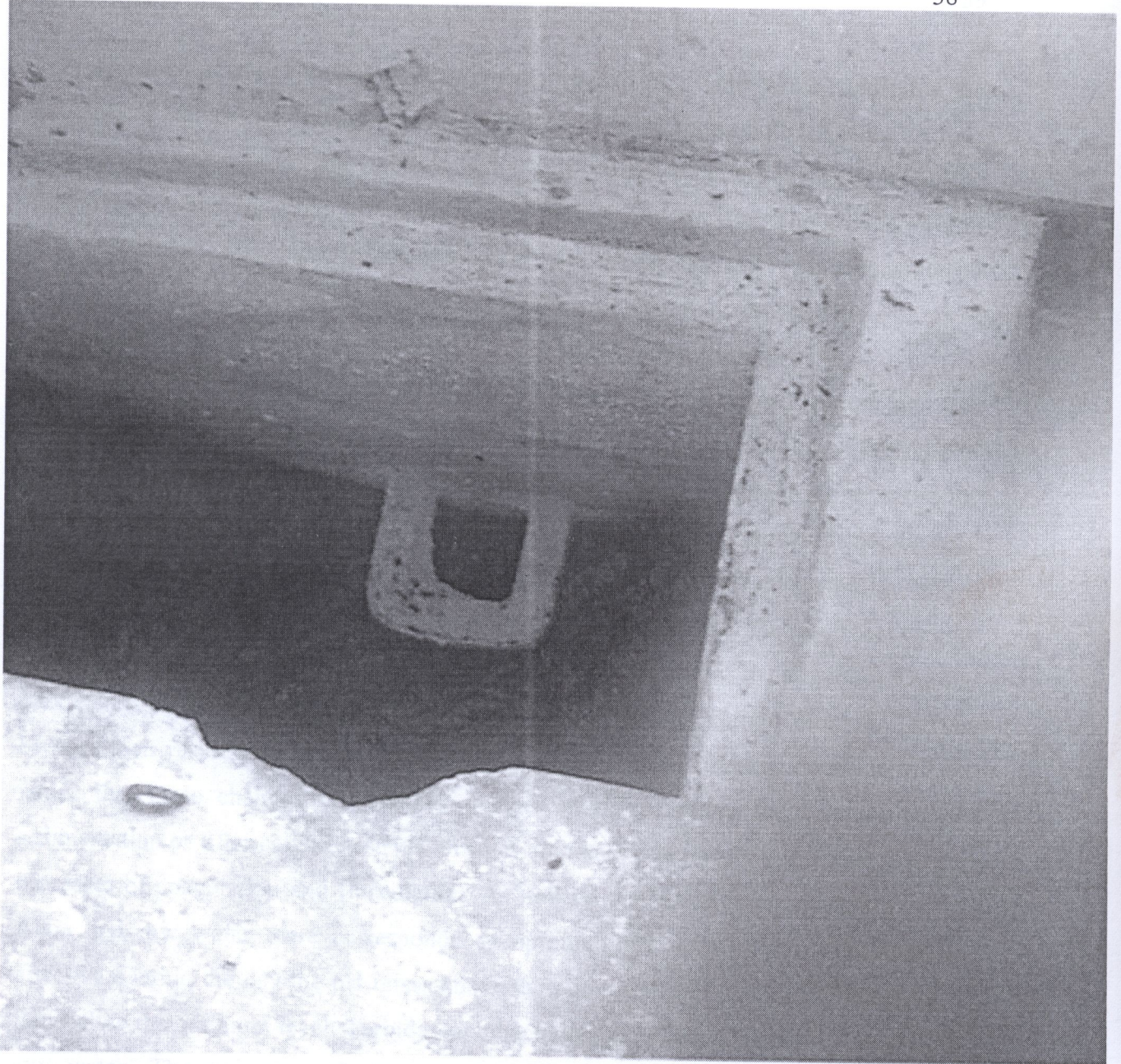


Figure 3.5 shows the contact tank observation hole where chlorine is administered.

CURATIVE MEASURE

Find a means of first making a solution of hypochlorite solution with water. The concentration of the supernatant should be known. Then administer this supernatant to water at a rate that will meet the chlorine demand of that water as well as leave enough as residue chlorine. Alternatively, resort to gas chlorination as all the infrastructure is there at the treatment plant.

The life which develops in waters of sedimentation and filter cells when exposed to the atmosphere and sunlight consists of vegetation and animal forms both of which include macroscopic and microscopic varieties. Initially, algae and fungi are microscopic but by multiplication and aggregation they produce readily visible growths. The growth of both fungi and algae is influenced by seasonal conditions, the mineral and organic constituents of the water. The undue prevalence or multiplication in water may give rise to serious difficulties like Clogging of filters and production of turbidity

Algae are free floating microscopic plants and animals known as Plankton and are divided into many classes. They are found in the free floating and clinging varieties. The clinging type will embed itself into pores and crevices in concrete and is more persistent. Algae use carbon dioxide in their photosynthetic activity and this removal is responsible for such high pH condition. An alga reduces the free carbon dioxide concentration below its equilibrium concentration and consequently forms a change with the result that carbon dioxide is extracted for algae growth both from bicarbonates and from carbonates. During dark hours of the day algae reproduce rather than consume carbon dioxide. This is because their respiratory process in darkness exceeds photosynthetic process. It will be notice that these changes bring about changes in pH of either the solution in the sedimentation or filter cells. These pH changes are undesirable as they interfere with the processes of coagulation and flocculation. As noticed that for a given concentration of Alum and raw water there corresponds an optimum pH where hydrolysis Alum is effective. During the day the pH raises above the optimum level and during the night it falls below the optimum level. Turbidity and bacteria are not significantly removed from raw water. The presence of algae in the filter cells necessitates more frequent backwashing due to the clogging of the filter beds.

CURATIVE MEASURES

Pre-chlorinating of the water to be treated will prevent the growth of algae in both the sedimentation and filter cells in additional to its bactericidal action.

DISCONNECTION OF ALUM AND LIME DOSING PUMPS

Coagulants and alkali are dissolved separately in small tanks popularly known as mixing chambers. Concentrated solutions are prepared in these structures. The mixing is brought about by agitators which in turn are turned by pumps. The dissolved coagulants are corrosive because the PH is low.

Solutions prepared in dissolving tanks flow by gravity into larger storage tanks. From the storage tanks, the dosing pumps will inject the chemicals onto a continuous stream flow of water. These include Alum dosing pumps and lime pumps. It is apparent that calculated concentrations and flow rates can easily be monitored and controlled .

DOSING BY GRAVITY: The current practice at the plant is to let the chemicals flow from the mixing tanks directly through pipes into the sedimentation cells. From continuity equation

$$A_1 V_1 = A_2 V_2 = A_3 V_3 \dots \text{etc} \dots \dots \dots (3.1)$$

$$\text{But } V = (2gh)^{0.5} \dots \dots \dots (3.2)$$

Where V = the velocity of chemical to be dosed

A = the cross- sectional area of the pipe outlet from the chemical mixing tank

g = gravitational pull

h = height of solution in the mixing tank

Rates of flow from the tanks are dependant on the heights of these tanks. It can be seen from the continuity equation that the rate of flow varies with height and as such metering of chemicals is not possible. Furthermore directing the flow straight into the sedimentation cells does not give optimum time for coagulation and flocculation. In the absence of these processes turbidity is not removed. The only particles that are removed are those which are in suspension and denser than water.

LIMING: This added to water so as to give water the capacity to neutralize the acids. Processes such as corrosion control in pipes, coagulation and PH changes during aeration of water require lime. As regards to the plant in question this is not done at all and the dosing facilities have been disconnected. In short there is no means of regulating the PH.

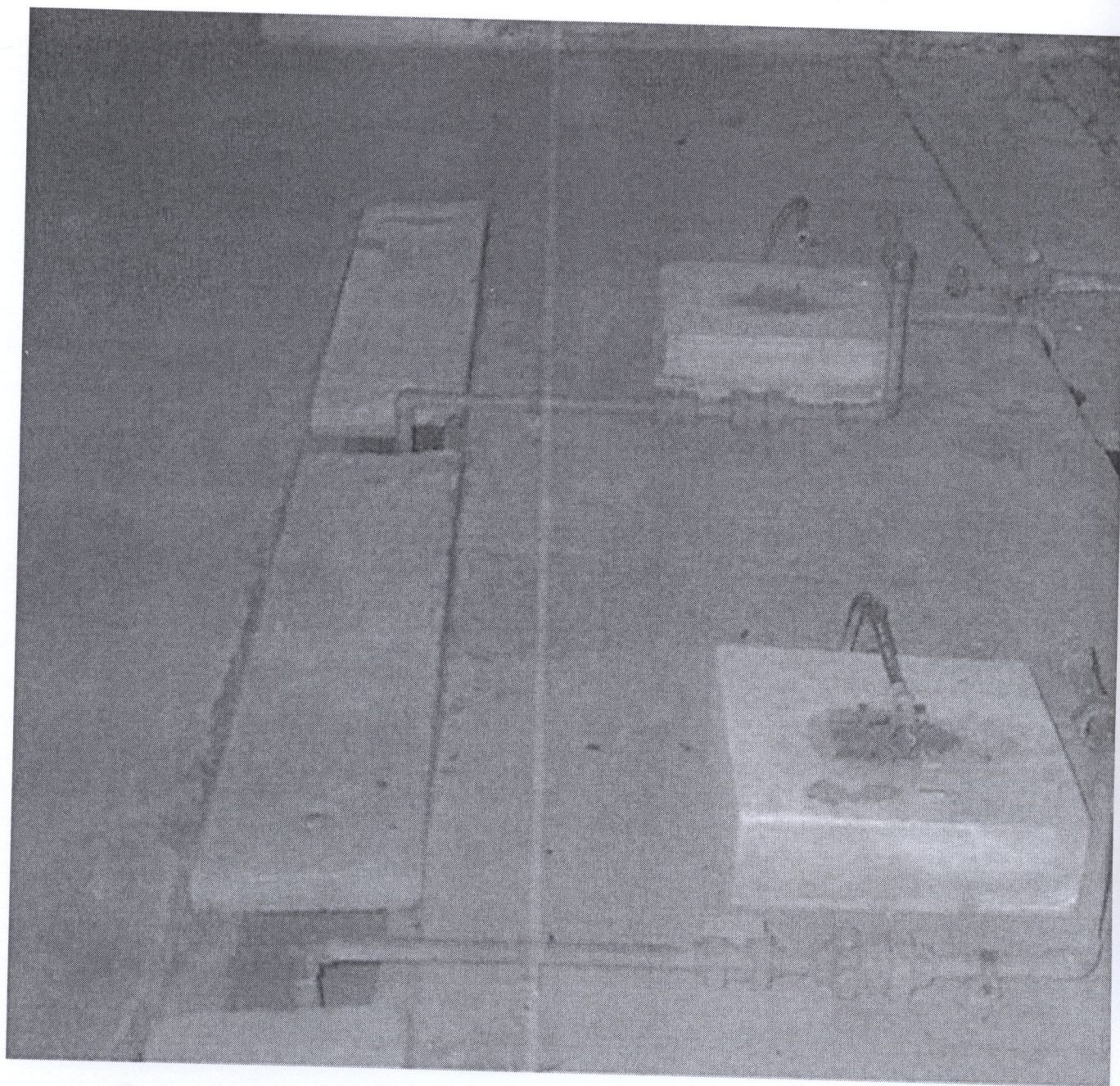


Figure 3.5 shows dosing pump house stripped off of the pumps

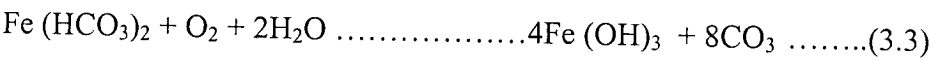
CURATIVE MEASURES

All the dosing and chemical mixing pumps should be connected back into the Plant treatment system,

BROWN OR BLACK COLORATION OF DRINKING WATER

Many deep wells and boreholes in the cretaceous water bearing formations such as the chalk yield slightly ferruginous waters which require treatment to render them suitable for public use. .

Iron is dissolved in the form of ferrocious usually bicarbonate but may also be found as oxides. The exposure of water to air results in the oxidation of soluble bicarbonate to insoluble ferric oxide.



The presence of iron and manganese in water is objectionable owing to the production of discoloration, turbidity, deposit and taste. Iron in water causes brown-colored deposition. It is objectionable for laundry purposes and gives rise to iron-molding of linen and other fabrics being washed.

Water containing manganese will give black coloration to water upon exposure to air. Small traces of iron and manganese give rise to accumulation of appreciable deposits in the distribution mains and reservoirs. In such conditions growth of iron bacteria often develops in the distribution system.

CURATIVE MEASURE

Laboratory tests for the presence of manganese and iron showed insignificant quantities of these. This implies that the distribution system should to be checked for possible causes of coloration. However, this is outside the scope of this project.

INTAKE PUMPING RATE FAR MUCH HIGHER THAN WATER WORKS REQUIREMENT

43

This causes loss in terms of chemicals, wear and tear on machinery, labor and electricity costs. As shown in the picture below, the excess water from the sand filter gushes out back to the river.

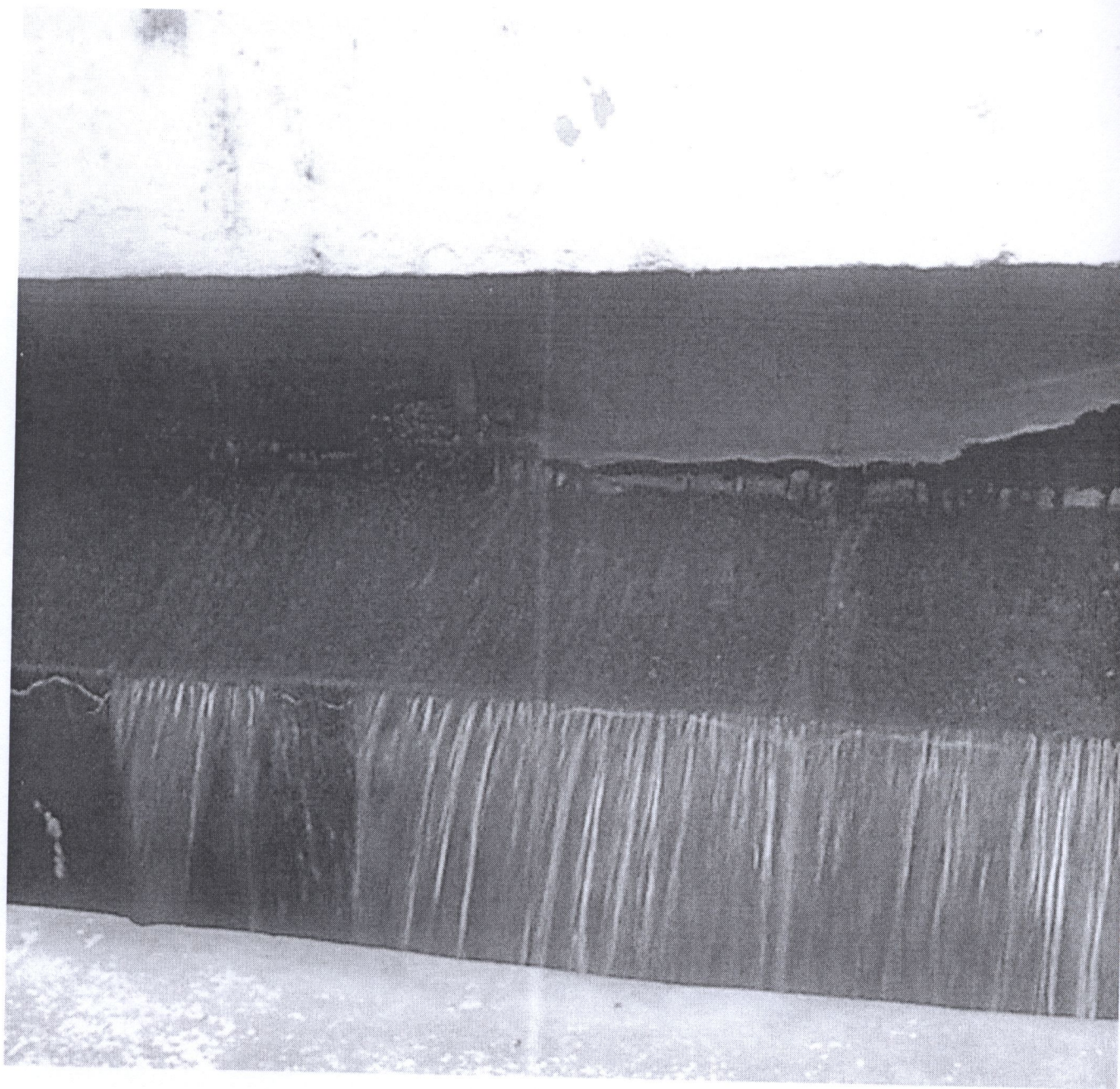


Figure 3.6 Shows the over flow of water from the filter cells.

Regulate the intake water works pumping rate such that it is slightly above the plant treatment capacity.

4.2 POPULATION ESTIMATES AS AT YEAR 2000

Residential Area	Low density Area	Medium density area	High density Area	Subtotal
Malundu	2056			2056
Part of Kafue East	4326	4020		8346
Rail compound	730			730
Part of Kafue Estates	1023	1500		2523
Part of Kaseba		1024	1055	2079
Shikoswe		8507		8507
Part of location		1010	1060	2070
Chawama			5048	5048
Zambia compound			8608	8608
Soloboni			5078	5078
Total	8135	16,061	20849	45,045

Table 4.10 showing residential population distribution

Low density areas (LD) ----- 8135

Medium density areas (MD) -----16061

High density areas (HD) -----20849

Total population..... 45045

AREA	DESIGNATION	CONSUMPTION RATE L/cap/day
Low density	LD	150
Medium density	MD	100
High density	HD	80

Table 4.2 showing the consumption rate as per Zambian standard

Growth rate-----2.5% per year

Forecasting period---15yrs

DESCRIPTION OF HOUSING CATEGORIES

1 High Cost: Houses which have individual connections with internal plumbing and a kitchen, toilet and bathroom/shower-more than one WC, multiple taps water borne sanitation. (Separate servant's quarter).

2 Medium Cost: Houses with individual connections just as for high cost but having their plots smaller than the HC and with no separate servants quarter.

3 Low Cost: Yard connection, no internal plumbing, and shower outside and connected to yard connection –reduced number of taps, one WC water borne sanitation.

4.3 WATER DEMAND PER HOUSING CATEGORY

HIGH DENSITY AREA

$Q_1 = \text{CONSUMPTION RATE} \times \text{TOTAL POPULATION IN THAT CATEGORY}$

$$= 80\text{l/cap/day} \times 20849 \text{ caps}$$

$$= 1667920\text{litres/day}$$

MEDIUM DENSITY AREA

$$Q_2 = 100\text{L/cap/day} \times 16061\text{caps}$$

$$= 1606100\text{litres/day}$$

LOW DENSITY AREAS

$Q_3 = 150\text{L/cap/day} \times 8135 \text{ caps}$

$= 1220250\text{L/day}$

$Q_{\text{total}} = 1667920 + 166100 + 1220250$

$= 4494270\text{L/day}$

$= 4,494.27\text{m}^3\text{/day}$

4.4 INSTITUTION WATER ESTIMATES REQUIREMENT

INSTITUTION	NUMBER OF CONSUMERS	COSUMPTION RATE l/unit/day	TOTAL CONSUMPTION M ³
District hospital	186	365	67.9
8Primary schools	8000	25	200
6Basic secondary schools	9000	25	225
2High schools	3000	25	75
Offices (estates)	300	20	6
		TOTAL	498.9

Figure 4.4 COMMERCIAL AND INDUSTRIAL WATER REQUIREMENTS

PREMISES	NUMBER OF CONSUMERS	CONSUMPTION RATE IN l/unit/day	TOTAL CONSUMPTION M ³
Nkosi breweries	1	15286	15.3
Council lodge	25	150	3.8
		TOTAL	19.1

4.5FIRE FIGHTING DEMANDS

This was obtained from the ZS where it is given that 0.25/cap/day of the total population served. The total water demand for fire fighting is based on the total population

FIRE DEMAND = 0.25 X 45 000 = 11250L/DAY =11.25m³/day

Summing up 4494.27 +498.9 +19.11 + 11.25 = 5,023.52

The total water demand is 5030 m³/day. This is approximately 5030m³/day and projecting this to the year 2015 using the exponential model.

From appendix 1 (population of Kafue town as at 1990 as 2000) the only method that conforms to the distribution of the data is the exponential. The others require more than two sets of data (1990 and 2000) .

$Q_{i+n} = Q_i(1 +a)^n$ (28)

- Where Q = current population (1990)
- i = year of forecasting population (2000)
- n = period of forecasting
- a = rate of population growth as a percentage

Taking “a” , “n”and ”P₁₉₉₀” to be 2.5% ,10years and 117,354 we can calculate the expected population of people for the year 2000 to see if it tallies with the actual population as follows;

P₂₀₀₀ = P₁₉₉₀(1 + 0.025)¹⁰
= 117354(1+ 0.025) ¹⁰
= 150,224

Comparing this figure with that in the appendix 1 which is 150,217 one would simply say they are tallying. As such it was adopted for water demand forecasting.

- Taking Q = current water demand (2000)
- i = year of forecasting current water demand (2006)
- n = period of forecasting
- a = rate of population growth as a percentage

Evaluating the water demand as at the year 2006 we have

$$Q_6= 5030(1 + 0.025)^6=5840\text{m}^3/\text{day}$$

Owing to the fact that the metering system is not working for the distribution system and the fact that most of the African countries losses and wastages amount to 40%, this figure was adopted for this report.

Taking wastage and losses to be 40%, the total water requirement works out to be

$$\frac{5840}{1-0.4}$$

$$\text{ADD} = 9740\text{m}^3/\text{day}$$

Projecting this through a 15years period

$$\text{ADD} = Q_{2021} =14,110\text{m}^3/\text{day}$$

4.6 EVALUATION OF THE TREATMENT PLANT CAPACITY

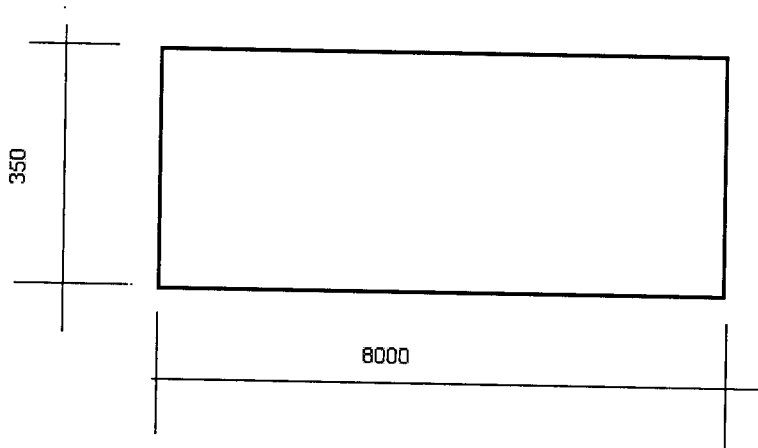
In view of the fact that there are no flow meters to reflect the rate of flow of filtrate to the contact tank, one by one the filter cells' influent was cut-off when they were at full supply level line. At this level a mark was made on the wall of the filter cell and the drop in this full water supply line noticed after 4minutes.A stop watch and a steel metre rule were used for this exercise. Results obtained were as follows:

FILTER CELL NUMBER	DURATION IN MINUTES	DROP IN FULL SUPPLY LINE (cm)
1	4	9
2	4	10
3	4	9
4	4	10
5	4	08
6	4	08
	TOTAL	54

Table 4.5 showing drop in FSL

The average depth is $54/6 = 9\text{cm}$ Or 0.09m per 4minutes.Basically which is $0.0225\text{m}/\text{minute}$.Multiplying this by 60×24 to get the depth per day gives $32.4\text{m}/\text{day}$.However there six filtration cells each measuring $3.5\text{m} \times 8\text{m}$ in plan

The capacity of the plant will be $32.4 \times 3.5 \times 8 \times 6 = 5443.2\text{m}^3/\text{day}$ which is approximately **5,500m³/day**. This assumed that the effect of head reduction in 4minutes on the filtration rate was negligible and so was the head loss.



PLAN VIEW OF ONE OF THE FILTRATION CELLS

Figure 4.2 showing a layout of one of the sand filter cells

4.7 QUANTIFICATION OF VARIOUS PARAMETERS

MANGANESE

For the determination of manganese persulphate method was used. It is based on the oxidation of soluble manganous sulphate compounds to form permanganate in the presence of silver nitrate under certain conditions. The resulting is stable if excess persulphate is present and organic matter is absent thus can be measured by a photometer.

Results **0.01mg/l** for water in the contact tank

Colour

The color of a filtered sample is expressed in terms that describe the sensation realized when viewing the sample. The hue (red, green, yellow, etc.) is designated by the term “dominant wavelength”, the degree of brightness by “luminance”, and the saturation

(pale, pastel, etc.) by “purity”. These values are best determined from the light transmission characteristics of the filtered sample by means of a spectrophotometer

Results: The purity is 40% and wavelength is 490-500nm. The color is blue-green

Bacteriological examination of contact tank water

A measured volume of water is filtered through a membrane of pore size 0.45microns, made of cellulose compound. The membrane is then incubated on a suitable selective medium, allowing the coliforms bacterial to reproduce and form colonies. The number of characteristic colonies produced at 35degrees Celsius on a particular medium gives the total coliforms (TC) content of the water sample. When incubated at 44.5degrees Celsius on MFC medium the colonies represent the Feacal coliforms (FC) of the sample.

ITEM	CONCENTRATION IN mg/100L
TC	65
FC	28

Results: Table 4.6 **TC and TC**

CHLORINE DEMAND

A sample of raw water was subdivided into sub-samples and each dosed with the standardized oxidant (chlorine) solution to yield a series of dosing doses.

After 10minutes oxidant residues were measured by the difference between initial and final concentrations

Initial chlorine used = 3.102mg

Final chlorine found = 0.443mg

Chlorine demand $3.102 - 0.443 = 2.658\text{mg/l}$

RESIDUE CHLORINE EVALUATION

5 Samples of water were taken from different tapping off points on the distribution system and tested for the presence of chlorine by introducing a DPD1 tablet (reagent) in each sample. If there is chlorine present the water color turns out to be purple. However the concentration of chlorine can be determined by matching the purple intensity with

that on the portable comparator. Considering the fact that each of the purple intensities on the color disc has a corresponding chlorine concentration stipulated on it.

SAMPLE	1	2	3	4	5
CHLORINE CONC. IN mg/l	Less than 0.1	Less than 0.1	Less than 0.1	Less than 0.1	Less than 0.1

Table 4.7 Residual chlorine tests results.

ADJUSTING GAS CHLORINATORS

The gas flow Q_{gas} in g/h is the variable to be adjusted. The chlorine dose D_{CL} and the flow of water to be treated Q_w are: chlorine demand **2.7mg/l**

: Water flow **230m³/h**, this is the flow to the contact tank. Since flow meter for the flow to the contact tank is not there, the rate of plant treatment for the plant has been taken.

$$\begin{aligned} Q_{gas} &= Q_{cl} \times Q_w \dots\dots\dots (4.1) \\ &= 230 \times 2.7 \\ &= 621\text{g/h} \end{aligned}$$

Turbidity and PH of the untreated water was measured and the results are

$$\begin{aligned} \text{Turbidity} &= 11.88\text{NTU} \\ \text{PH} &= 7.88 \end{aligned}$$

JAR TEST

Colloids cause turbidity and sometimes color in water and carry micro organisms including pathogens .as such the colloids and the accompanying micro organisms need to be removed from raw water especially if it is to be used for drinking. A jar test is used to determine how much in terms of concentration coagulant and pH to reduce the turbidity to certain minimum level.

This test was conducted on the raw water from Kafue River. The results are as follows.

CONCENTRATION IN mg/l	pH	TURBIDITY IN NTU
0.00	7.88	11.8
20.00	7.24	1.26
40.00	6.89	1.02
60.00	6.59	1.32
80.00	6.38	2.35
100.00	6.48	2.56

Table 4.8 coagulation test results

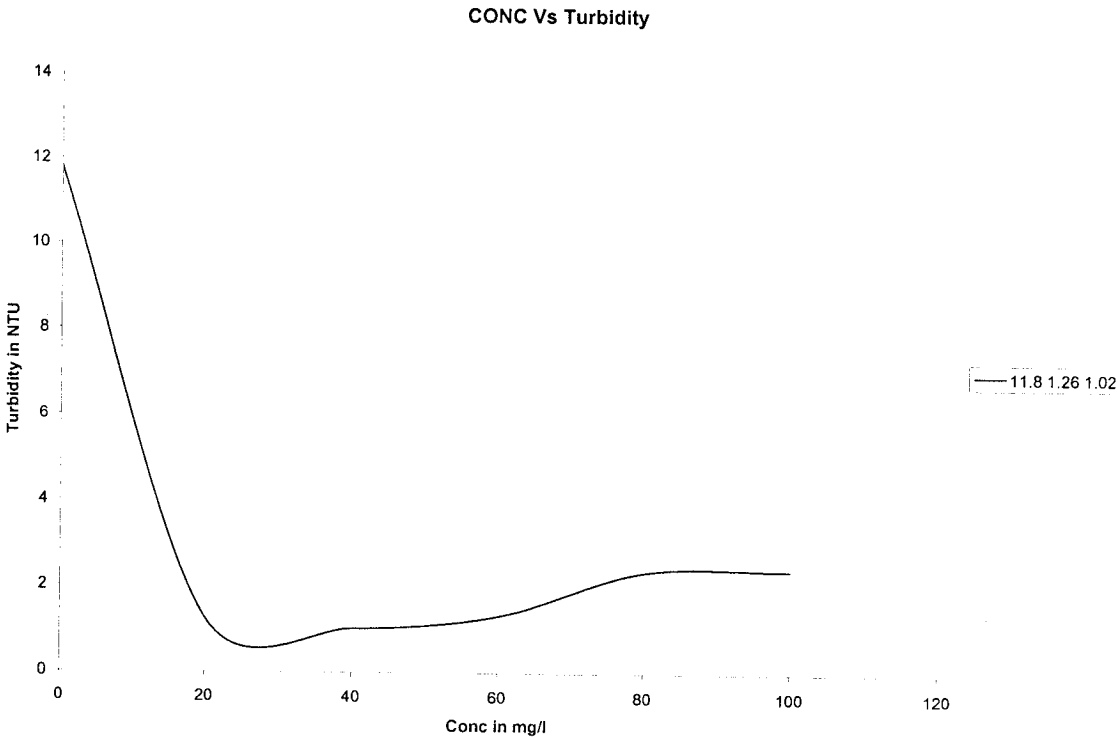


Figure 4.3: A plot of concentration against turbidity

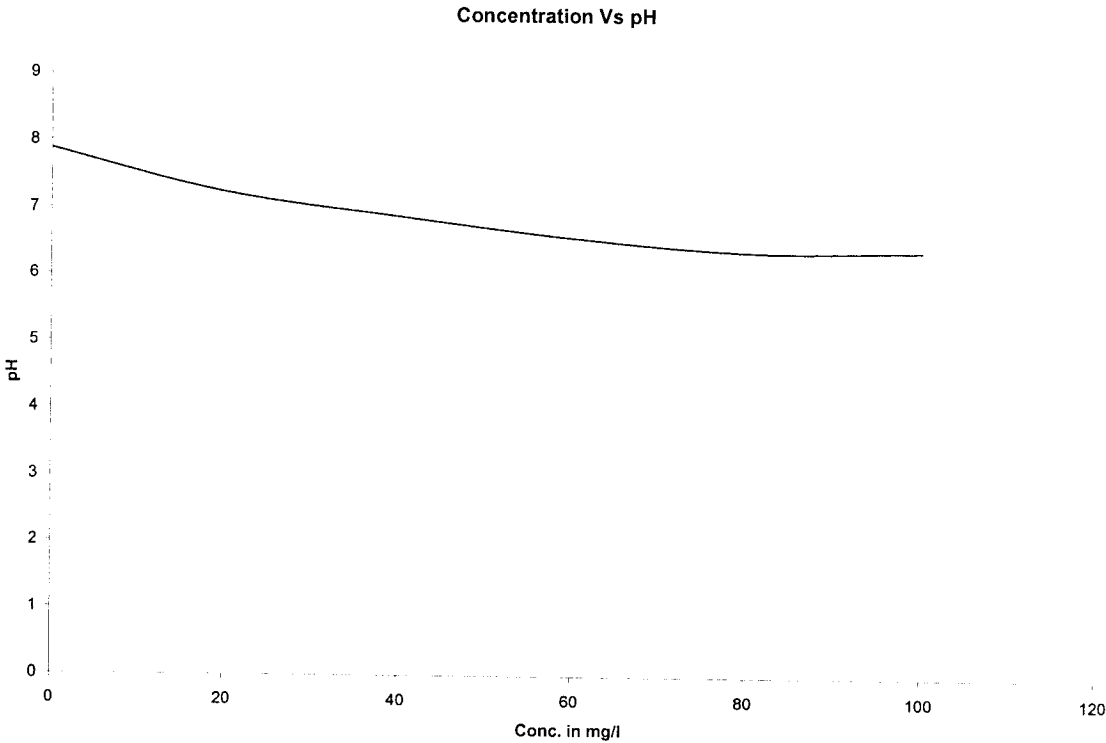


Figure 4.4: **A plot of pH against concentration**

From the data distribution above it can be noticed that the turning point of the graph of turbidity against concentration is between 20 and 40 mg/l. That is 25mg/l.

CHAPTER FIVE

DISCUSSION, RECOMMENDATIONS AND CONCLUSION

5.1 DISCUSSION

Quality of water

From the laboratory analysis of both raw and treated water of the Kafue water supply system a table of comparison between the Zambian standard and the quality of the water can be tabulated as below;

PARAMETER	ZS MAXIMUM RECOMMEN DED LEVEL**	RAW WATER	FILTERED WATER ONLY (Contact tank)	WATER TREATED WITH ALUM IN LAB	TAP WATER	UNITS
Manganese	0.1	0.01	0.01	0.01	0.01	mg/L
Iron	0.3		0.02	0.02	0.02	mg/L
Turbidity	5.0	11.8	2.02	0.5	2.02	NTU
Residual chlorine	0.5	0.00	Less than 0.1	-	Less than 0.1	mg/L
Total coliforms/100ml	0.0	-	65	-	85	Number
Feacal coliforms/100ml	0.0	-	28	-	68	Number
PH	6.5- 8.5	7.56	-	7.25	-	Number

Table 5.1 Actual water parameter level against ZS standard (Source: laboratory of the department of civil and environmental engineering UNZA)

It's clear from the above results that the color of Kafue town water is not caused by either iron or manganese but turbidity. This is in view of the fact that the concentrations of these elements are way below that stipulated by ZS.

In as far as the quantity of residual chlorine in drinking water is concerned; the field results indicate that the amount present in water is very insignificant. This poses a danger to the health of the people and the presence of Feacal coliforms in both filtered water (sampled from the contact tank) and tap water justifies this. Both Feacal and total coliforms are not supposed to be present in drinking water going by the ZS stipulations.

Water of Kafue water works does not go through the process of coagulation and flocculation (field observation). This is in fact compounded by the fact that there is no equipped laboratory nor is there an agreement with a reputable water utility company like LWSC to assist in the analysis of water in the laboratory. A laboratory a diagnostic centre were prescription in terms of what to be removed and how much, what to be added and how much, is done in order to supply palatable drinking water. Alum is a good example in question, you need a concentration of 25mg/l and a pH of 7.25 order to reduce turbidity of raw water to 0.5 NTU. The water has color and its color is blue-green with a purity of 40%

Quantity of water

From the estimated water requirements of the town for both 2006 and 2021 (9970, 14,110m³/day), these requirements exceed the plant capacity of 5500m³/day by far. This causes rationing of water supply in town.

5.2 RECOMMENDATIONS

These are in two categories, one to give “short and medium term” solutions and then the other, long time solutions.

SHORT AND MEDIUM TERM SOLUTIONS

Most of these have been highlighted in chapter three as curative measures. However, factors such as employing qualified manpower and striking an agreement with well established water utility companies such as LWSC to provide laboratory services on weekly basis can not be over emphasized.

LONG TERM MEASURES

There is need to expand the water treatment plant so that the plant can meet the 2021 water requirement of 14,110m³/day.

5.3 CONCLUSION

It is quite obvious from the water works effluent quality test results which were measured against that of the Zambian standards that they fall short of expectation. This short fall in expectation is attributed mainly to;

- 1.0 The absence of a well equipped laboratory
- 2.0 Wrong or no chemical dosages prescribed for water treatment and even then, wrongly administering methods
- 3.0 Lack of appreciation of some operational treatment units employed at water works which have been stripped off.

With regards to the plant's capacity of 5500m³/day, this is inadequate to meet both current (2006) and future (2021) water demand. The population of the town has over years grown significantly to exert massive pressure on supplying adequate and palatable drinking water to the Kafue town residents (Refer to appendix 1). This pressure has led not only to erratic water supply and but also inadequate quantities to consumers.

REFERENCE:

- 1.0 Robert L. Sanks “water treatment plant design for practicing engineers” Ann Arbor science, 1978.
- 2.0 Ray K. Linsey & Joseph B.F,”Water resources engineering”3rd Edition, McGraw-Hill, 1979
- 3.0 Joseph Munalula “Guidelines on water demand estimation and forecasting, sewer load generation and design of networks and infrastructure”, 1999
- 4.0 A.C Twort R.C. Hoather & F.M Law “Water Supply” 2nd Edition,Adward,London 1974
- 5.0 Joseph Munalula “Guidelines on water demand estimation and forecasting, sewer load generation and design of networks and infrastructure” 1999.

APPENDIX 1: 2000 CENSUS OF POPULATION FOR LUSAKA PROVINCE

Residence	Population Size 1980	Annual Growth rate 69-80	Population Size 1990	Annual growth rate 1980-1990	Population size 2000	Annual Growth rate 1990-2000
ZAMBIA	5,661,801	3.1	7,759,117	2.7	9,885,591	2.5
Lusaka	691,054	6.3	991,226	3.6	1,391,329	3.2
Rural	139,687		167,213	1.2	258,327	5.1
Urban	551,367		824,013	4.2	1,133,002	3.2
DISTRICT						
Chongwe	-	-	95,738	-	137,461	3.7
Kafue	-	-	117,354	-	150,217	2.5
Luangwa	143,762	3.4	17,070	3.5	18,948	1.1
Lusaka	535,830	18.4	761,064	3.7	1,084,703	3.6

Source: 2000 census of population and housing
 -Not applicable as they are new districts

APPENDIX 2: LABORATORY ACTIVITIES

ITEM NO.	TESTED/EVALUATED PARAMETER	POINT OF SAMPLE COLLECTION	REASONS TO TEST THE SAID PARAMETER
1.0	Iron and Manganese	Tap	Consumers complain of brown and black coloration in water
2.0	Residue Chlorine	Tap- end user of the Distribution system	To find out whether the dosage currently administered to water is correct.
3.0	Total chlorine water demand	Treated water	To dose the right amount of chlorine enough to leave the needed residue amount in the distribution system
4.0	Bacteriological Examination of water	Both raw and tap (treated water)	A lot of reported cases of cholera And diarrhea
5.0	Turbidity	Both raw and treated water	Water from the tap has color
6.0	Coagulation jar test	Raw water	To determine the correct Alum dosage and at the optimum PH.
7.0	Color	Treated	Water from the tap has color

APPENDIX 3: COLOR TEST RESULTS OF WATER FROM THE CONTACT TANK

wavelength in nm	X transmittance in %	Wavelength In nm	Y Transmittance in %	Wavelength in nm	Z Transmittance in nm
430	83.8	490	98.4	422	80.5
461	93.1	515	96.3	432	85.0
544	94.8	530	96.8	439	87.4
564	109.1	541	93.4	444	89.0
577	131.5	552	122.5	450	90.9
589	60.3	562	117.0	456	92.7
600	52.8	573	113.4	462	93.7
611	44.0	585	60.2	469	94.9
624	37.8	601	50.9	478	96.2
646	31.2	627	36.5	495	97.8
Total	738.4	Total	885.4	Total	908.1
Factor for 10 ordinates used	0.09806	Factor for 10 ordinates used	0.100000	Factor for 10 ordinates used	0.11814
	72.407504		88.54		107.82934

Table 4.16 Transmittance results
Calculating for trichromatic coefficients x and y

$x = X / X+Y+Z = 72.407504 / 72.407504 + 88.54 + 107.82934 = 0.2693 = 0.27$

$y = Y / X+Y+Z = 88.54 / 72.407504 + 88.54 + 107.82934 = 0.329418259 = 0.33$

**Locating the point (x, y) on one of the chromaticity diagrams to determine the dominant wavelength (nm) and the purity (%) directly from the diagram we have

Purity = 20%
Wavelength = 490-500

APPENDIX 4:** COLOUR HUES FOR DORMINANT WAVELENGTH RANGES

ITEM	Wavelength range in nm	Hue
1	400-465	Violet
2	465-482	Blue
3	482-497	Blue-Green
4	497-530	Green ***
5	530-575	Greenish yellow
6	575-580	Yellow
7	580-587	Yellowish orange
8	587-598	Orange
9	598-620	Orange-red
10	620-700	Red
12		
13	400-530c	Blue-purple
14	530c-700	Red-purple

Results: the color in the water is GREEN

APPENDIX 5: COLOUR TEST RESULTS OF COAGULATED WATER

WAVE LENGTH IN nm	% X TRANSMITTANCE	WAVE LENGTH IN nm	% Y TRANSMITTANCE	WAVE LENGTH IN nm	% Z TANSMITTANCE
430	76.1	490	96.4	422	78.7
461	84.3	515	96.6	432	83.7
544	85.4	530	95.4	439	86.4
564	99.5	541	92.5	444	88
577	115.2	552	119.6	450	92.5
589	52	562	117	456	93.9
600	45.6	573	109.9	462	95.2
611	39.6	585	56.6	469	96.5
624	35.6	601	48.8	478	97.7
646	30.3	627	35.3	495	99.2

The purity is 40% and wavelength is 490-500nm.The color is blue-green

- ** Data from” standard methods for the examination of water and wastewater”,20th edition by Lenore chair,Arnode Alpha and Andrew Awwa.published by American public Health Association-----

ABSTRACT

This project was aimed at evaluation of the effectiveness of the operational treatment units of Kafue Water Plant and its capacity to meet the current (2006) and future (2021) water demands.

The infrastructure at the treatment plant was examined with much emphasis laid on operational units. The water quality in these units was analyzed for various parameters and lastly the plant capacity was quantified. It was found out that the quality of filtrate falls below the Zambian standards and this was attributed to disregarding components such as dosing pumps, laboratory raw water analysis, flow measuring meters stripped off the treatment system, lack of knowledge by the personnel running the treatment plant and no coagulant being used during the treatment process. As regards to the capacity of the plant, it falls below both the current and future water demands.

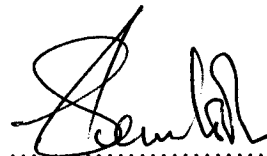
It has been recommended that the treatment plant be expanded to meet these demands and employing qualified personnel to run the plant. In addition, all disconnected units to be connected back to the treatment units and the laboratory be revamped or enter into agreement with a well established water utility company such as Lusaka water and sewerage company.



Supervisor

J.M. Tembo

05/02/2007



Student

Patrick Tembo