LOCATION OF ADDITIONAL DEPOTS OF NAIROBI CITY COUNCIL'S WATER DEPARTMENT

by

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This thesis is my original work and has not been presented for a degree in any other University.

James M. Wagura.

This thesis has been submitted for examination with my approval as University supervisor.

Dr. David Kohler.

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ABSTRACT

The objective of the thesis is to find the ideal locations of additional depots of Nairobi City Council's Water Department. The objective is accomplished in two major phases.

In phase one, a forecast of the number of leaks expected to occur in different regions of the City, in 1985, is made. The forecast is made through the use of a predictive model, a model which is in form of two three-dimensional equations. To develop this model, representative regions were selected and the annual number of leaks which occurred in each region, between 1975 and 1979 were found, and through regression analysis, the number of leaks occurring in a region were found to vary or depend on the number of houses and the age of the pipes in the region.

In phase two, the total weighted distances(Distance multiplied by predicted number of leaks), from the possible locations to the repair sites are calculated. The possible locations are then ranked, in an ascending order, starting from those with the lowest total weighted distance. Theoretically, the ideal locations of additional depots should be those with the lowest total weighted distance, but the final choice as to where the additional depots should be located will obviously be influenced by non-quantifiable factors.

1. INTRODUCTION

1.1 A BRIEF HISTORY OF NAIROBI

Nairobi, a Maasai word which means a place of cold water, was established around the year 1899 as a railway depot for storing railway construction equipment up-country for the then Uganda Railway. Situated on that point where the Kenya Central Highlandsmerge into the Athi river plains, cold crystal clear water was available from these highlands, and as such the spot was ideally selected as a resting place after the long haulage from the coast through the hot dry savannah-otherwise known as Nyika. The railway authorities established themselves in the same spot where they are today. They took or acquired a big piece of land.

The Administration followed in the footsteps of the railway, and Nairobi was made a Provincial Headquarters for Nairobi environs and the Machakos area. But the central location of Nairobi, in relation to the British sphere of influence in East Africa, and especially its closeness to Uganda - which was of immense economic interest to the British (they went as far as nick-naming it (Uganda) "The Pearl of Africa") and was in fact the main reason for building the railway - made it a more suitable location for a head-quarters as opposed to Mombasa, and in 1905, it was proclaimed the capital. By this date, Nairobi had in a space of six years grown to a population of 10,000 people, an impressive growth which was to be maintained in many years to come, and this process of rapid growth is very much a present day feature of Nairobi, where rural folk and school leavers are flocking in numbers every year in search of jobs and other economic opportunities.

As the administration established itself and security was thus guaranteed, businessmen started coming in numbers, pioneered by railway workers (who were mainly Asians). The administrators occupied the hill (Hospital Hill Area) where the air was reportedly fresh and the drainage was good, the Asians occupied Parklands, and the city centre started to assume its commercial role. These areas then became the nucleus for the city expansion.

Due to rapid growth and the fact that it was the capital, Nairobi was proclaimed a Municipality in 1919 as a prelude to becoming a city, the only town in the country to be accorded this status so far. The importance of Nairobi grew even to greater heights with the fast increase of European settlers, who came to settle in Nairobi environs and in the Kenyan highlands (which they fondly referred to as the "White Highlands") at the end of the First World War as part of the general demobilization process. These settlers not only engaged in politics thus introducing a new flavour to the life of Nairobi, but also became big contributors to the economic growth of the colony through the cultivation of a variety of cash crops and the rearing of livestock. Nairobi served their needs very well as an import and export centre.

Nairobi which had started as a railway depot, had not only become the capital of Kenya, but also its commercial centre in addition to being a centre of settler politics, thus surpassing Mombasa in importance; and with the coming of the industries, the growth was very rapid indeed. The earlier growth of the city was controlled by purely economic factors, and among other things, land speculation (which has persisted up to this day though in a rather mild manner) was threatening to introduce a haphazard growth not conducive to the provision of the necessary infrastructure. A need was thus felt to control these forces and introduce order to the growth of the city. A town planning consultant was appointed to make recommendation on zoning arrangements in 1926, but there was no official crackdown on land speculation and the city continued to grow in an uncontrolled manner. The trend continued for over twenty years, when things attained crisis proportions, and a master study was commissioned in 1948 to lay down guidelines for the following twenty years, earmarking land for residential, industrial and other uses. The present day Industrial Area layout is mainly as a result of that study.

The growth of the city, as stated above, was very rapid, and by independence (1963) when the administrative boundaries were being adjusted to fit the interests of the new government and the country in general, the boundary of Nairobi was enlarged considerably to cater for the future expansion which was surely to come.

Throughout this development water has played a major role. Water was the main reason for the siting of the city, and its subsequent growth would have been impossible without a well regulated and maintained water supply. Nairobi's 900,000 residents literally depend for their lives on the water supplied to them by Nairobi City Council.

1.2 JUSTIFICATION OF THE STUDY

A significant difference exists between the amount of water supplied to the city and the amount of water which is finally sold to the consumers. The extent of this loss is exhibited in the table below on a quarterly basis starting from the fourth quarter in 1977 to the first quarter in 1980.

TABLE 1:1 :WATER LOSS

Year	Quarter	Amount of water supplied ('000 Gallons)	Water Sold ('000 Gallons)	% Lost
1977	4th	2,119,640	1,755,034	17.2%
1978	1st	2,089,830	1,740,457	16.7%
	2nd	2,121,390	1,761,809	16.9%
	3rd	2,050,578	1,734,274	15.4%
	4th	2,180,454	1,790,854	17.9%
1979	1st	2,309,405	1,930,825	16.3%
	2nd	2,281,145	1,905,315	16.5%
	3rd	2,393,067	2,009,179	16.0%
	4th	2,411,923	2,021,357	16.4%
1980	1st	2,578,552	2,069,230	19.7%
		22,535,984	18,718,334	17.0%
Average/quarter		2,253,598.4	1,871,833.4	17.0%

On average 382 million gallons are lost every quarter, which means on average 1,528 million gallons are lost every year. Given the charging out rate, we can approximately quantify this loss in monetary terms.

Current (May 1980) water charges are as follows:-

(i) The 1st 2,000 gallons are charged at a rate of Shs. 12.00 per 1,000 gallons.

(ii) The 2nd 2,000 gallons are charged at a rate of Shs. 15.00 per 1,000 gallons.

(iii) Over and above 4,000 gallons, at Shs. 17.05 per 1,000 gallons.

If for simplicity sake, we assume an average charging rate of 15.00 per a thousand gallons; the City Council is then losing revenue to the tune of 23 million shillings per annum. This is no mean sum for a Council which is chronically short of funds.

Looking at this loss from a wider perspective, the revenue lost by the council is a minor sum compared to the loss experienced by industry and other businesses due to constant shut-offs especially during the dry spells. Private households are also subject to this annoying phenomenon of occasional, and at times prolonged dry taps.

The said loss is due to leaks and bursts in the water system, and any step taken towards eliminating or at least reducing this loss would not only be welcomed by the City Hall but also by the wider public. This study, I hope, is a significant contribution towards that end apart from being a rewarding academic exercise.

1.3 OBJECTIVE OF THE STUDY

The objective of this study is to search for the optimum location of additional water repair depots, so that the city's water system can be serviced with minimum delay wherever leakages occur. In the preceding section, it was shown that there is an urgent need to control the amount of water being lost through leakages.

The search for the optimum location of the additional depots calls for an accurate forecast of the number of leaks expected to occur in the various estates.

Forecasting is an estimation of how the future will look like, and since the future is crowded with uncertainty it is an attempt to minimise this uncertainty. A reduction of uncertainty opens the way for rational planning to meet the challenges of the unknown future.

Decisions whose consequences will stretch far into the future entail long-range planning in order to avoid committing initial mistakes, which might be impossible to correct or can only be corrected at very high costs. Deciding where to locate a given source to serve a number of destinations calls for such long range planning. Demand at the destinations must be accurately forecasted, if at all an optimum location is to be found.

There are different forecasting techniques - qualitative as well as quantitative. Qualitative techniques such as panel consensus, delphi method, visionary forecast, historical analogy, cross impact analysis, etc., are used mainly where historical data is scarce or lacking. Quantitative techniques on the other hand rely heavily on history (historical data) to predict the future. Examples of important quantitative techniques include time series models and causal models. Time series models such as trend projections, moving average, exponential smoothing, census bureau X-11 and Box-Jenkins, try to extrapolate the past into the future and thus the time factor is very important. The underlying assumption of such an extrapolation being "a future like the past", a just assumption (in many cases) for the immediate future, but a dangerous assumption where the time horizon spans far into the future. Causal models such as regression and econometric models on the other hand are directed towards explaining the causes - the relationship between a number of independent variables and a dependent variable. Causal models are powerful forecasting tools, very appropriate in many business situations but also very costly and time-consuming to employ. Which technique to employ is a matter of personal decision in each pertinent case, bearing in mind such factors as cost and the urgency of the results.

In this study I have chosen to use regression models which I have no doubt are the most appropriate for this study. The models are used effectively in predicting the future work-load of the Repair Section in the Water and Sewerage Department of the City Council of Nairobi.

The work-load and how it is geographically spread over the city, forms the basis of selecting the optimum locations and number of repairs depots to be set-up. Presently only a single repair depot (Kampala Road Depot - in the Industrial Area) exists and it does not appear to be centrally located in relation to working sites.

A source of operations should be located in such a place that the cost of operations between the source and the destinations is minimised. In this study, the purpose is to minimise the cost of operation between the depots and the repair sites. The cost to be minimised being the cost of travelling between the depots and the sites. The components of such cost include among others such variables as fuel cost, depreciation of vehicles and cost of non-working hours. One sure way of reducing the travelling cost is by reducing the road distance between the depots and the working sites. Reducing the road distance implies that lesser time will be spent on travelling and thus the workers productivity will be raised. In addition, an enormous amout of fuel will be saved and the vehicles' depreciation rate will be lowered. Raised productivity will in turn mean faster response to consumer complaints. In general, by lowering the cost and increasing the efficiency of the Repair Section the consumer will pay less for the water he consumes, and his complaints will be answered much faster than before.

The total road distance can be reduced by setting up many additional repair depots, but obviously we cannot dream of setting up a large number of depots. The cost of operating such a number of depots would surely exceed the attendant benefits. The issue is thus reduced to a search for the best places to locate one, or at most two, additional depots. The optimum location of water repair depots, as stated above, entails an accurate forecast of the work-load for each destination (estate). To forecast the work-load, it is necessary to examine among others, the following variables:

i) Past and projected growth of the city in terms of water needing units or facilities e.g. households and industrial plants.

ii) Past incidence of repair works.

These variables and the other relevant ones are analysed, and a rational inter-relationship between these variables and the incidence of repairs established, thus enabling a long-range forecast of work-load per estate to be made.

The forecasted work-load per region is used in the search for the ideal location of the additional depots.

1.4 SCOPE AND METHODOLOGY OF THE STUDY

Scope

The study is confined to the City Council water supply system. Private water supply systems are excluded mainly due to lack of data; these are relatively tiny and are confined to some parts of the new city (the area incorporated into the city after the change of the boundary in 1963). Private water systems are being phased out systematically as the supply is increased from the various sources; and the plan is to accelerate this process with the completion of the Chania II water supply project which is expected to be completed around 1983. Chania II is planned to satisfy the demand which at the moment exceeds the supply, and to eliminate the need for private water supplies in future.

Methodology

Personal extraction of primary and secondary data from the various existing records has been the main method of data collection. The following have been the main sources of data:-

i) Daily Complaints Book:

This is the main source of historical data used for predicting the future number of repairs expected to occur in the various estates. The book, which is given extensive coverage in the relevant chapter, contains the record of past incidence of repairs.

ii) Record of Certificate of Occupation:

Before the bulk of new premises are occupied, the City Council has to give approval, through the issue of a certificate of occupation. A record of all the certificates issued is maintained at the City Hall and this record has been used to determine the annual increase of the number of houses in an estate.

iii) Billing Schedule:

These schedules have been used in ascertaining the amount of water used in an estate over a selected period. They contain summarised water consumption figures, on a month-to-month basis, covering all the estates.

iv) Type of Soil:

It was necessary, at a later stage of the study, to incorporate the type of soil into the prediction model. A soil survey map, by the Survey of Kenya, was very useful in this respect and in fact it was the main source of that data.

v) Area of Estates:

The areas of the estate were found by direct measurement. The instrument used for that purpose was the planimeter.

The above approaches were direct methods of obtaining all required data, but in a few cases the data had to be obtained by an indirect method. Indirect methods were also applied, and where a high degree of accuracy in the resulting data was required enough safeguards were introduced to guard against the danger of processing inaccurate data. Conversion of population into the number of houses is the best example where this approach was extensively applied.

To supplement the above, or where recorded data was lacking, personal interviews were conducted. Personal interviews served an added purpose of obtaining expert opinion on non-quantifiable variables, which have a bearing on the setting up of a depot in any particular place of the city.

In selecting the variables to be incorporated into the forecasting model, simple analyses were carried out in each case. After selecting the appropriate variable, regression models were used extensively in forecasting the future incidence of repairs for each destination.

The incidence of repairs per destination (estate) were used in selecting the optimum locations of water repair depots.

Finally, computer programmes were used at appropriate stages, to ease the computational burden.

1.5 LIMITATION OF THE STUDY

Whereas it would have been desirable to cover all types of leaks and bursts, it is only practically possible to consider those that have been reported. Underground leaks which go on for a long time before they are detected were only included at that point where the oozing water came to the surface; before this happens a lot of water is normally lost. Their early detection can only be done by a specially trained leak detection team, a team which has not been formed yet. The cost of maintaining such team would be very low compared to the revenue which could be generated by the sale of the water saved, apart from sparing the consumers the hardship of water shortages.

1.6 ORGANISATION OF THE STUDY

The body of the study is made up of three chapters - chapters two, three and four.

Chapter two in a sense sets the stage by introducing the reader to the City's organisation for water repairs. It is divided into four short parts. The first part dwells on the organisation of the Water Department - how it fits in the overall organisation of the City Council and how it is sub-divided into sections, giving particular attention to the Water Repair Section.

Part two concentrates on water supply, right from the sources up to the point where it is distributed to the various consumers. Parts three and four are devoted to the existing style of operation, in the water repair section, its shortcomings and the necessity of setting up additional depots.

Chapter three can rightly be regarded as the most important phase of this study. In this chapter the detailed methodology of data collection is set out, and the collected data is displayed in suitable tables and in other convenient forms. The data is in turn analysed, and from this analysis, a step-by- step development of the prediction model is accomplished.

Chapter four is devoted to the application of the prediction model developed in the previous chapter. The result of this application is the number of leaks expected to occur in the various estates of the city around 1985. The chapter closes by accomplishing what the researcher had set out to do at the commencement of the study - namely specifying where additional depots can be located.

The final (fifth) chapter summarises the study as a whole.

2. WATER SUPPLY

2.1 EXISTING ORGANISATION

2.1.1 City Council of Nairobi:

The City Council of Nairobi (hereafter referred to as NCC) is a local authority responsible for the public welfare of approximately 850,000 residents (1979 census).

The highest governing body is made up of more than 40 elected (representing the various city wards) and appointed (by the Minister fo Local Government) councillors. The councillors who are elected for a term of five years, elect a Mayor from among themselves who assumes the Chairmanship of the Council. They normally act as a group on matters of high policy and major decisions e.g. firing of departmental head. To facilitate the decision making process, various standing committees, headed by councillors, are set-up to deal with departmental and general matters before they are referred to the whole council where necessary. Such committees are:-

Town Planning Committee
Finance Committee
General Purpose Committee
Works Committee
Education Committee
Social Services Committee
Staff Committee
Housing Committee
Public Health Committee
Water and Sewerage Committee.

The committees in turn establish sub-committees, which are supposed to deal with lesser matters, and to give first consideration to important matters before they are referred to the committee for further approval. For an example, the Water and Sewerage Committee has the following sub-committees:-

Water and Sewerage Appointments Sub-committee
Unadopted Drainage Works Sub-committee.

The committee decisions need ratification by the Council, and some important decisions by the Council need further approval by the Ministry of Local Government before implementation e.g. addition of staff above establishment. As is common with the the current level of/committee structure, the decision-making process of NCC is full of red-tape and is thus very time-consuming. An item costing between £100 and £500 passes through such an elaborate procedure that at least a month is required before the ordering department can request delivery from the supplier.

Departmental Organisation

The NCC is organised into seven departments, each department being charged with related NCC responsibilities:-

i) The Water and Sewerage Department, which is headed by a General Manager, deals with the engineering as well as commercial activities in the field of water supply and sewerage.

ii) The City Treasurer's Department, headed by City Treasurer, deals with financial matters.

iii) The Education Department, headed by City Education Officer, deals with primary education.

iv) The Public Health Department, headed by Medical Officer of Health (M.O.H.), deals with preventive and curative medicine, town cleaning, and collection and disposal of refuse.

v) The Social Services and Housing Department, headed by the Director of Social Services and Housing, deals with housing and welfare matters.

vi) The City Engineer's Department, headed by City Engineer, deals with Town Planning, construction and maintenance of roads, drains, bridges, street lighting, fire services, building inspection etc. It is the largest department in terms of responsibilities.

vii) The Town Clerk's Department, headed by Town Clerk, handles administrative matters and the Town Clerk is the Chief Executive Officer of NCC.

As pointed out earlier, the committees are the governing heads of the various departments, and the departmental heads who are the chief executives of their departments, are members of their relevant committees. In addition there are regular meetings between the Mayor, the Councillors and the Departmental Heads.

2.1.2 Water and Sewerage Department

The Water and Sewerage Department the principal department for this study, was established in 1970 as a pre-condition for a World Bank loan, made to the NCC in that year, for the development of a new source of water from the middle-Chania. Prior to that, the engineering aspects of water supply and sewerage were handled by the City Engineer's Department, and the related commercial functions by the City Treasurer's Department.

The primary responsibilities of this department are the provision and distribution of water supply, and the collection and treatment of sewage for the city.

As pointed out earlier, the department is headed by a General Manager, who reports to the Water and Sewerage Committee. He co-ordinates and manages the operational activities of the department. Under him there are two deputies: The Deputy General Manager (Engineering) and the Deputy General Manager (Commercial), each deputy being the head in his section. The sections are further sub-divided on functional lines (see figure 2.1). The Water and Sewerage Department carries out the following specific functions:-

Commercial and Finance

Water Supply and Sewerage Planning, Design, Operation and Maintenance

Administration

and the department is organised along these functional lines as apparent from the organisation chart.

The Administration staff headed by the Principal Administrative Assistant assist the General Manager in administrative matters.

The Commercial Section, which works in close collaboration with the City Treasurer's Department, is responsible for:-

Billing consumers

Meter reading

Book-keeping and

Budgeting

whereas the Treasurer's Department is responsible for cash collection.

The Sewerage Planning, Operation and Maintenance Section, headed by a Chief Assistant Engineer, is responsible for planning, design, construction, operation and maintenance of treatment plants and sewer network.

The section is also responsible for maintenance of the storm-water drainage system, though the construction falls under the City Engineer's Department.

The Water Planning, Design and Construction Section headed by two Chief Assistant Engineers, is responsible for planning and designing of new distribution schemes and the supervision of the execution of new works. The section is really responsible for medium sized schemes for large schemes are normally handled by outside consultants and small schemes by the Operation and Maintenance Sections.

The Operation and Maintenance Section, which is of direct relevance to this study, is also headed by a Chief Assistant Engineer, and is responsible for operation and maintenance of dams, water treatment works, water laboratories and water distribution. The section is also responsible for the design and construction of minor water distribution network projects.

2.1.3 The Operation and Maintenance Section

The section operates from Kampala Road Depot, in the Industrial Area of Nairobi. The theoretical organisation chart maintained at this depot is supposed to effect a rational division of duties, but due to chronic shortage of high level manpower (principally engineers), the divisions are not always maintained as per organisation chart. Some functions are normally grouped together under one engineer, which would otherwise be handled by two or more engineers. At times some specialised tasks are contracted to outsiders, who are called upon whenever needed e.g. at the time of the study electrical work was handled by an outsider due to the lack of a qualified electrical engineer. At the time of the study, the tasks were organised (see figure 2.1) on the following practical lines:-

- Planning headed by a Senior Assistant Engineer.
- Distribution Co-ordination, headed by a Senior Assistant Engineer.
- Trunk Mains and Transport, headed by a Principal Assistant Engineer.
- Treatment Works, headed by a Principal Assistant Engineer.
- Labour, headed by a Chief Inspector.

2.1.3.1 Planning

As stated earlier, minor distribution network projects are the responsibility of the Operation and Maintenance Section, in particular the planning and laying of pipes. The estates involved are very small, say fifty or less houses. The laying of a main pipe is restricted to at most a few kilometres. They may also be called on to strengthen an existing distribution network by adding a few pipes.

In planning and designing, the senior assistant engineer is assisted by two engineer assistants and two draftsmen. But, for construction, he works in close collaboration with the Chief Inspector of Labour, as we shall see later. For routine jobs, he simply passes the drawings to the Chief Inspector, who gets the work done, but for specialised or larger jobs, the senior assistant engineer has to exercise personal control.

2.1.3.2 Distribution Co-ordination

This section is in charge of water distribution from the various reservoirs and tanks to the consumers. It regulates the pressure and the flow of water in the whole water system in the city. There are flow and pressure regulating valves all along the water system, which are opened and closed when necessary e.g. after 5 p.m. every day and over the weekend the flow of water to the Industrial Area is reduced significantlly to allow the reservoirs to fill up overnight and to divert the water to more needy residential areas. Boosters are also maintained to pump water to higher ground consumers, whose level is not much lower than that of reservoirs and storage tanks. But by and large gravitational force is used to supply the bulk of the consumers.

The section is also in charge of checking repairing and cleaning the meters, and a meter workshop is maintained at the depot for this purpose. Practically all the consumers are metered, and complaints of overconsumption from the consumers are quite many, and all the disconnected meters (meters are disconnected daily for non-payment) have to be cleaned and checked before any subsequent reconnection.

It is the responsibility of the senior assistant engineer, to co-ordinate take-overs of newly completed schemes from the Planning, Design and Construction Section, and outside contractors. He has to subject the pipes to a certain level of pressure before the new system can be considered good enough.

Finally, he is nominally the head of repair works, and the Chief Inspector of Labour has to consult him in case of problems during the routine repair work.

2.1.3.3 Trunk Mains and Transport

This section is in charge of maintaining the Trunk Mains- the pipes bringing the water from the various sources of supply to city reservoirs. There are four of such pipes:-

- Sasumua to Kabete
- Ruiru to Kabete
- Ngethu to Gigiri
- Kikuyu to Kabete

A number of labourers are permanently deployed to keep a close watch on these very vital pipes for any sign of developing leaks or any other problems. They maintain a regular patrol over the length of the pipe, clearing bushes around the pipes, cleaning the valves, and generally maintaining the pipes. There are sixteen such men taking care of the Sasumua pipeline and nine on the Ngethu pipeline.

This section is further charged with the responsibility of maintaining the water reservoirs and tanks.

The head of this section is also responsible for the maintenance, and allocation of vehicles to various sections and sub-sections of the Water and Sewerage Department. In this task he is assisted by an Engineer Assistant. He is responsible for sending these vehicles for repair to the Council garage when the need arises. Normally there should be over sixty vehicles but at the time of the study, only forty vehicles were operational; all the others were lying in the Council garage, some for as long as a year. The Engineer felt that it could be more profitable for the council to engage an outside garage to repair its vehicles. A single vehicle, like a Mercedes lorry costs over a million shillings, and for it to remain idle for over a year is quite a big loss to the Council.

2.1.3.4 Treatment Works

This section is in charge of water treatment, dams maintenance and water laboratories. The supervision of the day-to-day operation of dams, water treatment works, and water laboratories is delegated to superintendents who work at the plants but keep in constant touch with the engineer at the Kampala Road Depot. Treatment plants are located at Sasumua, Ngethu and Kabete, and the central laboratory is located at Kabete. The water from Sasumua and Ngethu is treated at the source, whereas that from Ruiru and Kikuyu is treated at Kabete.

The function of the water laboratories is to test the water to determine whether it is suitable for human consumption before it is distributed to the consumers.

The Resident Engineer at Kampala Road Depot is mainly occupied in ordering and supplying chemicals for the various plants and in serving as a consultant for any problems which the Superintendents at the site cannot solve, and in giving general advice on matters of water treatment and quality. He also maintains records of water flow and quality, and reservoir levels.

2.1.3.5 Labour

There is an intricate relationship between this sub-section and all the other sub-sections of the Operation and Maintenance Section, for the labour is organised on a pool basis. Each sub-section uses a part of the labour force either continuously or on an intermittent basis.

As apparent from the organisation chart, the maintenance gang is organised into four groups on a more or less permanent basis:-

i) Meter Section - This group, working very closely with the Commercial Section, is mainly deployed to disconnect meters for non-payment of water bills, and to reconnect them for subsequent payment. The group is also responsible for the installation of new meters.

ii) Trunk Mains Group - This group maintains the pipes from supply sources to water reservoirs i.e. from the sources to city storage reservoirs, and reservoirs themselves.

iii) Distribution Mains Group - Distribution mains are pipes of 3 inches and above in diameter, distributing the water from the various storage tanks and reservoirs to the estates. Apart from maintaining these pipes, this group is also responsible for regulating the flow of water by closing and opening the relevant valves.

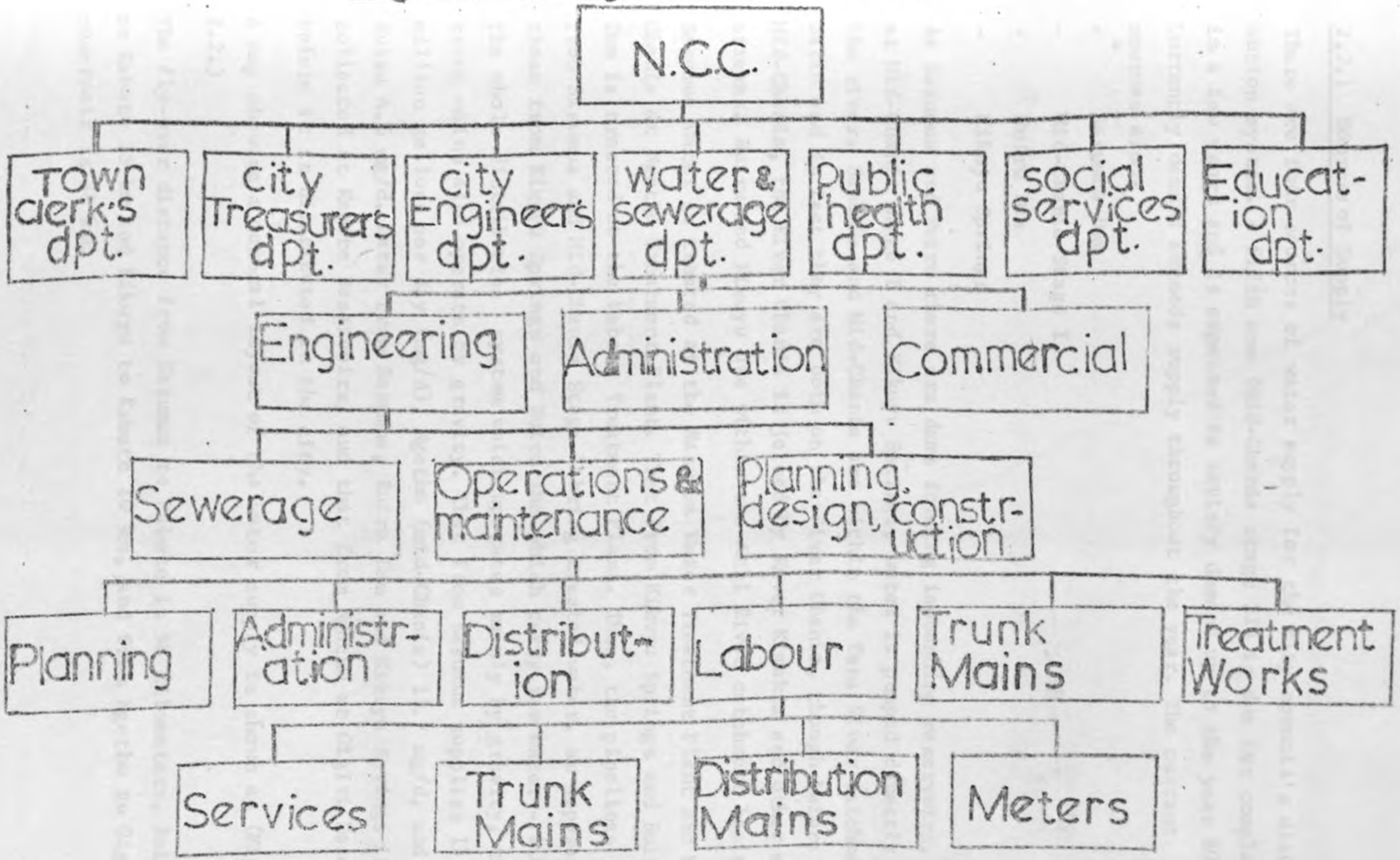
iv) Service Connections Group - Service pipes are those below 3 inches in diameter, and they distribute water in the estates and to individual consumers. This group together with Distribution Mains Group comprise the bulk of the maintenance gang.

In addition to these more or less permanent groupings, a new group is formed wherever a new supply scheme has to be constructed and on completion of such a scheme, the labourers rejoin their original groups.

The purpose of maintaining a pool labour force is for better industrial relations. Since nearly all the sub-section heads are expatriate Engineers, who are normally engaged on two and half year contracts, it is felt that by the time they come to grips with the social-cultural factors guiding labourers' behaviour, their time is up for leaving; hence a local person is entrusted with the control of labour. Each group is headed by an Assistant Chief Inspector who is subordinate to the Chief Inspector.

The service connections and distribution mains groupings are of major significance to this study, for they are charged with the responsibility of repairing the leaks and bursts which form the backbone of this study. The line of authority in these groups flows from the Assistant Chief Inspector to Inspectors down to foremen - who are in charge of the artizans and the unskilled labourers.

Figure 2.1: Organization Chart



2.2 SUPPLY SYSTEM

2.2.1 Sources of Supply

There are four sources of water supply for the city council's distribution system. A fifth one (Mid-Chania stage II) is due for completion in a few years and is expected to satisfy demand up to the year 2000. Currently demand exceeds supply throughout the year. The current sources are:-

- Sasumua Dam
- Mid-Chania Stage I
- Ruiru Dam
- Kikuyu Springs

At Sasumua and Ruiru there are dams forming impounding reservoirs, but at Mid-Chania Stage I and Kikuyu Springs, water is pumped directly from the river. Sasumua and Mid-Chania are within the Tana River catchment basin and in fact they are both on the River Chania, though before the Mid-Chania, the River Chania is joined by River Kimakia and other minor streams. Ruiru and Kikuyu are within the Athi River catchment basin.

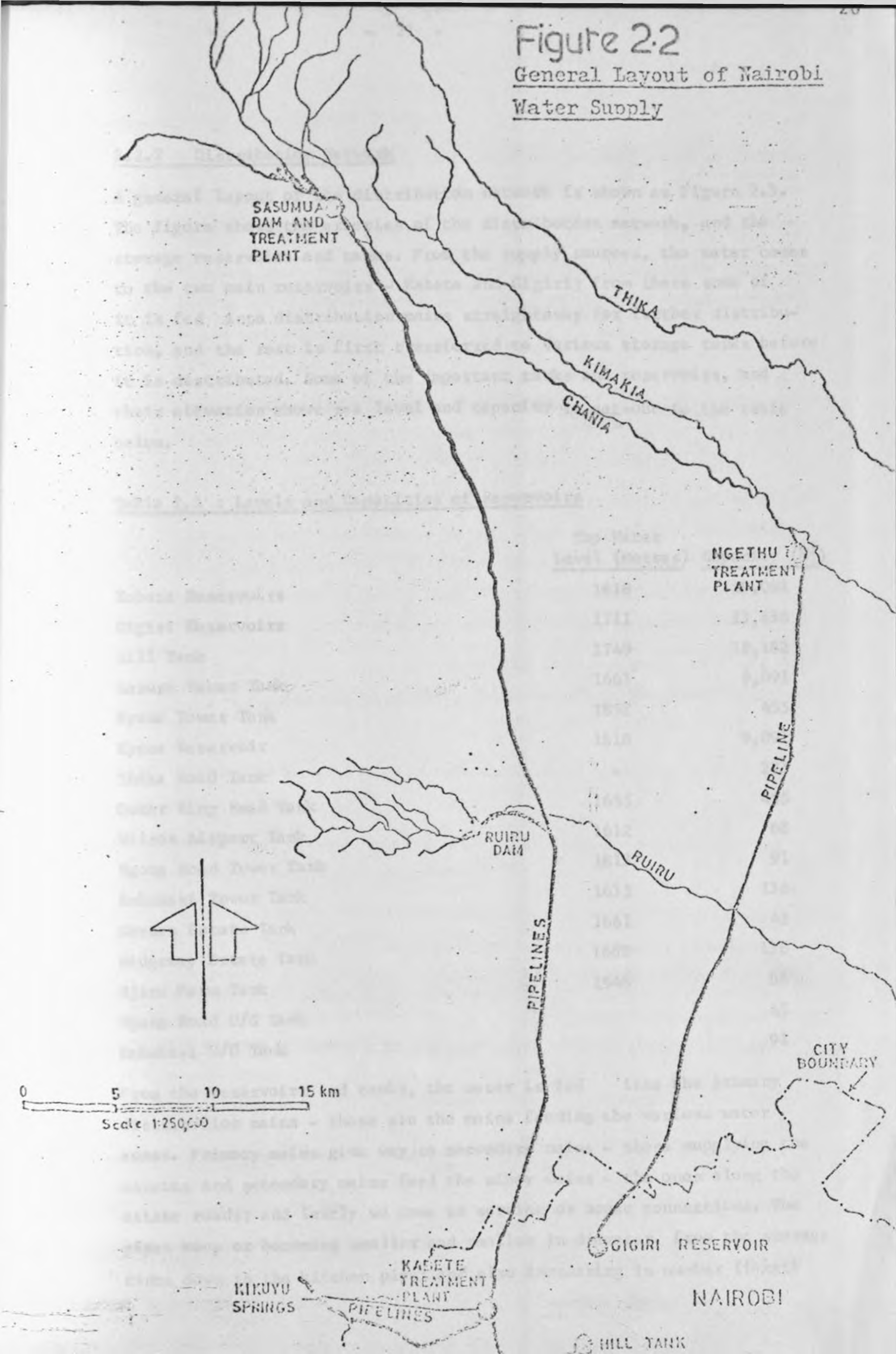
Sasumua water is treated at the Sasumua Water Treatment Plant and Mid-Chania at Ngethu Treatment Plant. That from Kikuyu Springs and Ruiru Dam is treated at the Kabete Treatment Plant. Thus, the pipelines from Sasumua and Mid-Chania Stage I bring treated water, as opposed to those from Kikuyu Springs and Ruiru Dam which carry raw water - like the whole distribution system which operates mainly by gravity, these trunk mains also operate by gravity. That from Sasumua supplies 13 million gallons per day (mg/d), Ngethu (mid-Chania) 11.7 mg/d, and Ruiru 4.5 mg/d. Water from Sasumua, Ruiru Dam and Kikuyu Springs is collected at Kabete Reservoirs, and that from Ngethu at Gigiri Reservoirs, before it is distributed in the city.

A map showing a general layout of the water supply is shown as (Figure 2.2.)

The fly-over distance from Sasumua to Kabete is 58 kilometers, Ruiru to Kabete 25 km and Kikuyu to Kabete 10 km, and from Ngethu to Gigiri reservoir is 38 km.

Figure 2.2

General Layout of Nairobi Water Supply



2.2.2 Distribution Network

A general layout of the distribution network is shown as Figure 2.3. The figure shows the arteries of the distribution network, and the storage reservoirs and tanks. From the supply sources, the water comes to the two main reservoirs - Kabete and Gigiri; from there some of it is fed into distribution mains straightaway for further distribution, and the rest is first transferred to various storage tanks before it is distributed. Some of the important tanks and reservoirs, and their elevation above sea level and capacity is set-out in the table below.

Table 2.1 : Levels and Capacities of Reservoirs

	Top Water Level (Metres)	Capacity (M^3)
Kabete Reservoirs	1818	59,091
Gigiri Reservoirs	1711	13,636
Hill Tank	1749	18,182
Karura Tower Tank	1663	9,091
Kyuna Tower Tank	1852	455
Kyuna Reservoir	1818	9,091
Thika Road Tank	-	273
Outer Ring Road Tank	1655	455
Wilson Airport Tank	1612	68
Ngong Road Tower Tank	1813	91
Embakasi Tower Tank	1635	136
Garden Estate Tank	1661	45
Ridgeway Estate Tank	1688	136
Njiru Farm Tank	1548	68
Ngong Road U/G Tank		45
Embakasi U/G Tank		91

From the reservoirs and tanks, the water is fed into the primary distribution mains - these are the mains feeding the various water zones. Primary mains give way to secondary mains - those supplying the estates and secondary mains feed the minor mains - the ones along the estate roads; and lastly we come to service or house connections. The pipes keep on becoming smaller and smaller in diameter, from the storage tanks down to the kitchen pipe; and also increasing in number (length and lines) as the diameter falls.

The flow is entirely by gravity, except a few booster pumps which have been installed to pump water to high grounds.

There are pressure zones, but these are not clearly distinct:-

i) Western zone, from Upper Hill and bounded roughly by Ngong forest and Waiyaki Way to the North, is fed from Kabete reservoirs and Dagoretti Area in particular is fed by water from Kikuyu Springs.

ii) Central zone, covering city centre, part of industrial area and Nairobi West area, is fed from Kabete reservoirs and Hill tank.

iii) Near Eastern zone, west of the central zone up to Outer Ring Road and extending from Mathare to the lower part of the Industrial area, is supplied from Hill Tank through a pressure reducing value in Lusaka Road, directly from Gigiri reservoir and from Kabete reservoir through a pressure reducing value in Forest Road.

iv) Far Eastern zone, east of Outer Ring Road and south of Thika Road is fed from Karura reservoir, Thika Road Tank and Outer Ring Road Tank.

v) Airport zone, is supplied from Outer Ring Road Tank and Embakasi Tank.

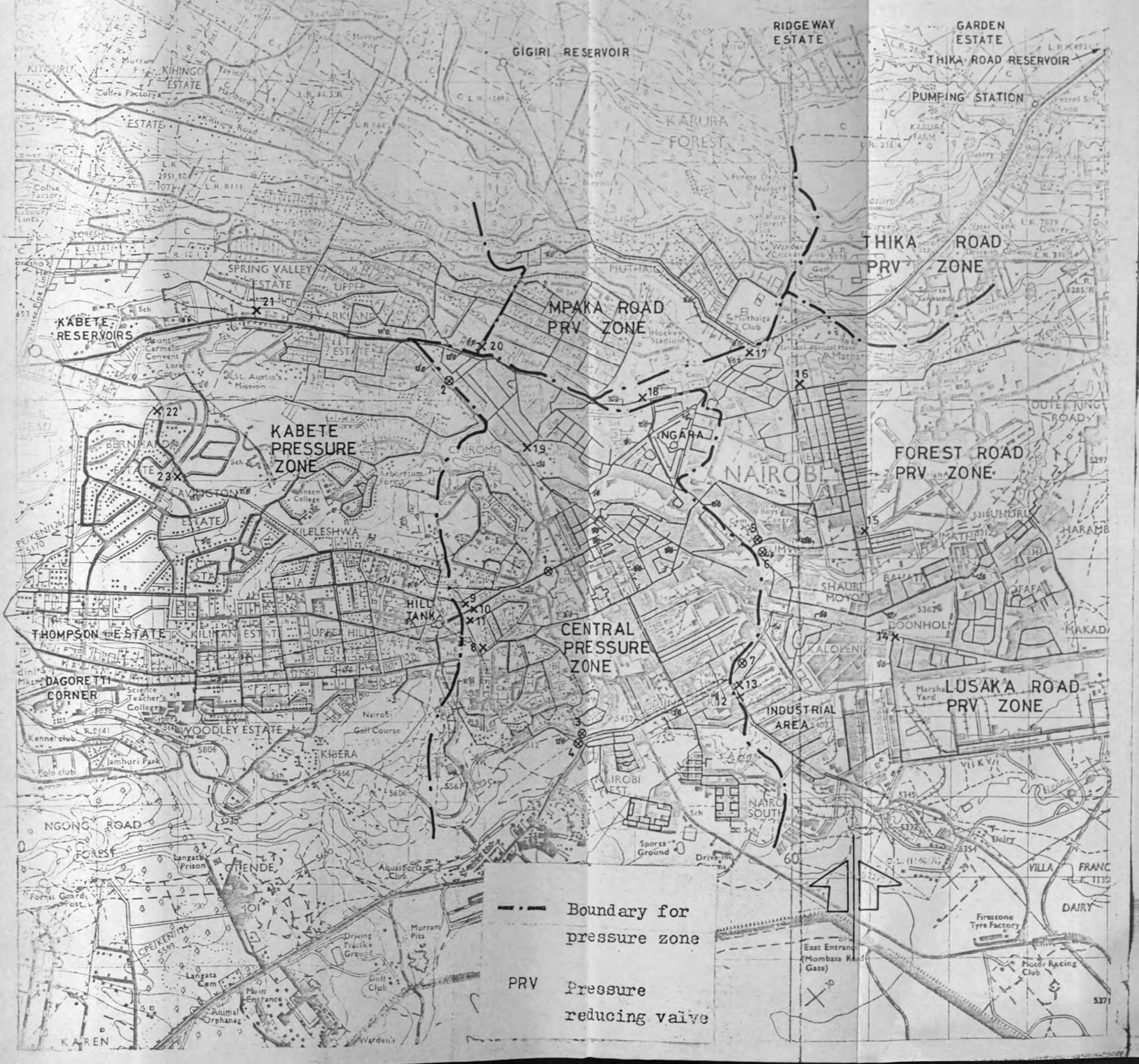
vi) North-Eastern zone, around Garden and Ridgeway estates, is fed directly from Gigiri reservoir.

vii) Northern zone, beyond Upper Parklands and Waiyaki Way, is supplied directly from Gigiri reservoir and the western side from Kyuna reservoir.

Most of the older areas (within the 1963 city boundary) are supplied with water from Kabete as opposed to the new areas which are supplied from Gigiri reservoirs.

Figure 2.3

Existing Water Distribution System



2.3. NATURE AND METHOD OF OPERATIONS

2.3.1 Control Room

This room is the hub of communication to and from Kampala Road Depot. There are three telephones and two radios, manned by a foreman and six attendants, who work around the clock in three shifts.

Telephones are used just like other ordinary telephones, though most of the time is spent in receiving consumer complaints and messages from the various points in the water system where there are telephones.

Radios are for communicating with men on the working sites and with the outer stations like Sasumua, Gakoe, Mundoro, Ngethu and Ruiru. One set (yellow set) is for communicating with the outer stations whereas the other set (blue set) is for Nairobi area only. Similar to the blue set in the control room there are other blue sets fitted into vehicles (10 at present) and it is through these sets that the men on the sites are able to communicate with the depot. The men on the sites can also communicate between themselves, but they have to be connected by the base. In addition to those fitted on the vehicles, there are also two portable blue sets, one at Karura and the other at Loresho reservoirs.

Outer stations, apart from possessing the yellow sets for communications with the depot, have red sets for their own internal (local) communication. Each colour set uses a different frequency, hence the existence of the three different colours.

2.3.2 Water-works

When consumer complaints come in, mainly through the telephone, they are recorded on a water-work sheet which contains the following information - Figure 2.4.

Figure 2.4 : Water-works

CITY COUNCIL OF NAIROBI WATER-WORKS	No........
Situation..................................	Date................
Road/Street................................	
Plot No....................................	
To: Chief Inspector Please attend to the following:	To: General Manager Action taken.
....	....
....	....
....	....
....	....
.... Signed.	..............for Chief Inspector

The main contents of this sheet are the location of the fault, the type of fault and the subsequent action taken.

One copy of the water-work is passed on to the relevant person (often to the Assistant Chief Inspector for further distribution) for action. Most of the complaints are sent either to the Mains or Services, and a few to the Meter Section. When the necessary action is taken, the worker who performs the job, fills the "Action Taken" side of the water-works and the sheet is returned to the Control Room for filing.

The Control Room also maintains a record book, having the number of columns as shown below:-

Figure 2.5

DAILY COMPLAINTS BOOK

Date	Time	Address	Complaint	Water-works Sheet No.	Passed to	completed by
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

This book is thus a permanent record of the contents of the Water-works, and note that the serial number of the water-work is also recorded to keep a track of all......

the water-works filled by different attendants. The contents are the same as those of the water-works i.e. the complaint, its address, and finally the action taken.

Reports are also received in the control room, from the general public. about various problems or faults seen or detected in the water system. Such problems are dealt with or follow the same process as those received from affected consumers - going through similar recording before any action is taken. A few serious problems like bursts of the mains are given preferential treatment. Such problems are reported directly by radio from the control room to the men in the field(preferably those working near the burst) for quick action.

The Daily Complaints Book has been a major source of data for this study.

2.3.3 Labour Deployment

The labourers are collected from different areas of the city in the morning (collection centres being mainly in their areas of residence) and are brought to the depot. The labourers (unskilled labour) and the artizans leave the depot with a foreman in a lorry and around 8.30 or 8.45 a.m. and often even later. The foreman then drops groups of men and artizans at different jobs in different areas. These jobs can be very far from each other, so usually by the time he drops the last batch of men, it can be as late as 10.30 a.m. or 11.00 a.m. The foreman then goes around to supervise and enquire about any shortages or further materials required in these jobs. At times some teams do finish their jobs before the foreman comes around, and they have to sit idle until he comes to transport them to another job or back to the depot.

The foreman starts picking up the workers at around 2.30 p.m. and in order to reach back at the depot by 3.30 p.m. where the tools are returned and materials for the following day are drawn out. The men are ready for home by 4.00 p.m. From here the men are taken back to the various areas in the city where they are dropped to go home.

From the above account, it is clear that on average the labour is working for 4 to 5 hours out of the official 8 hours a day.

The foremen are normally assigned to particular areas of the city on a permanent basis, so that he becomes familiar with the place, roads pipes, valves etc. The foreman normally comes back for material after dropping his men and determining the material required for the jobs. The main reason for coming back for material, is the lack of knowledge in advance as to the material required by various jobs until the pipes are dug-up and inspected. The Assistant Chief Inspector is responsible for allocation of work. The allocation is done by 4.30 in the evening for the next day. Changes in this allocation only occur in case of emergency or absentees.

Night emergencies are handled by a night team (a foreman, an artisan and 3 labourers, and a driver).

Normally each team of operative workers on routine repair jobs is composed of an artisan and three labourers.

2.4 NEED FOR MORE THAN ONE DEPOT

During the long vacation following the end of our first year 1978/79 Academic Year, (see bibliography) we conducted a research in the operation and maintenance section with the aim of investigating its operational efficiency. The inefficiencies revealed gave me the impression that, the present location of the depot does contribute significantly to the overall in-efficiency of this section. I discussed this view with the Chief Assistant Engineer and my supervisor (Dr Kohler), and they also saw the necessity of an alternative location of the depot. The funds already sunk in this construction (present depot) precludes the idea of transferring it to another location. The only feasible alternative is the setting up of minor depots, but we shall come to that later.

2.4.1 Operational inefficiencies

One of the findings of that study, which is of significance to this study is how the repair teams utilize an average day. The table of utilisation is reproduced here for further analysis:-

TABLE 2.2 UTILIZATION OF AN AVERAGE DAY

	Total time	Average time spent in depot in the morning		Average travel time to job		Average time on job		Average travel time from job	
SECTION	HRS	HRS.	MIN.	HRS.	MIN.	HRS.	MIN.	HRS.	MIN.
MAINS	8	1	00	1	21	4	22	1	17
SERVICES	8	1	14	1	13	4	08	1	25
AVERAGE	8	1	07	1	17	4	15	1	21

The table shows that:-

i) The non-working time is 3 hours and 45 minutes (1.07 + 1.17 + 1.21) which means that out of the official working hours, the workers are off the job and non-working for 47% of the working day.

ii) the travel time to and from the depot amounts to 2 hours and 38 minutes (1.17 + 1.21); which is 33% of the official hours.

Whereas idle time at the depot in the morning (caused by the morning allocation of jobs which in theory are allocated the previous day, and by locating the exact position or site of the various jobs) can be reduced considerably by better management, very little can be done about time lost in travelling as long as the depot remains as the only base of operation.

The main reasons why the travelling time is so high, is the non-central location of the present depot and the large geographical size of the area served.

2.4.2 Size of the area served

The mid-Chania phase I project was taken into service in 1974 and prior to that date, the area supplied with water was roughly confined to the pre-1963 city boundary. The size of the old city is about 11,500 hectares with a distance of 15 km. from East to West and 8 km. from North to South. The increased water supply from the mid-Chania Phase I, emabled the NCC to supply water to new areas outside the old city boundary. The new area covers about 9,200 hectares; and with that expansion of water supply, the distance now served by the Repair team from East to West in 17 km. and from North to South is 15 km. The total area served with water is 20,700 (11,500 + 9,200) hectares, and this is not a small area by any standards.

The total area which will be supplied with water after the completion of Mid-Chania Phase II, which is due for completion by 1983, will be quite large. The daily water supply from this project will be more than double the amount currently supplied by Phase I.

If this huge area will continue to be served from the present depot only, the travelling time between the depot and the various working sites will surely keep on rising as more and more outlying zones are supplied with water. The amount of fuel consumed by vehicles and their depreciation will equally rise, and the consumer complaints will take longer to satisfy. The longer the leaks are left unattended, the higher the amount of water will be lost, resulting in financial loss to the NCC.

The problem of long distances between the depot and repair sites will be further aggravated by the fact that, the present depot is located in southern edge of the city, in fact very close to Nairobi National Park which limits the expansion of the city to the southern side. The city is expanding to the eastern side which is literally devoid of any population, and to a lesser extent to the western side where the city services (water included) are being provided on a gradual basis to the existing population. As these services are provided, the population increases at a faster rate.

3. DATA COLLECTION, ANALYSIS AND INTERPRETATION

The ultimate purpose of this study is to find the ideal location of additional depots. The best location can only be found after predicting the number of leaks expected to occur on the water system in the future. To predict the number of leaks expected to occur, the historical data available i.e. the number of leaks reported over the five years - 1975 to 79 had to be collected and analysed to reveal the main causes of these leaks.

Two main problems, namely how to subdivide the city into small regions for the purpose of data collection, and how to measure the length of piping in the water system, were encountered at the commencement of the study. These problems were nevertheless solved, thanks to the constructive suggestions from relevant council employees and my supervisor in particular.

3.1 CORE DATA

The number of reported leaks formed the backbone of this study and the very initial task which had to be undertaken was to collect this data in an organised manner suitable for testing the two variables i.e. the length of piping and the age effect, believed to be the main determinants of these leaks.

3.1.1 Organisation of Data Collection

As stated in the introductory paragraph of this chapter, it was crucial in the course of this study to predict the number of leaks expected to occur in the water system in the near future, this being the necessary ground work upon which the next phase of the study, i.e. depot location, was to be based.

The immediate goal being to find out the number of leaks expected to occur in the various sections of the city, it was necessary to subdivide the city into small regions. After finding the number of leaks in each of these regions the question of the ideal location of the depots could then be taken up. Finding out the number of leaks in each and every region would not have been feasible and as such representative samples had to be selected. A predictive model developed for such representative area was used to predict the number of leaks expected to occur in all the other regions of the city which had the same characteristics (type of soil, type of pipes) as the representative area.

The overiding criterion for the subdivision of the city into small regions was to permit an easy measurement of the length of piping in a region at least in relative terms. In addition to that basic criterion it did become apparent at a later stage in the study that each region had to have one type of soil only, due to the different degree of corrosiveness of these soils on the piping material.

Relative length of piping can be calculated with ease where the plot size in a region is the same. In a region zoned for a certain plot size, the length of piping would double if a further area equal in size to the one already developed is also developed. Detailed explanation for this assumption is given in Section 3.2.4. But to apply this general rule of the number of plots as the relative measure of the length of piping, the present and the future or planned development of a zone had to be quite similar i.e. the plot size would remain the same.

The City Engineer's Department maintains maps of existing and proposed plot sizes. One such map completed in January 1979 divides the city into 20 zones, and in addition to specifying the existing and proposed plot sizes, it also gives the current and proposed land use for each zone i.e. whether such zone is predominantly residential, commercial or industrial in use. Such categorization of land use was also important since population data which is used extensively in this paper, for estimation of number of houses in an estate - apply only in residential areas.

The subdivision of the city into 20 zones was too broad for the purpose of this study, nevertheless it was a very important starting point upon which further refinement was to be based. The zoning was particularly important in two aspects: the plot size and the existing and proposed type of development.

The 20 zones were further sub-divided into smaller zones by grouping two or three neighbouring estates into a single unit. The sub-division in the end produced forty regions; where you find:-

1) The existing and proposed plot sizes are nearly the same.
2) A single type of soil is predominant
3) The existing and proposed road network is quite comprehensive.

Establishing what type of soil was predominant in each region was a matter of checking on the soil survey maps available.

3.1.2 Number of Leaks

The representative samples upon which the final generalization for the whole city was to be based was selected very carefully, particular care being taken to make sure the requirements set out in section 3.1.1 were met. The selected areas were well spread over the whole city, covering the main requirements i.e.

a) The different plot sizes

b) The different types of soils

c) Recent and old estates

d) The different land uses.

The areas selected were the City Centre, Industrial Area, Lavington, Muthaiga, Umoja, Eastlands, Buruburu, Parklands and Nairobi South-West which was a necessary addition as we shall see later.

To cover the different plot sizes, the city was classified into three categories of residential zones, the high, middle and low income areas. A 1974 classification classifies people earning between 0 to 699/- per month into low income group, 700 to 2,499/- and over 2,500/- into middle and high income groups respectively. The general level of incomes must have risen a bit over the 1974 incomes, and the general shortage of housing in the city has forced some families to live in poorer sections of the city than would be expected, but all the same the general demographic distribution is in line with income levels. Secondly, the City Council is strict on the standard of housing for each estate for the purposes of planning of social amenities.

Low income earners are confined to poorer sections of the city, where the standard of housing is generally poor and the plot sizes are the smallest. Residences range from small terraced houses and single rooms with communal bath and toilet facilities, to highly congested slums like Mathare Valley. High income earners on the other extreme, reside in the "posh" areas of the city, where plot sizes are biggest, each family occupying a detached housing unit and the very rich have even gardens as big as a full hectare. The middle income group live in houses of a standard in between the poor and the rich, most of them living in semi-detached houses like those found in areas like Buruburu Estate. Plot sizes are progressively bigger as you move from low income to high income areas.

Muthaiga and Lavington were selected to represent high income areas, Parklands, Buruburu and Nairobi South-West the middle income areas, and Umoja and Eastlands the low income areas. Such selection then ensured proper representation of each income level, and hence different plot sizes.

The age factor was also catered for in the choice of these areaa, and as we shall see later, each set was made up of a recent and an older region. The spread of this choice of region over the whole city ensured the coverage of different soil types.

The Industrial Area and the City Centre were to represent industrial and commercial areas respectively; as opposed to the other purely residential areas.

The data on the number of leaks (the term leak as used in this study covers all types of faults occuring on the water pipes) as extracted from the Daily Complaints Book are set out in the table below.

TABLE 3.1

NUMBER OF LEAKS

	High Income		Middle Income			Low Income			
	Lavington	Muthaiga	Buru-Buru	Parklands	Nairobi S.West	Umoja	Eastlands	Industrial Area	City Centre
1975									
Services	63	20	39	108	138	15	288	122	207
Mains	8	2	5	20	22	0	25	22	40
TOTAL	71 (85)	22 (26)	44 (53)	128 (154)	160 (192)	15 (18)	313 (376)	144 (173)	247 (296)
1976									
Services	22	30	41	198	189	19	315	127	269
Mains	4	5	3	28	16	3	33	39	41
TOTAL	26	35	44	226	205	22	348	166	310
1977									
Services	48	42	109	247	232	113	311	239	399
Mains	4	2	12	27	26	11	16	33	40
TOTAL	52	44	121	274	258	124	327	272	439
1978									
Services	55	44	123	398	271	95	344	316	377
Mains	12	2	21	45	32	14	29	91	75
TOTAL	67	46	144	443	303	109	373	407	452
1979									
Services	113	42	235	389	280	224	463	389	408
Mains	11	1	37	61	55	51	44	128	84
TOTAL	124	43	272	450	335	275	507	517	492

The data available for 1975 was from the months of March to December, and an adjustment was made by multiplying the figures for these ten months by 1.2. The new figures (in blackets) which were obtained are the ones that were used in subsequent analysis.

The data for each year is classified into services and mains, pipes of over 3 inches in diameter being classified as mains, and those of 3 inches and below as service pipes. Repair gangs, as explained in Chapter II are also grouped into these two broad classifications mains and services, and there are good reasons for these groupings. Vehicle allocation (different sizes of vehicles), job scheduling, and the need for job specification being among the most important reasons.

No rigorous analysis was made along these two classifications, apart from noting the nearly consistent ratio between the number of leaks on the services and the mains. The ratio itself is a useful tool for future planning of labour deployment.

3.2 REGRESSION MODEL BUILDING

An exciting discovery from an elementary analysis of the table of the number of leaks was the fact that the number of leaks per hectare was rising from year to year in each of the chosen regions without exception. This fact is quite apparent from the table below.

TABLE 3.2
NUMBER OF LEAKS PER HECTARE

Period	Lavington	Muthaiga	Buru-Buru	Parklands	Nairobi S-West	Umoja	Industrial Area	City Centre
1975	0.11	0.03	0.11	0.18	0.37	0.04	0.13	0.80
1976	0.03	0.04	0.09	0.27	0.39	0.05	0.15	1.00
1977	0.06	0.05	0.25	0.33	0.49	0.25	0.25	1.42
1978	0.08	0.06	0.30	0.53	0.58	0.22	0.37	1.46
1979	0.15	0.05	0.57	0.54	0.64	0.56	0.47	1.59

The immediate task following this important discovery was to investigate, in a rather approximate manner, whether each of the three factors (length of piping, age of piping and the type of soil) contributes significantly to this continous increase in the number of leaks.

3.2.1 Length of Piping

The length of piping laid in an estate should be proportional to the number of houses in that estate. The reasoning behind this assumption is clearly set out in a later section of this chapter. Given that this assumption is correct, the length of piping would double where the number of houses are doubled approximately.

Armed with the above assumption, what was necessary was to find out the number of houses in a particular estate, at the commencement of the study and those built during the period of the study, and relate these initial and the subsequent constructions to the number of leaks reported over the same period. This was the ideal way of relating the number of houses to the number of leaks, but at this early point of the study when a complex analysis was not intended, an exact determination of the number of houses would have taken too much time in view of the simple analysis intended. An easy way of determining the number of houses in an estate at a given point in time had to be found, and the population of the estates, which was easy to determine, became very useful in that respect.

Council planners are convinced that the population of a particular type of an estate is proportional to the number of houses in such an estate, and they make extensive use of this apparent relationship for their planning purposes. Using their established and tested standards, it was easy to translate the population of an estate into the number of houses. But, even without going to the trouble of this conversion, this proportionality between the number of houses and the population means that, if a relationship between the population and the number of leaks was established, this would be a positive confirmation of an existence of a relationship between the number of leaks and the number of houses.

The City Council maintains fairly accurate estimates of the population of the various estates (a fact which is confirmed by Census figures). These estimates of the population were used in trying to establish the existence of the said relationship. First a table of population versus the reported number of leaks was constructed then plotted on a graph, and finally correlation analysis was undertaken in an effort to prove either the existence or non-existence of a relationship between the number of houses and the number of reported leaks.

TABLE 3.3.

POPULATION AND NUMBER OF LEAKS

	Lavington		Muthaiga		Buru Buru		Parklands		Umoja	
	No.of Leaks	Pop.	No.of Leaks	Pop.	No.of Leaks	Pop.	No.of Leaks	Pop.	No.of Leaks	Pop.
1975	85	7080	26	3750	53	11,650	154	28,500	18	5,600
1976	26	7240	35	3850	44	15,950	226	29,500	22	11,800
1977	52	7400	44	3950	121	20,250	274	30,500	124	18,000
1978	67	7560	46	4050	144	24,550	443	31,500	109	24,200
1979	124	7720	43	4150	272	28,850	450	32,500	275	30,400

The growth of population is assumed to be roughly uniform between the two points, 1974 and 1979. In 1974, a population survey was carried out and the 1979 estimate was based on the results of this survey.

The above data was plotted on graphs, reproduced at the end of this section as figures 3.1 to 3.5, and in each graph, the points seemed to fall in a line.

Eastlands was excluded since the City Council estimated its population would remain static, and in fact no new constructions were undertaken in this region over the five years. City Centre, a commercial centre, and the Industrial Area were excluded from this population/leaks analysis for obvious reasons. Nairobi S.West was a later addition to the study and hence the omission at this point.

A closer look at these graphs revealed some sort of a linear relationship between the population and the number of reported leaks; and this would seem to strengthen the idea of the existence of a relationship between the two.

A freehand fit of regression lines revealed that such lines were neither passing through the origin nor cutting the Y - axis on the positive side, as would be expected. This behaviour implies that, below a certain level of population there were no leaks reported. This was rather puzzling at the beginning, but what one has to bear in mind is that a considerable number of houses have normally to be built before an area is supplied with water, and in other cases, an estate normally starts off with quite a number of houses. There is no time then when an estate has a very small number of houses for water supply purpose.

Correlation Analysis

A visual appearance of an apparent linear relationship between the number of leaks and the population had to be confirmed statistically. Secondly it was important to evaluate the strength of that relationship. The steps involved in carrying out these twin process were as follows:-

Step 1: Calculation of coefficient of determination, r^2.

Step 2: Taking the square-root of coefficient of determination, to get the correlation coefficient, r. By the look of the trend of the points on the graphs, r is bound to be positive, and the closer it is to one, the stronger the relationship between the number of leaks and the population.

Step 3: Computation of the following test statistic, t, where:-

$t = r\sqrt{\frac{n-2}{1-r^2}}$, which is distributed as student's t distribution with n-2 degrees of freedom.

The resulting t would determine whether the number of leaks were correlated to population at the chosen level of significance.

The analysis combines Muthaiga and Lavington, both high income areas, Parklands and Buru Buru together being middle income areas, and Umoja is treated alone since it is the only low income area from the set.

TABLE 3.4 -

HIGH INCOME AREAS

		Population (in 1,000's)		No.of Leaks (in 10's)		
		X	X^2	Y	Y^2	XY
Lavington	1975	7.08	50.1	8.5	72.3	60.2.
	1976	7.24	52.4	2.6	6.8	18.8
	1977	7.40	54.8	5.2	27.0	38.5
	1978	7.56	57.2	6.7	44.9	50.7
	1979	7.72	59.6	12.4	153.8	95.7
Muthaiga	1975	3.75	14.1	2.6	6.8	9.8
	1976	3.85	14.8	3.5	12.3	13.5
	1977	3.95	15.6	4.4	19.4	17.4
	1978	4.05	16.4	4.6	21.2	18.6
	1979	4.15	17.2	4.3	18.5	17.8
	$\sum$	56.75	352.2	54.8	383.0	341.0

$$r^2 = \frac{\left(\sum X_i Y_i - \frac{(\sum X_i)(\sum Y_i)}{n}\right)^2}{\left(\sum X_i^2 - \frac{(\sum X_i)^2}{n}\right)\left(\sum Y_i^2 - \frac{(\sum Y_i)^2}{n}\right)}$$

$$= \frac{\left(341 - \frac{56.75 \times 54.8}{10}\right)^2}{\left(352.2 - \frac{56.75^2}{10}\right)\left(383 - \frac{54.8^2}{10}\right)}$$

$$= 0.3627569$$

$$= 0.36$$

and, $r = 0.6$

An r of this magnitude means that there is a fairly strong relationship between the number of leaks and the population in the high income areas.

We may now compute the t statistic to enable us to conclude whether or not our sample data provides sufficient evidence to indicate that p (population correlation coefficient) $\neq 0$. The process involves the rejection of a null hypothesis that $p = 0$, and it is after this rejection we can conclude that there is a linear relationship between the population and the number of leaks. But before the hypothesis can be tested, we need to set the significance level, and we can let $\alpha = 0.1$.

The test statistic is:

$$t = 0.602293 \sqrt{\frac{8}{1 - 0.3627569}}$$

$$= 2.1340286$$

$$= 2.1340$$

$2.1340 > 1.8595$, the critical value of t for 8 degrees of freedom at 10% level of significance. The null hypothesis can be rejected, and we conclude that there is a linear relationship between the population and the number of reported leaks in the high income areas.

TABLE 3.5

MIDDLE INCOME AREAS

		Population (in 1000's) X	No.of Leaks (in 10's) Y
Buru Buru	1975	11.65	5.3
	1976	15.95	4.4
	1977	20.25	12.1
	1978	24.55	14.4
	1979	28.85	27.2
Parklands	1975	28.5	15.4
	1976	29.5	22.6
	1977	30.5	27.4
	1978	31.5	44.3
	1979	32.5	45.0
Total		253.75	218.1

$$\sum X_i^2 = 6896.7 \qquad \sum Y_i^2 = 6627.35 \qquad \sum X_i Y_i = 6314.5$$

$$r^2 = \frac{\left(6314.5 - \frac{253.75 \times 218.1}{10}\right)^2}{\left(6896.7 - \frac{(253.75)^2}{10}\right)\left(6627.35 - \frac{(218.1)^2}{10}\right)}$$

$$= 0.7108492$$

$$r = 0.8431187$$

$$= 0.84$$

This value of r tells us that there is a strong relationship between the population and the number of leaks in the middle income areas.

To compute the t statistic, we need to state the hypotheses and set the level of significance. The appropriate hypotheses are, $H_0: p = 0$
$H_1: p \neq 0$

Letting $\alpha = 0.05$

$$t = 0.8431187 \sqrt{\frac{8}{1 - 0.7108492}}$$

$$= 4.4348$$

Since 4.4348 $>$ 2.3060, the critical value of t for 8 degrees of freedom at 5% level of significance, Ho is rejected, and we conclude that population is linearly related to the number of leaks.

TABLE 3.6

LOW INCOME AREAS

		Population (in 1000's) X	No.of Leaks (in 10's) Y
Umoja	1975	5.6	1.8
	1976	11.8	2.2
	1977	18.0	12.4
	1978	24.2	10.9
	1979	30.4	27.5
Total		90.0	54.8

$\sum X_i^2 = 2004.4$ $\quad \sum Y_i^2 = 1036.9$ $\quad \sum X_i Y_i = 1359.1$

$$r^2 = \frac{\left(1359.1 - \frac{90 \times 54.8}{5}\right)^2}{\left(2004.4 - \frac{90^2}{5}\right)\left(1036.9 - \frac{54.8^2}{5}\right)}$$

$$= 0.8282$$

$$r = 0.9101$$

In these areas, the relationship between the number of leaks and the population is very strong.

We can now compute t, the hypotheses and the level of significance remaining the same as in the middle income areas.

$$t = 0.9101 \sqrt{\frac{3}{1 - 0.8282}}$$

$$= 3.803$$

3.803 $>$ 3.1825, and thus the null hypothesis can be rejected and conclude that the number of leaks are correlated to the population in the low income areas.

City population has tended to increase faster in lower income areas than in higher income areas. The strength of relationship between the number of reported leaks and the population, as would be expected is very much in conformity with this trend of population increase . Areas like Umoja with a high population increase, hence many new constructions and consequently longer new piping, show very strong relationship, unlike areas with very few new constructions, like Lavington and Muthaiga where other factors may have had a bigger influence on the number of reported leaks.

Before undertaking an investigation of these other factors, we may conclude this section by stating that, since the population of an estate is proportional to the number of houses, and having proved that there is a relationship between the number of leaks and the population, it is logical at this point to conclude that there is a relationship between the number of houses and the number of leaks. Given that a relationship exists between the number of houses and the number of leaks, we can likewise conclude that there is a relationship between the length of piping and the number of leaks.

Figure 3.1
Lavington

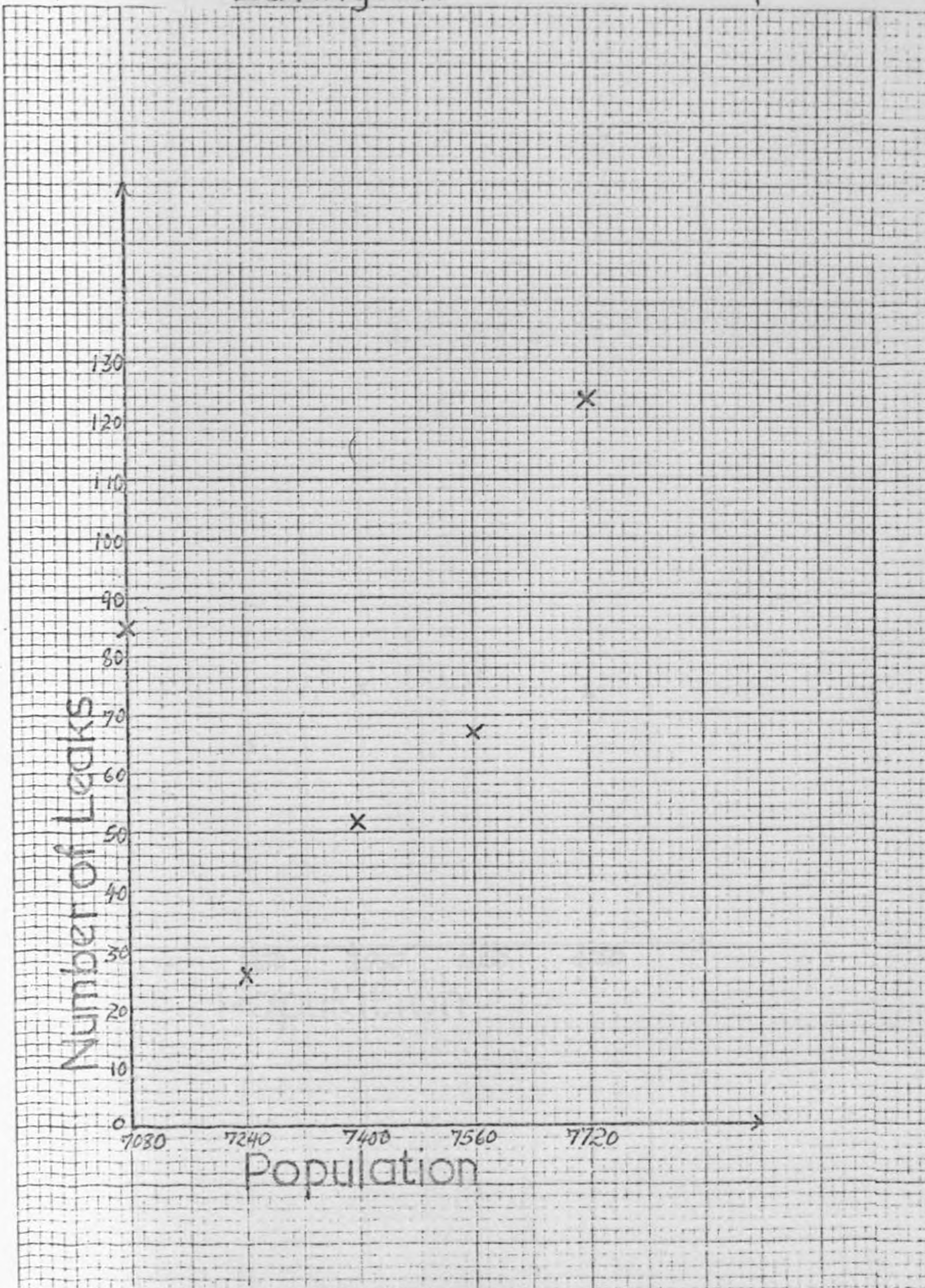


Figure 3.2

Muthaiga

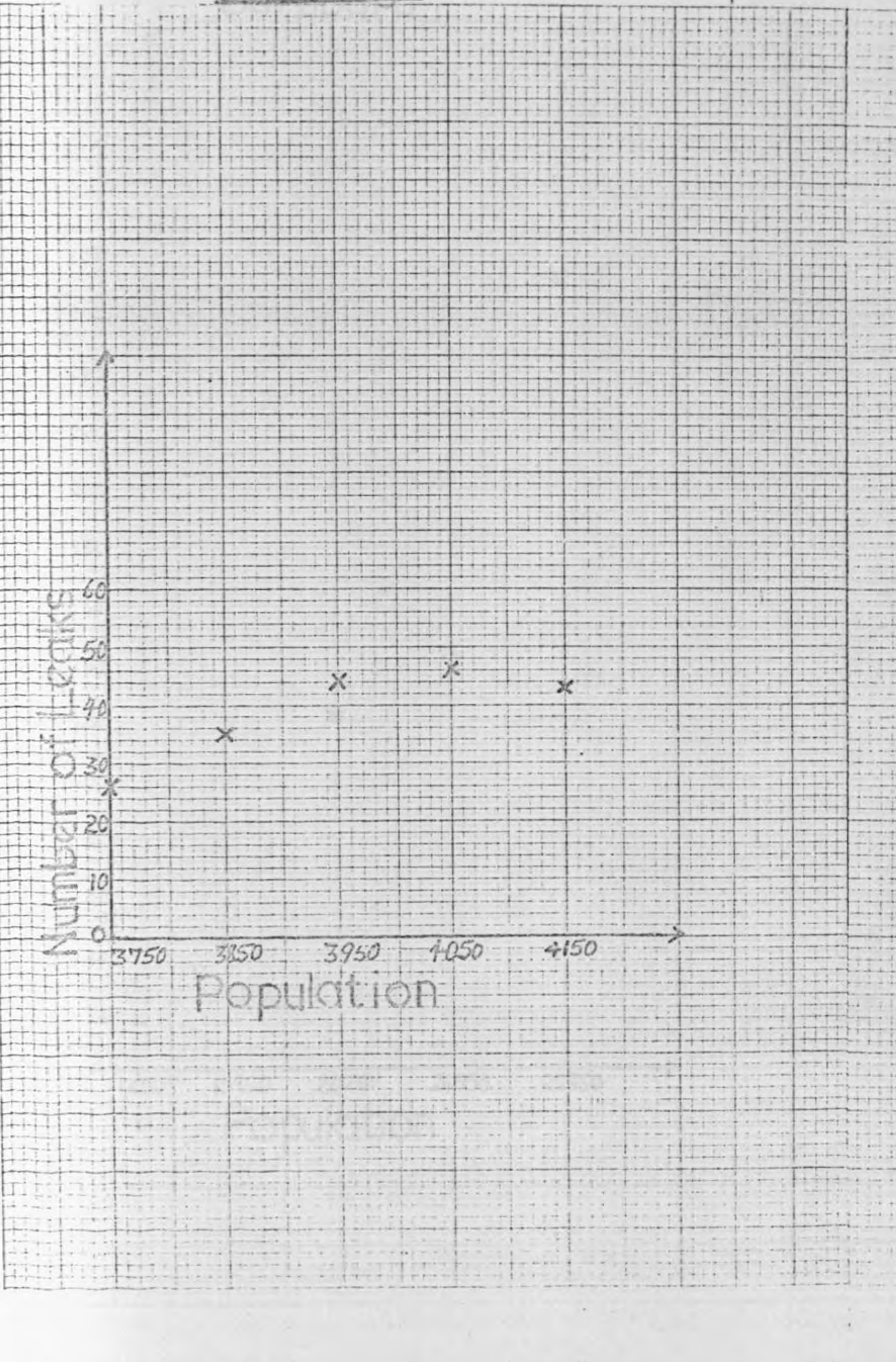


Figure 3.3
Buruburu

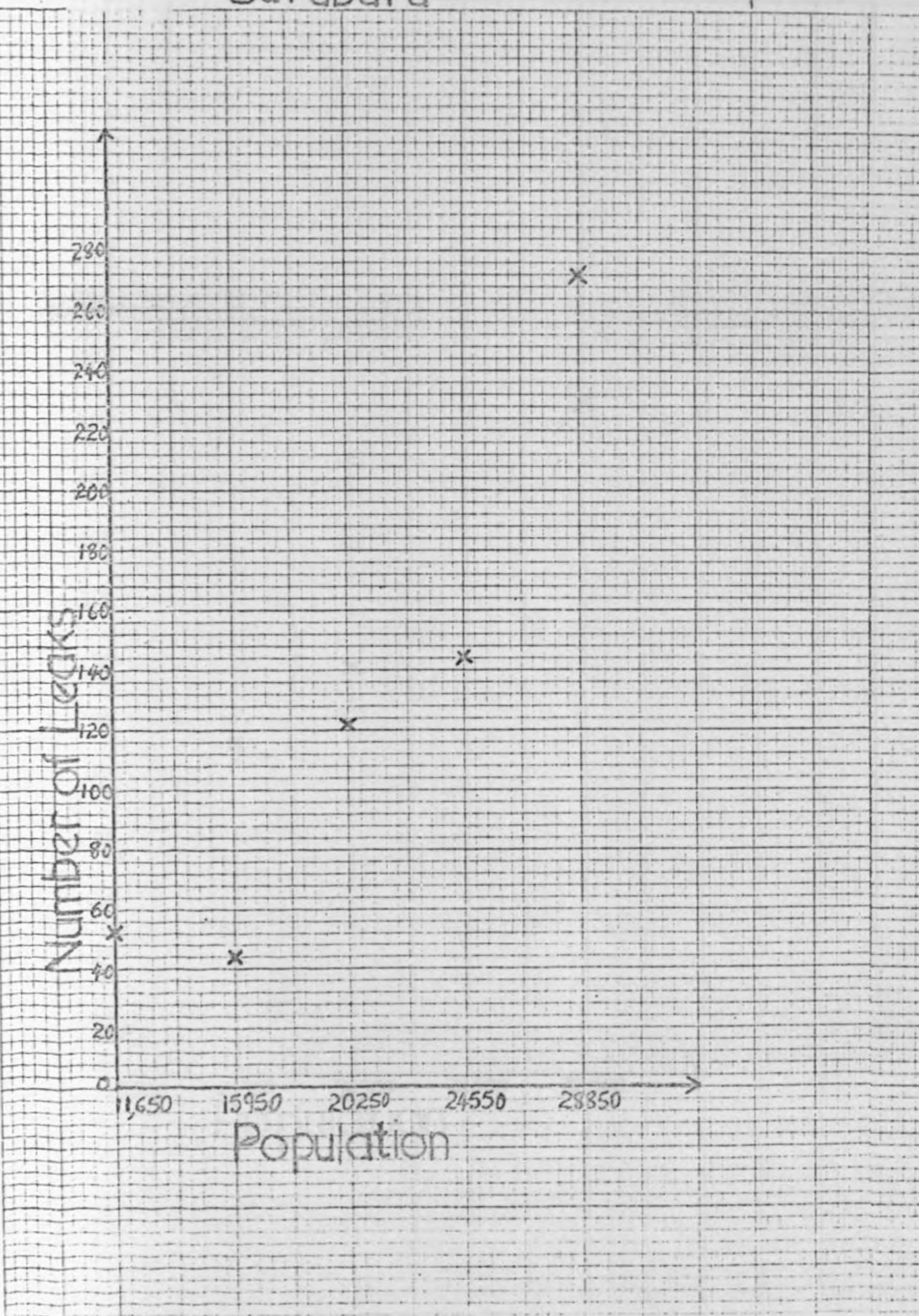


Figure 3.4
Parklands

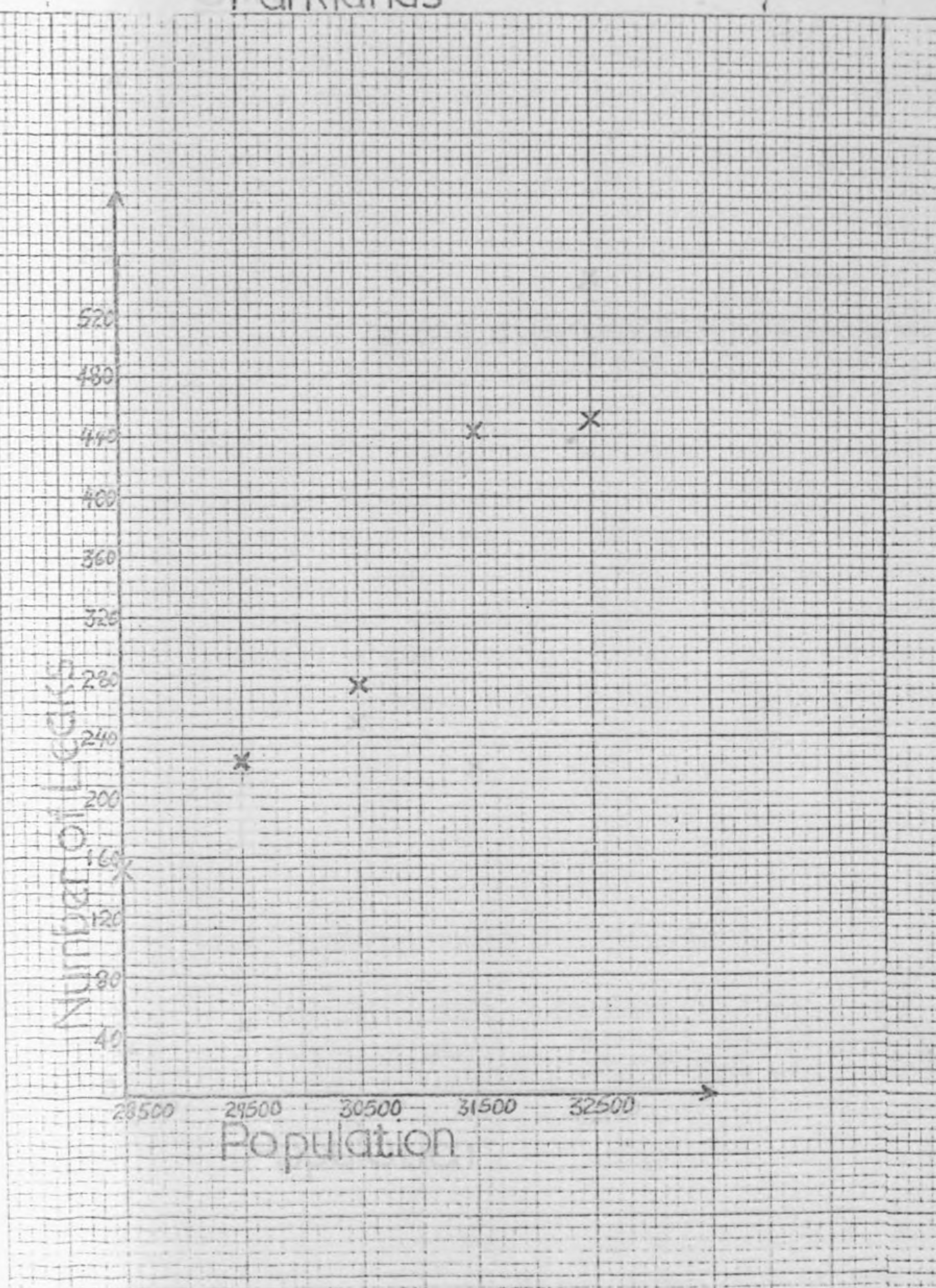
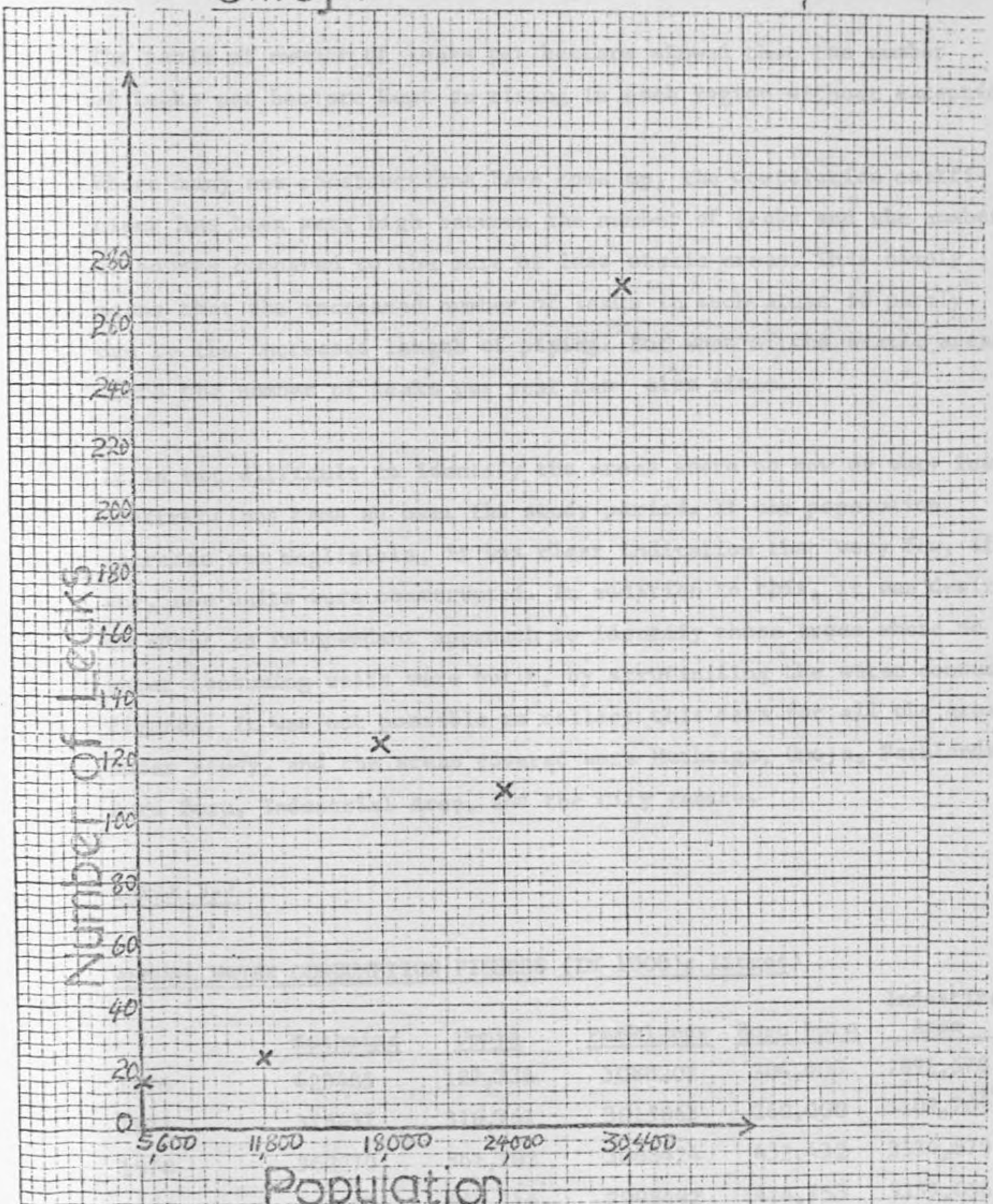


Figure 3.5
Umoja



3.2.2 Age Factor

The table of number of leaks per hectare showed that the number of leaks per hectare kept on rising in each region without exception.

Where many new constructions have come up, the correlation coefficient has been very high between the number of leaks and the number of houses compared to the more or less static areas. This simply means that the increased number of leaks in such areas is partly due to the increased length of piping. But what of the static areas where the number of leaks per year has also risen.

It is not difficult to identify the areas where no new or very few constructions came up over the study period. If the population increase was negligible, it was clear indication that very few, if any, new units were constructed. In addition to this, it was desirable to adopt an independent approach to identify those areas where no new water consuming units were built, by scrutinising the water consumption figures. It was not possible to collect this data for all the areas under study, and the areas covered were Muthaiga, Umoja, Parklands, Buru Buru, Industrial Area, and the City Centre.

TABLE 3.7

ANNUAL WATER CONSUMPTION FIGURES (IN 1000's litres)

	Muthaiga	Umoja	Parklands	Buru Buru	Industiral Area	City Centre
1976	423485	127,336	3088202	204,000	2891,578	3543700
1977	316437	316,761	3015063	360,000	3109,709	3529171
1978	362270	361,202	3088424	432,432	3534,879	3463443
1979	422503	444,316	2998492	474,753	3353,056	3920083

Droughts have an effect on water consumption figures, hence the occasional fall in consumption figures in some areas for some years instead of remaining constant or rising continuously.

A graph (not reproduced here) of litres per hectare against number of leaks per hectare was drawn for the following areas- Parklands, Buru Buru, Muthaiga and Umoja.

Consumption as well as the number of houses in Buru Buru and Umoja have increased tremendously, and there appeared to be a good linear relationship between consumption and the number of leaks in these two areas. The water consumption in an area should be proportional to the number of houses in that area, and therefore this relationship between consumption and the number of leaks, in addition to the presentation in section 3.2.1, showed that the number of leaks are related to the amount of housing.

Consumption in other areas, namely Parklands, Muthaiga, Industrial area and City Centre remained nearly constant, implying few houses came-up during this period. Nevertheless, the number of leaks in these areas continued to rise over the years. If no new houses, hence no change in length of piping, and the number of reported leaks continued to rise, it can only mean one thing, that as the pipes grow old, the number of reported leaks per year increase continuously. Age is thus a factor to be considered as the pipes grow old.

3.2.3 Soil Effect

A thorough study of the soil survey map reveals that the City of Nairobi is dominated by two contrasting soil types, whose characteristics and chemical compositions are quite different. These two types are commonly known as black cotton soil and red soil. There are of course transitional zones between these two types of soils, where the content of each type falls gradually as one moves from one zone to the other.

A SWECO study (see bibliography) of the underground leakage of the Nairobi water distribution system, states that black cotton soil is considered to be more corrosive than the red soil due to its higher moisture content than the red soil, and this fact is obviously important for this study and thus calls for a proper verification. In search for this verification, two areas, Westlands and Parklands were selected. The two areas are adjacent to each other and are quite similar in their development in terms of plot size and the general level of income of the inhabitants. Agewise the pipes in the two areas were laid around the same time. However, they are different in the type of soil found in each area, and thus they were ideally chosen for testing the soil effect on the number of leaks reported.

The data collected covered a period of two years 1978/79, and in each year, four months evenly spread over the whole year were covered.

TABLE 3.8

Number of Leaks in Parklands and Westlands

1978		West-lands	Park-Lands	1979	West-lands	Park-lands
February :	Services	13	13	March	15	21
	Mains	0	1		1	0
	TOTAL	13	14		16	21
May:	Services	27	21	June	21	19
	Mains	3	1		6	4
	TOTAL	30	22		27	23
August:	Services	11	13	September	19	15
	Mains	5	0		3	0
	TOTAL	16	13		22	15
November:	Services	14	20	December	22	8
		1	1		5	2
	TOTAL	15	21		27	10

The physical area of Parklands is 700 hectares as opposed to that of Westlands which is only 150 hectares. For comparative purposes it was then necessary to express the number of reported leaks in the two areas under a common denominator. This was accomplished by finding the number of leaks per hundred hectares for each of the month covered.

TABLE 3.9

Number of Leaks/100 hectares

1978	Westlands	Parklands	1979	Westlands	Parklands
February	8.7	2.0	March	10.7	3.0
May	20.0	3.1	June	18.0	3.3
August	10.7	1.9	September	14.7	2.1
November	10.0	3.0	December	18.0	1.4

These figures show clearly that the number of leaks/100 hectares are much more in Westlands than in Parklands and do not need any further analysis. Westlands is a black cotton soil area, whereas Parklands is a red soil area. The contention that black cotton soils are more corrosive than the red soils is thus confirmed. In addition to this confirmation, the Chief Assistant Engineer was emphatic on this fact, that black cotton soils are more corrosive than the red soils.

This fact established, the black cotton soil areas were treated separately from the red soil areas in the subsequent analysis.

3.2.4 Multiple Regression Analysis

In the previous section, it has been shown that the length of piping, age of the pipes and the type of soil have an effect on the number of reported leaks. The task of this section is to find a way of combining these separate causes into a single predictive model - thus developing the crucial equations for this study.

The starting point was to plot the number of leaks per 100 hectares against the number of houses per hundred hectares in each of the five regions (Umoja, Lavington, Muthaiga, Buru Buru and Parklands), plus Nairobi South West which was added at this point (in place of Eastlands which was dropped from the analysis for the reasons noted earlier), and compare the trend in each region with the others over the five years.

The following information was computed for the purpose of constructing the graph:-

a) Area of each region.

b) Total number of leaks in each of the years 1975-79. This data had already been compiled at the beginning of the study.

c) Number of houses in each region in 1974. These were obtained by converting population to number of houses based on the income group and on the type of houses typical of that region.

d) Number of new houses built in each of the years 1975-79. The numbers were obtained by counting the number of certificates of occupation issued in each year, or by the same process as in (c) where the necessary data was not available.

e) Estimated total number of houses in each of the years 1975-79. This was obtained by adding the annual figures in (d) to the base year (1974) on a cumulative basis.

f) Number of leaks per 100 hectares and also number of houses per 100 hectares in each of the years 1975-79.

This were obtained by dividing both (b) and (e) by (a) and multiplying by 100 in each case; the resulting data is displayed in the table below:-

TABLE 3.10 (a)

Number of Leaks per 100 hectares

	Lavington:	Muthaiga:	Buru Buru:	Parklands:	Umoja:	Nairobi S/West:
1975	10.5	3.2	11.0	18.3	3.7	36.6
1976	3.2	4.2	9.2	26.9	4.5	39.1
1977	6.4	5.3	25.2	32.6	25.4	49.2
1978	8.3	5.6	30.0	52.7	22.3	57.8
1979	15.3	5.2	56.7	53.6	56.4	63.9

TABLE 3.10(b)

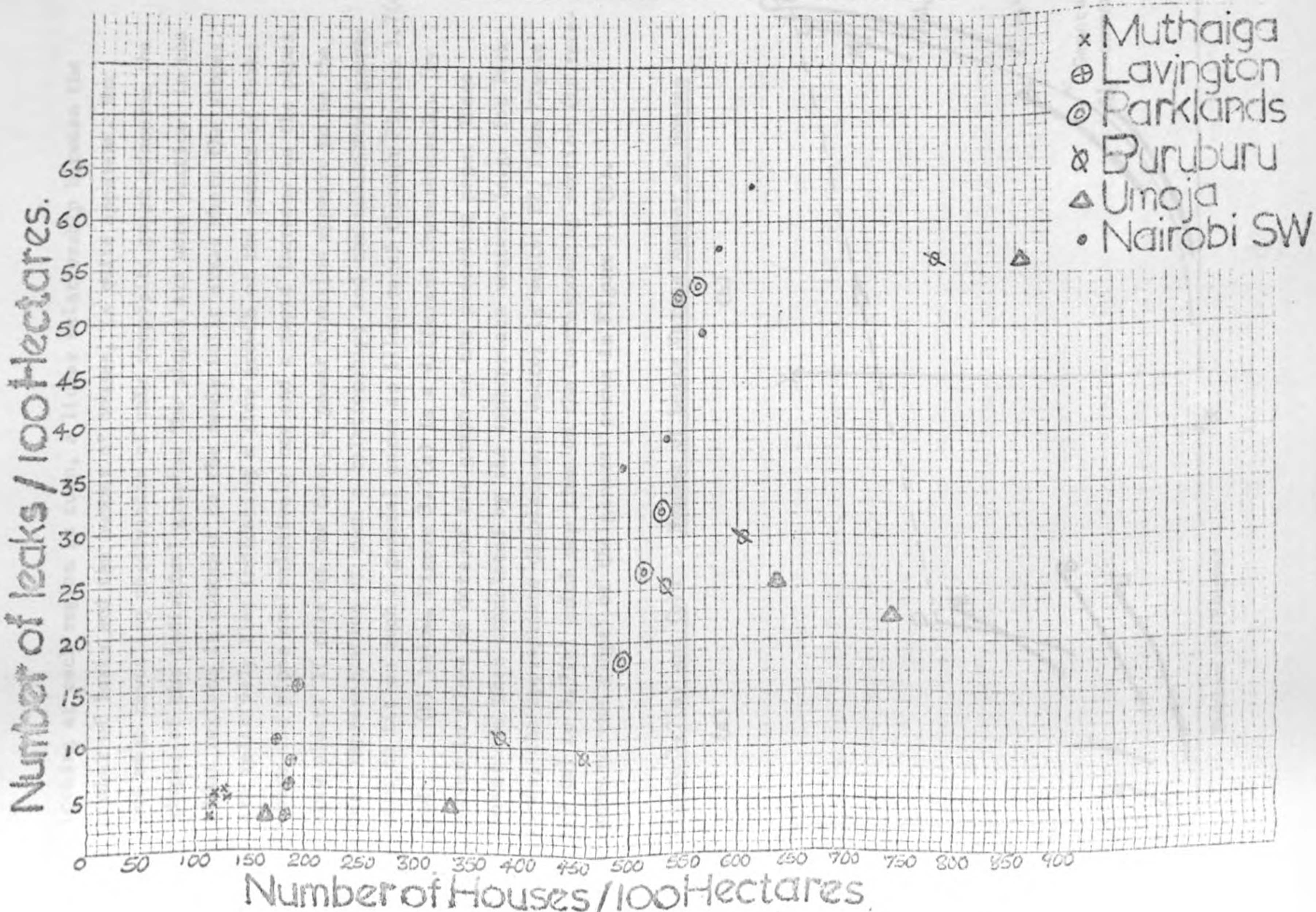
Number of Houses per 100 hectares

	Parklands:	Lavington:	Muthaiga:	Buru Buru:	Umoja:	Nairobi S/West
1974	476	173	112	283	65	464
1975	494	177	115	381	167	493
1976	512	181	118	456	331	537
1977	530	185	121	533	638	569
1978	548	189	124	615	741	582
1979	565	193	127	786	859	611

Certificates of occupation were used in arriving at the number of houses in Buru Buru, Umoja and Nairobi S. West; and in other areas, population figures were used.
The two sets of data are plotted on the graph on the next page, shown as Figure 3.6.

Figure 3.6

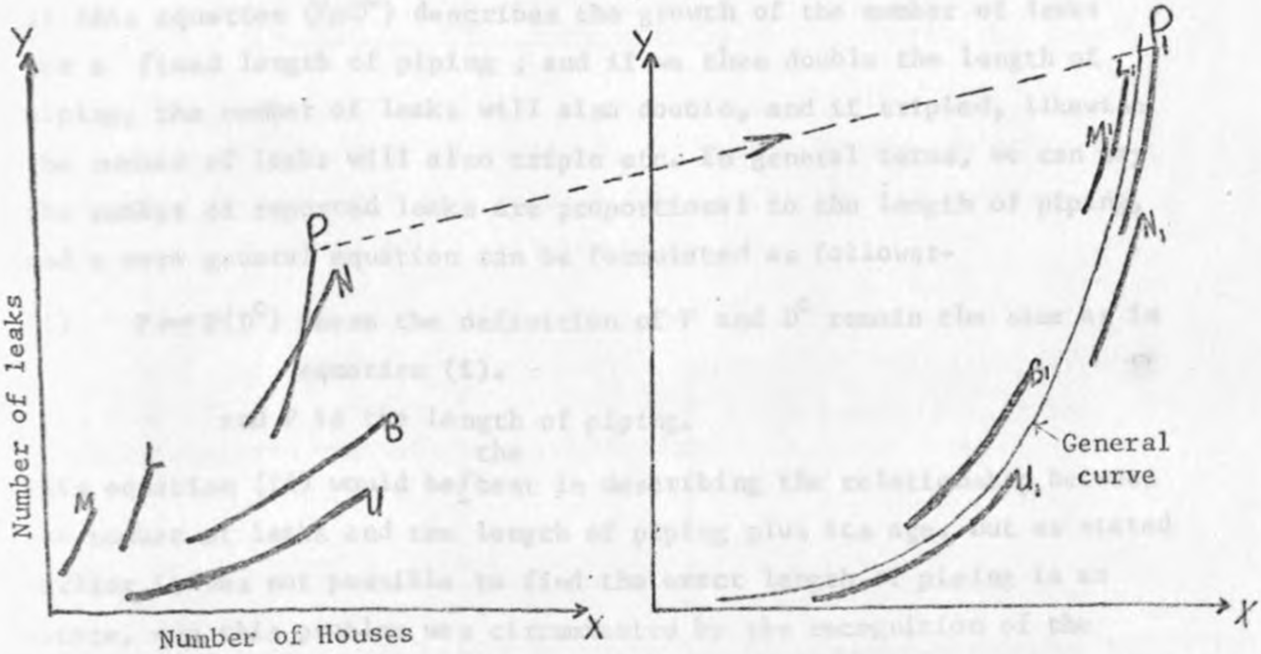
Number of leaks versus Number of houses



Looking at each region in turn, a linear relationship between the number of leaks and the number of houses, is quite apparent. But the most revealing observation of this composite graph concerns the slopes of the individual graphs. The slopes are more vertical in the older regions in contrast to the newly built areas where the slopes are relatively flat indicating a slow growth of the number of leaks where the pipes are relatively new and a rapid increase as the pipes grow older. If this be the case, a power function appears to be the best representation of such a relationship; and the individual graphs seem to fit on such a general curve as illustrated through Figures 3.7(a) and (b) below. Figure 3.7(a) is a different representation (by curves in place of dots)of the graph on the preceding page. These curves are then translated by the appropriate vectors (e.g. for Parklands, the appropriate displacement vector is vector PP_1 from Figure 3.7 (a) to 3.7(b) which map them on the corresponding section (in reference to the slope) of the general curve in Figure 3.7(b).

Figure 3.7(a) and (b): Number of Leaks Versus Number of Houses

(a) (b)



K E Y:

——M	Muthaiga
——L	Lavington
——P	Parklands
——B	Buru Buru
——N	Nairobi S/West
——U	Umoja

As the above general curve (Figure 3.7(b)) suggests one would intuitively expect the number of reported leaks to increase rather fast as the pipes grow old due to corrosion. Expressed mathematically, the number of reported leaks grow as a function of age. And symbolically:-

i) $F \rightleftharpoons D^c$, where F is the number of reported leaks per year

D is the age of the pipes

c is some constant.

If this equation ($F \approx D^c$) describes the growth of the number of leaks for a fixed length of piping ; and if we then double the length of piping, the number of leaks will also double, and if tripled, likewise the number of leaks will also triple etc. In general terms, we can say the number of reported leaks are proportional to the length of piping, and a more general equation can be formulated as follows:-

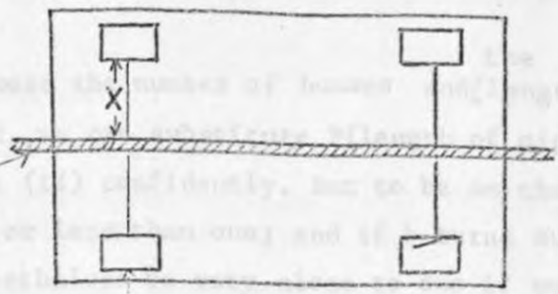
ii) $F \rightleftharpoons P(D^c)$ where the definition of F and D^c remain the same as in equation (i).

and P is the length of piping.

This equation (ii) would be the best in describing the relationship between the number of leaks and the length of piping plus its age. But as stated earlier it was not possible to find the exact length of piping in an estate, and this problem was circumvented by the recognition of the fact that the length of piping is approximately proportional to the number of houses. This proportionality is restated here for further clarification, and explained in two related ways.

Starting with four houses to a hectare, and if the length of piping to each house is equal to X, then the total length of piping to all the four houses is equal to 4X.

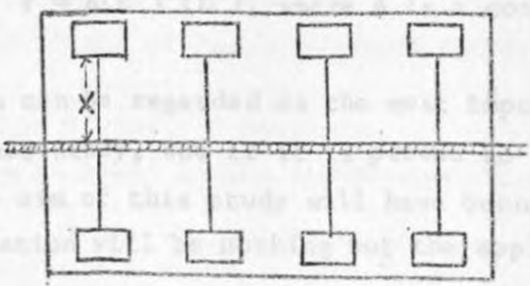
Main pipe



House

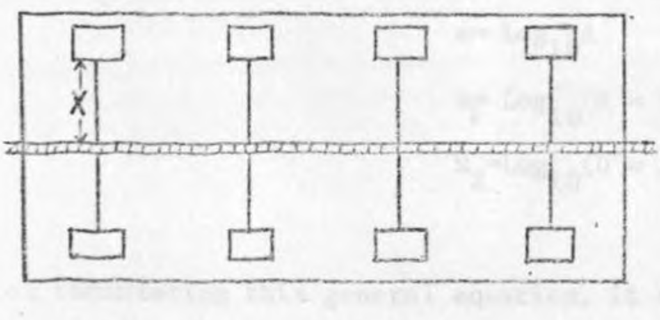
4 houses/hectare
Length of pipes = 4x

a) If the plot size is halved, and 8 houses are built in a hectare, the total length of pipes would be 8X.



8 houses/hectare
Length of pipes = 8x.

b) If the plot size is retained, and 4 more houses are built on a further hectare such that we have 8 houses in the two hectares the length of piping would still equal to 8X.



8 houses/2 hectares
Length of pipes = 8x.

Whereas in (b) the length of piping would no doubt double, in (a) it would nearly double but not exactly for the simple reason that the Mains running down the street would remain constant, but the Mains constitute a very small percentage of the total piping in an estate and thus their effect can be ignored; also we will recognise that the bulk of estate development is on the open spaces other than the intensification of density.

A link between the number of houses and the length of piping having been established, we can substitute P(length of piping) by H(number of houses) in equation (ii) confidently. But to be on the safe side, $P = H^b$, where b is equal or less than one; and if b turns out to be less than one, it should nevertheless be very close to one if our assumption of proportionality between the length of piping and the number of houses is correct.

From equation (ii), $F \propto (D^c)\ (H^b)$ where $P = H^b$.
and formulated in a general form;

$$\text{(iii)}\quad F = A(H^b)(D^c), \text{ where A is a constant.}$$

This equation can be regarded as the most important equation for the purpose of this study, and if it is proved to be the correct predictive equation, the aim of this study will have been achieved, since the rest of the calculation will be nothing but the application of this equation.

To simplify calculations in the process of finding the real values of A, b and c, equation (iii) was reduced to a linear equation by taking the logarithm of both sides:-

(IV) $y = a + bx_1 + cx_2$ where, $y = \text{Log}_{10}$ (F = No.of leaks/100 hectares)

$a = \text{Log}_{10}A$

$x_1 = \text{Log}_{10}$(H = No.of houses /100 hectares)

$x_2 = \text{Log}_{10}$(D = Age of the estate)

After formulating this general equation, it was a matter of finding the exact values of a, b&c and by so doing the line of the best fit will have been obtained. Black cotton soil area and the red soil areas are to be treated separately as stated earlier and hence two sets of values had to be obtained.

A manual analysis to obtain the required values can be performed, but this is unnecessary since computer programs are available for carrying out such calculations. One such a program, which was used in this particular case is "The ICL Statistical Analysis program XDS3".

Black Cotton Soil

A self-explanatory procedure, as evident from the table below, was followed in obtaining the input data. The letters in the table stand for:-

A = Name of the estate

B = Year when the estate was established

C = Year of observation

D = Age at time of observation = C-B

E = Log of age i.e. Log D

F = No.of leaks/100 hectares

G = Log of No. of leaks/100 hectares i.e. $Log_{10}F$

H = No.of houses/100 hectares

I = Log of No.of houses/100 hectares i.e. $Log_{10}H$

TABLE 3.11

INPUT DATA : BLACK COTTON SOIL

A	UMOJA					BURU BURU				
B	1974					1972				
C	1975	1976	1977	1978	1979	1975	1976	1977	1978	1979
D	1	2	3	4	5	3	4	5	6	7
$E = X_2$	0	0.301	0.477	0.602	0.699	0.77	0.602	0.699	0.770	0.845
F	3.7	4.5	25.4	22.3	56.4	11	9.2	25.2	30	56.7
G = Y	0.58	0.653	1.405	1.348	1.757	1.041	0.964	1.401	1.477	1.754
H	167	331	638	741	859	381	456	533	615	786
$I = X_1$	2.223	2.520	2.805	2.870	2.934	2.581	2.659	2.727	2.789	2.895

A	NAIROBI S. WEST					WESTLANDS				
B	1960					1955				
C	1975	1976	1977	1978	1979	1975	1976	1977	1978	1979
D	15	16	17	18	19	20	21	22	23	24
$E = X_2$	1.176	1.204	1.230	1.255	1.279	1.301	1.322	1.342	1.362	1.380
F	36.6	39.1	49.2	57.8	63.9	54.7	80	96.7	151.3	168
G = Y	1.563	1.592	1.692	1.762	1.806	1.738	1.903	1.985	2.180	2.225
H	493	537	569	582	611	494	512	530	548	565
$I = X_1$	2.693	2.730	2.755	2.765	2.786	2.694	2.709	2.724	2.739	2.752

The set of y, x_1 and x_2 were fed into the computer.

The number of leaks for Westlands were obtained by subdividing the original data for Parklands (which included Westlands) into Westlands and Parklands proper in the ratio of 53:47, this ratio having been calculated from the eight months analysis undertaken in the soil effect study.

Red Soil

The same procedure as for the Black Cotton Soil was followed to obtain the input data. The set of y, x_1 and x_2 fed into the computer, for this type of soil were:-

TABLE 3.12

Input Data : Red Soil

	Lavington					Muthaiga				
G = y	1.041	0.477	0.778	0.903	1.176	0.477	0.602	0.699	0.778	0.699
I = x_1	2.248	2.258	2.267	2.276	2.286	2.060	2.072	2.083	2.093	2.104
E = x_2	1.30/	1.322	1.342	1.362	1.380	1.301	1.322	1.342	1.362	1.380

	Parklands				
G = y	1.000	1.176	1.255	1.491	1.462
I = x_1	2.693	2.709	2.724	2.739	2.752
E = x_2	1.301	1.322	1.342	1.362	1.380

Analysis of the Output

Black Cotton Soil

The results of the regression of $y = a+bx_1 + cx_2$ for this type of soil were as follows:-

	Regression Coefficient	T. Stat.
Constant	- 1.7977055	2.35
/GHSE	0.9591487	3.24
/AGE	0.7982312	7.48

MULT. CORR. 0.933:

Since all the three T. Stat. (test statistics) are greater than 2.1098, the critical value of t for 17 degrees of freedom at 5% level of significance, we conclude that each variable, including the constant, contributes significantly to y; and they should all be included in our regression equation.

A multiple correlation of 0.933 is very significant, since anything above 0.46 is significant at the 5% level, and therefore this is a very good fit.

These two essential attributes of our regression having been established, we can now work backwards to obtain our fundamental equation for the Black Cotton Soil.

From the computer output table, we have:-

$\angle$GLEK = -1.80 + 0.96 x $\angle$GHSE + 0.80 x $\angle$GAGE.

where $\angle$GLEK $= y = \log_{10}$ (F = No.of leaks/100 hectares)

$\angle$GHSE $= x_1 = \log_{10}$ (H = No.of houses/100 hectares)

$\angle$GAGE $= x_2 = \log_{10}$ (D = Age of estate).

$$\text{Log}_{10} F = -1.8 + 0.96 \times \log_{10} H + 0.8 \log_{10} D$$

$$F = 10^{-1.8} H^{0.96} D^{0.8}$$

This now is our desired equation, and the value of $b = 0.96$ is very close to 1.0, confirming our assumption that the number of houses per hectare is proportional to the length of piping per hectare.

Red Soil

The results for this type of soil were:-

	Regression Coefficient	T. Stat.
Constant	- 6.2987049	3.23
$\angle$GHSE	0.9601277	6.40
$\angle$GAGE	3.7047133	2.56

Mult. Corr. 0.898.

All the T. Stat. are greater than 2.1788, the critical value of t for 12 degrees at 5% level of significance, hence all the variables contribute linearly to y.

A multiple correlation of 0.898 is very significant, since anything greater than 0.53 is significant at the 5% level; and therefore this also is a good fit. We can now obtain our fundamental equation for this type of soil:

$$y = -6.30 + 0.96x_1 + 3.70x_2$$

where $y = \angle GLEK = \log_{10}$ (F = No.of leaks/100 hectares)
$x_1 = \angle GHSE = \log_{10}$ (H = No.of house/100 hectares)
$x_2 = \angle GAGE = \log_{10}$ (D = Age of estate)

$$\log_{10} F = -6.30 + 0.96 \log_{10} H + 3.70 \log_{10} D.$$

$$F = 10^{-6.3} H^{0.96} \times D^{3.7}$$

This now is our desired equation for the red soil areas.

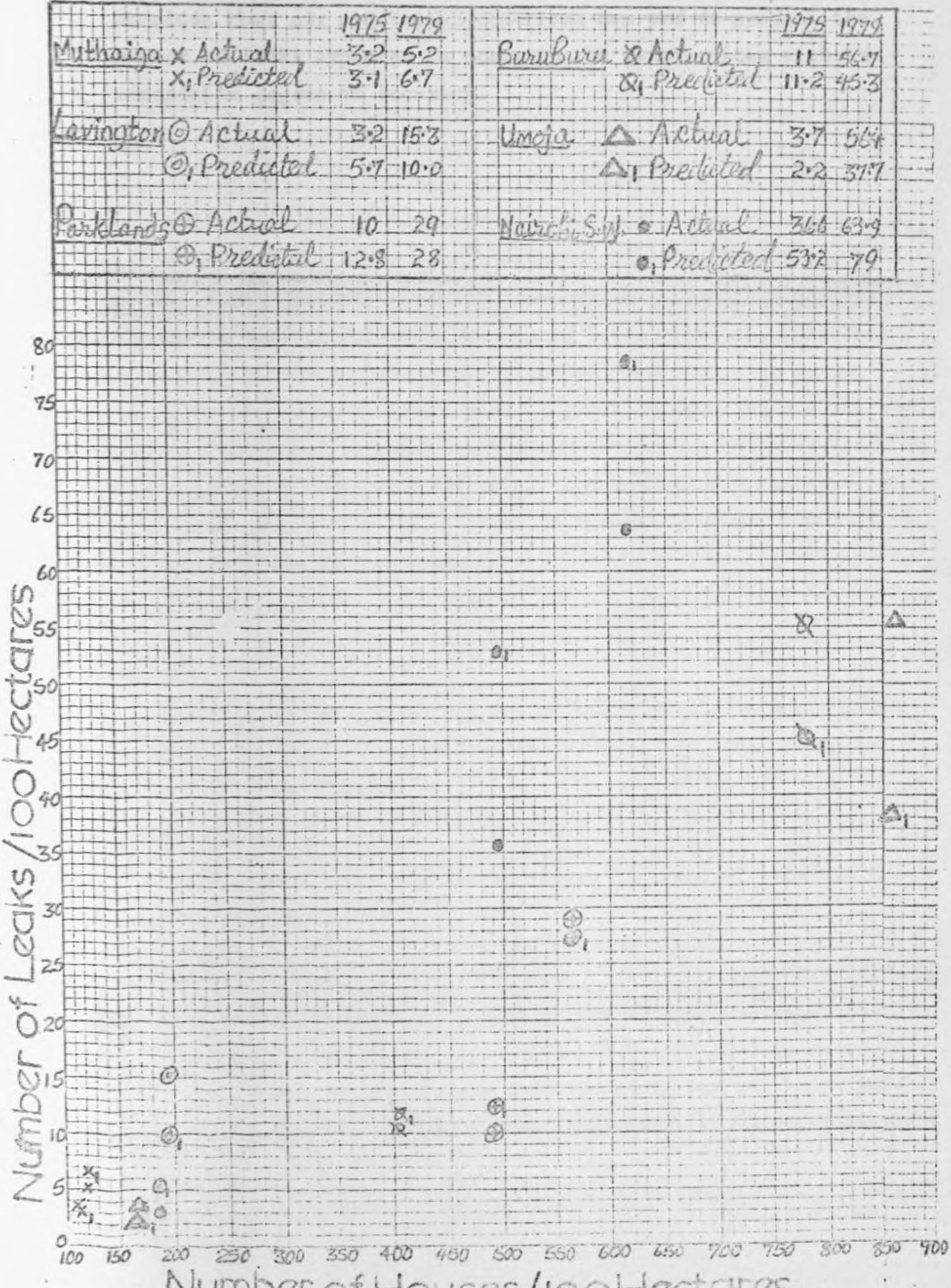
The value of b is the same for the two types of soils indicating that the number of houses/hectare is proportional to the length of piping/hectare.

The effect of age on the pipes in the two types of soils is really different, just as anticipated.

3.2.4.1 Validation of the Model

In order to check the accuracy of our prediction model before making use of it in the subsequent chapters, a plot was made of the predicted number of leaks and the actual number of leaks in 1975 and 1979 for each of our six regions - except for Lavington where 1976 is used in place of 1975 (which appears to be an exceptional year in respect of the actual number of leaks). The graph is reproduced in the next page as Figure 3.8.

Figure 3.8
Actual and Predicted Number of Leaks



In general, the two sets of figures are close enough for us to conclude that our prediction equations can and do predict the number of leaks expected to occur in the water system with an acceptable degree of accuracy.

4. LOCATION OF THE ADDITIONAL DEPOTS

In chapter three the two crucial prediction equations were developed using the data drawn from the representative areas. Through the application of these equations, we can now predict the number of leaks expected to occur in each of our forty regions in 1985, a medium range forecast being considered an optimum range so as to minimize the magnitude of any potential error. After predicting the number of leaks expected to occur in each region, the location of the additional depots was investigated thereafter.

The basis of subdivision of the city into forty regions was explained in section 3.1.1 - (See Figure 4.1 at the end of section 4.2); and here only a brief description of each region in terms of existing and planned development is given in order to provide the necessary background information for appraising the suitability or appropriateness of any selected site. The regions are numbered from A to OO, and this numbering is later on changed (coded) from 1 to 40 for computer analysis purposes.

4.1 THE REGIONS

A. Uthiru

A primarily low income rural population living on small private "shambas". Zoning is 1.2 hectares on average, and development is expected to remain private.

B. Waithaka

Another rural area similar to Uthiru in terms of existing and planned development.

C. Kangemi

Existing development is primarily low income housing on private plots in three townships and small "shambas." The area is zoned for 0.1 hectares development. Future development of low and a few middle income private housing is expected on subdivision of existing shambas.

D. Riruta

A densely developed area of low income rental housing and small "shambas" currently being subdivided. Future development of middle income housing expected.

E. Karen

Existing development is high income private housing on two hectares plots and a few large farms. Future development of high income housing expected when public water supply is made available.

F. Langata

Existing and planned development is similar to that of Karen.

G. Lavington

Existing development - low density high income housing, plus a number of large education sites.

Future development - more high income housing on the few vacant plots.

H. Kileleshwa

Existing development - mostly upper income private housing with some government staff housing.

Future development - more government staff housing at higher densities.

I. Kilimani

Existing development - middle and high income housing.

Future development - more middle and high income housing through subdivision of existing plots.

J. Chiromo

Existing development - private high income housing plus the state house and the university.

Future development - more high income housing and university flats.

K. Woodley

Existing development - Very high income private housing on one side, and middle income housing on the other side.

Future development - more middle income housing.

L. Hospital

Existing development - high income low density housing with some isolated high income flats plus large hospitals (Kenyatta & Nairobi) and golf clubs.

Future development - Redevelopment of existing plots at higher densities.

M. Otiende

Existing development - planned public sales housing for middle and high income at medium and high densities plus Langata barracks.

Future development - extension of the housing estate.

N. National Park & Ngong Forest

Existing development - housing for forestry and National Park Staff.

Future development - small extension of staff housing.

O. Nairobi South

Existing development - middle income public and private housing.

Future development - extension of the middle income public housing.

P. Kabete

Existing developement - educational and governmental institutions including junior and senior staff housing.

Future development - little change.

Q. Loresho

Existing development - high income private individual and estate housing.

Future development - development of high income housing through subdivision.

R. St. Benoist

Existing development - scattered high income housing, plus several institutions (UNEP, K.T.T.C. e.tc.).

Future development - more high income housing through development of large empty spaces.

S. Karura Forest

Existing development - Forestry staff quarters.

Future development - little change.

T2. Parklands

Existing development - upper middle and high income private housing plus a number of institutional sites.

Future development -intensification of density by conversion and re-development for flats and maisonettes.

T1. Westlands - Similar development as Parklands.

U. Central Area

Existing development - primarily a commercial centre (offices, shops & hotels); with some lower middle income housing to the east of Tom Mboya street.

Future development - reduction of residential quarters.

V. Pangani

Existing development - mixed private and public low and middle income housing.

Future development - little development except re-development of existing plots.

W. Eastleigh

Existing development - lower middle income private housing.

Future development - private development of vacant plots.

X. Kenya Air Force

Existing development - Kenya Air Force airfield and associated housing and institutions.

Future development - no change.

Y. Eastlands

Existing development - public low and lower middle income housing at high densities.

Future development - there is virtually no room for further development.

Z. Mathare

Existing development - squatter (slum) settlement.
Future development - upgrading of the slums.

AA. BuruBuru

Existing development - middle income housing estate.
Future development - extension of the housing estate.

BB. Industrial Area

Existing development - primarily industrial development with a few railway housing to the extreme north west and a few houses to the extreme east of the zone.

Future development - infilling of vacant industrial plots.

CC. Muthaiga

Existing development - very high income low density housing plus the City Park.

Future development - a few more high income housing expected to come up.

DD. Kigwaru

Existing development- coffee farms with scattered private high income housing.

Future development - more high income housing with sub-division of the existing plots.

EE. Roysambu

Existing development - large farms with labour lines on one side, and some middle income housing estates.

Future development - more middle income housing with subdivision of the large farms.

FF. Kahawa

Existing development - low income housing in a semi-rural environment on one side, and middle and high income institutional houses (Kahawa Barracks and Kenyatta University College).

Future development - low income housing estates plus the expansion of K.U.C.

GG. Breweries

Existing development - middle income institutional housing.

Future development - institutional development.

HH. Ruaraka

Existing development - middle income private and company housing, and industrial development.

Future development - high density low income housing.

II. Kariombangi

Existing development - company and private low income housing.

Future development - low and middle income housing.

JJ. Dondora

Existing development - middle and low income private housing.

Future development - site and service scheme housing for low income population.

KK. Dondora Industrial Area

Existing developemnt - industrial development.

Future development - further industrial development.

LL. Umoja

Existing development - low and middle income estate housing.

Future development - expansion of low income estates.

MM. Doonholm

Existing development - private middle and high income housing.

Future development - more middle and high income housing.

NN. Embakasi

Existing development - airport and associated staff housing.

Future development - expansion of the airport and associated development.

OO. Njiru

Existing development - scattered large farms including labour lines.

Future development - to retain its rural character for some time to come.

It is the policy of the government to preserve the forests and the National Park, and hence these areas are left out for the purposes of this study. No developments (residential, commercial or industrial) are expected to come-up in these areas in the foreseable future. Njiru area except a small portion close to the developed area is also excluded from this study since it will remain undeveloped for quite some time.

4.2 WORKLOAD PER REGION

The dependent variables entering into our prediction equations, for each type of soil, were found to be the age of piping and the number of houses in a region.

Types of Soil

As stated earlier Nairobi is dominated by two types of soils - black cotton soil and the red soil. The red soil being on the northern side and the black cotton soil on the southern side. The boundary between these soils is shown on the map at the end of this section (4.2).

Age of Piping

The age of the pipings in an estate is the average age of the pipes i.e. computed from the average date when such pipes were laid.

Number of houses

The number of houses in an estate is obtained by converting the population of an estate into an equivalent number of houses based on the income of the residents; a process which was properly explained in Chapter 3.

The above set of data was then obtained, and is displayed in the table 4.1 below. Note: Age and number of houses relate to 1985.

TABLE 4.1: SOIL, HOUSES AND AGE DATA

Region	Type of Soil	Number of Houses	Age (Yrs)
A	R	770	2
B	R	3320	2
C	R	6422	2
D	R	2578	2
E	R	1160	2
F	R	1600	2
G	R	1560	30
H	R	1940	30
I	R	3033	30
J	R	2500	30
K	R	3571	30
L	R	2667	30
M	B.C	1300	25
N	B.C	-	-
O	B.C	3201	25
P	R	786	2
Q	R	4167	9
R	R	1567	2
S	R	-	-
T1	B.C	970	30
T2	R	4530	30
U	B.C	3180	40
V	R	9375	30
W	R	9000	30
X	R	375	25
Y	B.C	12600	25
Z	R	8000	2
AA	B.C	3771	13
BB	B.C	2000	25
CC	R	1050	30
DD	R	1850	7

EE	R	671	6
FF	R	2688	5
GG	R	814	10
HH	R	1083	10
II	R	2389	10
JJ	R	5000	10
KK	R	535	9
LL	B.C	4190	11
MM	B.C	833	8
NN	B.C	2000	8
OO	B.C	1222	2

R Stands for Red Soil

BC " " Black cotton soil.

Through the use of the above data, the number of leaks expected to occur in each region were then calculated. To illustrate how the predicted number of leaks were obtained, let us take region V (Pangani):-

The red soil equation is used in this case,

$$F = 10^{-6.3} H^{0.96} D^{3.7}$$

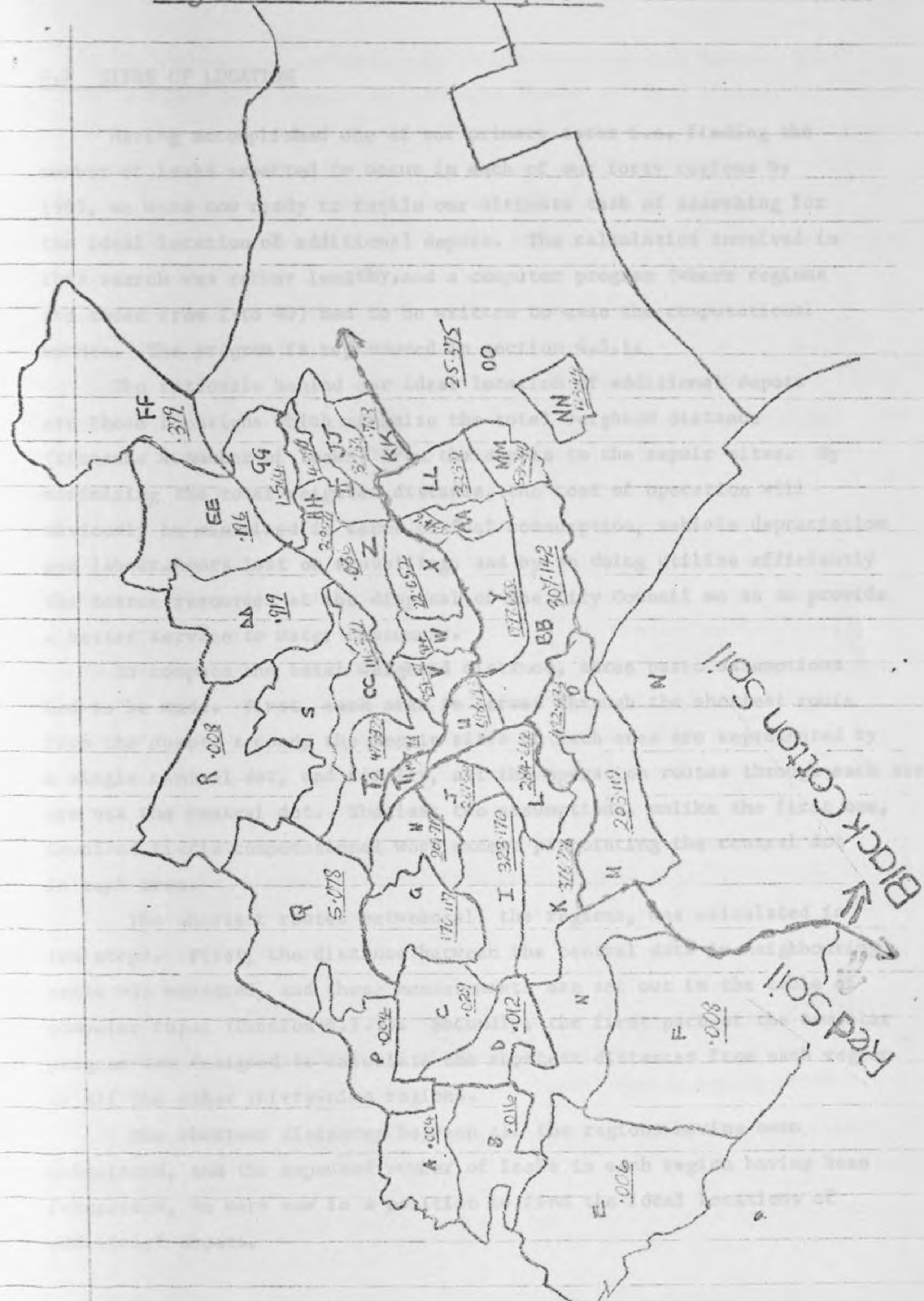
$$= 10^{-6.3} \times 9375^{.96} \times 30^{3.7}$$

$$= 10^{-6.3} \times 6502.68 \times 291977$$

$$= \underline{951.57 \text{ Leaks}}$$

The number of leaks expected to occur in each region were similarily calculated, using the appropriate equation in each case, and the resulting figures incorporated into the computer input data (Section 4.3.1). The number of leaks expected to occur in each region were also displayed in Figure 4.1 on the next page.

Figure 4.1: The Regions



4.3 SITES OF LOCATION

Having accomplished one of our primary tasks i.e. finding the number of leaks expected to occur in each of our forty regions by 1985, we were now ready to tackle our ultimate task of searching for the ideal location of additional depots. The calculation involved in this search was rather lengthy, and a computer program (where regions are coded from 1 to 40) had to be written to ease the computational burden. The program is reproduced in section 4.3.1.

The rationale behind our ideal location of additional depots are those locations which minimize the total weighted distance (Distance x Number of leaks) from the depots to the repair sites. By minimizing the total weighted distance, the cost of operation will obviously be minimized in terms of fuel consumption, vehicle depreciation and labour-hours lost on travelling, and by so doing utilize efficiently the scarce resources at the disposal of the City Council so as to provide a better service to water consumers.

To compute the total weighted distance, three basic assumptions had to be made. First, each area is served through the shortest route from the depot, second, the repair sites in each area are represented by a single central dot, and finally, all the operation routes through each area are via the central dot. The last two assumptions, unlike the first one, involved little computational work except pinpointing the central dot in each area.

The shortest routes between all the regions, was calculated in two steps. First, the distance between the central dots in neighbouring areas was measured, and these measurements are set out in the table of computer input (Section 4.3.1). Secondly, the first part of the computer program was designed to calculate the shortest distances from each region to all the other thirty-nine regions.

The shortest distances between all the regions having been calculated, and the expected number of leaks in each region having been forecasted, we were now in a position to find the ideal locations of additional depots.

At the commence-ment of our research, it was realized that Kampala Road Depot was a fixed depot due to the enormous amount of funds already invested in the construction of this depot; and the research efforts were to be directed toward finding the ideal locations of additional depots. The very fact that Kampala Road Depot was a fixed location dictated the kind of approach to be adopted in tackling our location problem i.e. an incremental kind of approach - where to locate one additional depot, two additional depots, e.tc. Logically, we had to start by computing the total weighted distance from Kampala Road Depot as a base for evaluating the achievement (reduction of that total weighted distance) attained in setting up additional depots. But how many additional depots to set-up was an issue to be resolved at this point, before the computer program was designed. Unfortunately the cost data required for carrying out a detailed analysis to resolve this issue was not available - namely depot establishments costs and total transportation costs, and there was no alternative except to consult the experts (mainly the Chief Water Engineer) on this issue. It was felt that one additional depot would be ideal, but since the methodology of investigating where any number of additional depots would be set-up is as important as specifying where one additional depot would be set up, the computer program was designed not only to specify where our one additional depot would be located but also where two possible additional depots can be located.

The total weighted distance from Kampala Road Depot was obtained by multiplying the shortest distance from Kampala Road depot to all the other regions by the respective number of leaks, and then taking the summation of the individual products.

<u>One additional Depot</u>

The ideal location for one additional depot is found as follows:-
Let R (L) be the forecasted number of leaks in region L.
We let K be a possible location for the additional depot, and we allow K to vary from 1 to 40 except that it cannot equal 27 which is the location of Kampala Road Depot.

For a given value of K we examine another region L (where L is not equal to either 27 or K) and we compare the distance from region L to Kampala Road (C (27, L)) with the distance to the additional depot (C (K, L)) and we assume that the region L is serviced from the nearest depot. In the case of ties we assume it is serviced from Kampala Road. We examine all possible regions L in this way and compute:

$$D1 = \sum_{\substack{\text{All regions L serviced} \\ \text{from Kampala Road.}}} C(27,L) \times R(L)$$

and

$$D2 = \sum_{\substack{\text{All regions L serviced} \\ \text{from the extra depot K.}}} C(K,L) \times R(L)$$

The total weighted distance when the depot is located at K is given by:

$$D(K) = D1 + D2$$

We compute D(K) for all possible values of K (other than 27) and identify the one that is smallest. That then is the ideal location for the additional depot.

Two Additional Depots

The ideal locations of two additional depots are found in a similar manner to the location of one additional depot.

Let R(L) be the forecasted number of leaks in region L.

We let K1 and K2 be the possible locations for two additional depots. We allow K1 to vary from 1 to 40 except that it cannot equal either K2 (the possible location for the other depot) or 27 which is the location of the Kampala Road Depot. For each value of K1, K2 is allowed to vary from 1 to 40 except that it cannot equal either K1 or 27.

For a given set of values of K1 and K2, we examine another region L (where L is not equal to K1, K2 or 27) and we compare the three distances:-

1) to Kampala Road Depot (C(27,L)).
2) to K1 depot (C(K1,L)).
3) to K2 depot (C(K2,L)

and assume that the region L is serviced from the nearest depot. In case of a three-way tie or a two-way tie and Kampala Road Depot is involved, it is serviced from Kampala Road Depot; and where Kampala Road Depot is not involved, it is serviced from K 1 depot. We examine all possible regions L in this way and compute:-

$$D27 = \sum_{\substack{\text{All regions L serviced from} \\ \text{Kampala Road Depot.}}} C(27,L) \times R(L)$$

$$DK1 = \sum_{\substack{\text{All regions L serviced from} \\ \text{K1 depot.}}} C(K1,L) \times R(L)$$

and

$$DK2 = \sum_{\substack{\text{All regions L serviced from} \\ \text{K2 depot.}}} C(K2,L) \times R(L)$$

The total weighted distance when the additional depots are located at K1 and K2 is given by:-

$$D(K1,K2) = D27 + DK1 + DK2$$

We compute D(K1, K2) for all possible sets of values of K1 and K2, and identify the one that is smallest. That then identifies the set of ideal locations for the two additional depots.

After showing how the computer program was designed to compute the ideal location of one additional depot and then two additional depots we can now look at the program itself together with the input data and the resulting output.

4.3.1. THE COMPUTER PROGRAM

The computer program (reproduced at the end of this chapter) was designed to execute four primary tasks in the following order:-

1) Finding the shortest distance between all the regions.

2) Computing the total weighted distance from Kampala Road Depot.

3) Specifying where one additional depot would be located, and the total weighted distance thereof.

4) Specifying where two additional depots can be located and the resulting total weighted distance.

The Input Data

The input data, consisting of the number of leaks expected to occur in each region in 1985 and the distances between neighbouring regions, is set-out in table 4.2 at the end of this chapter.

The Output

The computer output consisted of:-

1) A matrix of the shortest distances between each pair of regions, which was checked on a test-check basis and found to be correct.

2) The total weighted distance from Kampala Road Depot, which came out as 49253.5 Kms/year. This computation was checked through the use of the appropriate row in our matrix and found to be correct.

3) The total weighted distancesfrom each of the thirty-nine possible locations for one additional depot. The ideal location with the lowest total weighted distance was region 20, with a total weighted distance of 31,688.9 Kms/year. This is a 36% improvement over the total weighted distance from Kampala Road Depot.

4) The ideal locations of two additional depots and the total weighted distance thereof. These regions were regions 20 and 24 with a total weighted distance of 24,838.4 Kms/year. This shows a further improvement of only 14% over the total weighted distance from Kampala Road Depot.

4.3.2 Conversion Factor

In an earlier study - by Veena Gupta under the title "Scheduling and Control of Transport, Labour Force and Material in Nairobi City Council's Water Department", it was found that on average a vehicle travels 150 Km/day. There were 11 vehicles at the time of this study, and assuming there are 305 working days in an year excluding Sundays and Public Holidays, the total distance travelled by all the repair vehicles is (11 x 150 x 305)=500,000 Kms. per year.

The total weighted distance from the present depot (Kampala Road Depot) is approximately 50,000 Kms. The conversion factor from the total weighted distance to the actual distance travelled is thus 500,000/50,000 = 10. This conversion is necessary due to the assumptions made in calculating the total weighted distance which differ quite significantly from the present mode of operations. The assumptions as stated earlier were:-

1) Each area is served through the shortest route from the depot.
2) Repair sites are represented by a single central dot.
3) All the operation routes through each area are via the central dot.
4) A single return journey is made for a repair job.

In contrast to the above assumptions, the real style of operation which was described in part, in section 2.3.3. is as follows:-

1) Normally for each repair job, the foreman comes back to the depot for the required material.

2) The foreman, at any given time, is in charge of a number of jobs which can be widely scattered, and he has to supervise them as well as supply his men with all the material required, and therefore he is always on the move.

3) Workers are collected from centres which are close to their place of residence and taken back in the same place after work.

4) The road net work in the City is such that, there are few direct routes between neighbouring estates, and consequently longer routes have to be used to move from one estate to a neighbouring estate.

The reality of the situation then justifies the said conversion factor. Given the total weighted distance per year, one can then convert it to the actual distance which would be covered by the repair vehicles in a year.

4.3.3 Where is Our Depot?

As stated earlier, the final recommendation would be to specify where one additional depot would be located.

This final step of specifying where the additional depot would be located calls for a careful appraisal of the suitability of the site chosen through the computer program. Other factors which could not be incorporated into the program have to be considered in this appraisal.

Region 20, which was shown as the ideal site, is the City Centre. Acquiring land here must be an expensive undertaking, and therefore the possible sites should be ranked (in an ascending order of their total weighted distance) from the best, second best, third best e.t.c. So that the City Council can compare the transportation savings with the cost of buying the land and building the additional depot in the City Centre as opposed to those other possible sites. The costs to be compared are the differential cost between buying the building site in the City Centre and in the other possible locations, with the transportation cost saved by operating from the City Centre as opposed to operating from the other possible sites.

If the saving is greater than the differential cost, the City Centre will still be our ideal location for the additional depot, if not greater, the other possible site will be a better choice.

The cost of land to be considered would be the price of land ruling at the time the decision to build the additional depot is taken.

The transportation cost depends mainly on the amount of fuel consumed by the service vehicles, their depreciation and repairs. The earlier study (by Veena Gupta) mentioned in the preceding section showed that at the time of the study - on average the vehicles consume 300 litres of petrol and 84 litres of diesel per day; and taking these as our working figures, we can illustrate how the City Council can select the ideal location.

Let us take the current price of petrol of 6/20 per litre and 4/10 per litre for diesel - though these figures would have to be substituted with the actual price figures at the time of decision - making, and with forecasted price figures since the future costs are more relevant than the current costs for a location problem - as our working figures, and 305 working days per year as stated earlier; and calculate the annual fuel cost.

Petrol:	300 x 6.20 x 305	=	Shs.567,300
Diesel:	84 x 4.10 x 305	=	Shs.105,042
		Total	Shs.672,342

This total figure is incurred while operating from the current depot (Kampala Road Depot). By building the additional depot, this figure would obviously be reduced. The resulting cost figure when the additional depot is built in any of the other possible sites would be in the same ratio to the total cost figure as the corresponding total weighted distance bears to the total weighted distance from Kampala Road Depot. In other words , the total cost figure would be multiplied by the total weighted distance from any possible site and divided by the total weighted distance from Kampala Road Depot, to obtain the relevant fuel cost.

Example: Total weighted distance when the additional depot is at the City Centre is 31688.9 Kms/year.

Fuel Cost:

$$672{,}342 \times \frac{31{,}688.9}{49{,}253.5} = \text{Shs.}432{,}574$$

$$= 433{,}000/=$$

Fuel cost saved in this particular case is Shs.(672,000 - 433,000) 239,000 per year.

Similar calculations are made for the other nine ranked possible locations, and the following data summarized in the table below:-

Table 4.3: Fuel Savings

Rank	Name of the region	Total Weighted Distance (Kms/year)	Annual Fuel Cost (Shs'ooo)	Fuel Cost Saved (Shs'ooo)
1	City Centre	31,688.9	433	239
2	Pangani	33,413.4	456	216
3	Chiromo	34,832.8	475	197
4	Westlands	35,495.0	485	187
5	Kileleshwa	36,624.0	500	172
6	Hospital	36,755.8	502	170
7	Parklands	37,140.3	507	165
8	Eastleigh	37,582.2	513	159
9	Kilimani	37,886.0	517	155
10	Eastlands	38,359.4	524	148

This table can be extended to cover all the 39 regions.

The above illustration is based on fuel cost only, and although the fuel cost is the major component of the total transportation cost, other costs e.g. the differential cost of depreciation and repairs of vehicles, would also be considered.

Non-quantifiable factors which are peculiar to particular sites would also be considered before the City Council makes the final choice.

Lastly, it must be stressed that, by setting up an additional depot, other savings which have not been quantified will also accrue, e.g. there will be a lesser loss of water as a result of attending to leaks faster than at present. Lesser loss of water will mean more income to the City Council from the sale of the saved water, and an improved supply of water to industrial and other businesses and to private households.

Computer Program

SUBFILE WAGP IN CARD MODE.

```
      MASTER MAIN
  REGION CODE  REGION CODE  REGION CODE  REGION CODE  REGION CODE
    A      1      I      9      R     17      Z     25      HH    33
    B      2      J     10      T1    18      AA    26      II    34
    C      3      K     11      T2    19      BB    27      JJ    35
    D      4      L     12      U     20      CC    28      KK    36
    E      5      M     13      V     21      DD    29      LL    37
    F      6      O     14      W     22      EE    30      MM    38
    G      7      P     15      X     23      FF    31      NN    39
    H      8      Q     16      Y     24      GG    32      OO    40

      DIMENSION A(40,40),B(40,40),C(40,40),R(40),KREG(8),DIST(8)
      N=40
      DO 2 I = 1,N
      DO 1 J=1,N
    1 A(I,J)=999.9
    2 A(I,I)=0.0
      DO 3 I=1,N
      READ(5,8001)R(I),NOREG,(KREG(J),DIST(J),J=1,NOREG)
 8001 FORMAT(F10.5,I1,7(I2,F2.1))
      DO 4 J=1,NOREG
      K=KREG(J)
    4 A(I,K)=DIST(J)
    3 CONTINUE
      DO 5 I=1,N
      DO 5 J=1,N
      B(I,J)=A(I,J)
      IF(A(I,J).EQ.A(J,I))GO TO 5
      WRITE(6,9701)I,J,A(I,J),A(J,I)
 9701 FORMAT(41H ASYMMETRIC DISTANCES. I,J,A(I,J),A(J,I)=,2I3,2F6.1)
    5 CONTINUE
      WRITE(6,9001)
 9001 FORMAT(22H FIRST 20 COLUMNS OF A)
      DO 6 I=1,N
      WRITE(6,9002)(A(I,J),J=1,20)
 9002 FORMAT(20F6.1)
    6 CONTINUE
      WRITE(6,9003)
 9003 FORMAT(23H SECOND 20 COLUMNS OF A)
      DO 7 I=1,N
      WRITE(6,9002)(A(I,J),J=21,40)
    7 CONTINUE
      DO 100 L=2,N
      DO 50 I=1,N
      DO 50 J=1,N
      C(I,J)=B(I,J)
      DO 50 K=1,N
      IF((A(I,K)+B(K,J)).LT.C(I,J))C(I,J)=A(I,K)+B(K,J)
   50 CONTINUE
      DO 75 I =1,N
      DO 75 J=1,N
   75 B(I,J)=C(I,J)
```

```
  100 CONTINUE
      WRITE(6,9004)
 9004 FORMAT(28H FIRST 20 COLUMNS OF FINAL C)
      DO 110 I=1,N
      WRITE(6,9002)(C(I,J),J=1,20)
  110 CONTINUE
      WRITE(6,9005)
 9005 FORMAT(29H SECOND 20 COLUMNS OF FINAL C)
      DO 120 I=1,N
      WRITE(6,9002)(C(I,J),J=21,40)
  120 CONTINUE
COMPUTE TOTAL WEIGHTED DISTANCE FROM KAMPALA ROAD DEPOT
      D=0.0
      DO 200 K=1,N
      IF(K.EQ.27)GO TO 200
      D=D+C(27,K)*R(K)
  200 CONTINUE
      WRITE(6,9006)D
 9006 FORMAT(42H TOTAL WEIGHTED DISTANCE FROM KAMPALA ROAD,F12.1)
C TRY OUT ALL POSSIBLE LOCATIONS K FOR ONE ADDITIONAL DEPOT
      DMIN=100000000.0
      DO 300 K=1,N
      IF(K.EQ.27)GO TO 300
      D1=0.0
      D2=0.0
      DO 250 L=1,N
      IF((L.EQ.27).OR.(L.EQ.K))GO TO 250
      IF(C(27,L).GT.C(K,L))GO TO 240
      D1 = D1 + C(27,L) * R(L)
      GO TO 250
  240 D2=D2+C(K,L)*R(L)
  250 CONTINUE
      D=D1+D2
      WRITE(6,9007)K,D1,D2,D
 9007 FORMAT(17H WHEN DEPOT IS IN,I4,9H D1,D2,D=,3F12.1)
      IF(DMIN.LE.D)GO TO 300
      DMIN=D
      KMIN=K
  300 CONTINUE
      WRITE(6,9008)DMIN,KMIN
 9008 FORMAT(11H MINIMUM OF,F12.1,26H ACHIEVED WHEN DEPOT IS AT,I4)
C  TRY OUT ALL POSSIBLE LOCATIONS K1,K2 FOR 2 ADDITIONAL DEPOTS
      DMIN = 100000000.0
      DO 400 K1 = 1,N
      IF (K1 .EQ. 27) GO TO 400
      DO 400 K2 = 1,N
      IF ((K2 .EQ. 27) .OR. (K2 .EQ. K1)) GO TO 400
      D27 = 0.0
      DK1=0.0
      DK2=0.0
      DO 450 L=1,N
      IF ((L.EQ.27).OR.(L.EQ.K1).OR.(L.EQ.K2))GO TO 450
      IF ((C(27,L).LE.C(K1,L)).AND.(C(27,L).LE.C(K2,L)))GO TO 410
      IF (C(K1,L).LE.C(K2,L))GO TO 420
      DK2 = DK2 + C(K2,L) * R(L)
      GO TO 450
  410 D27=D27 +C(27,L) * R(L)
      GO TO 450
  420 DK1 =DK1 + C(K1,L) * R(L)
  450 CONTINUE
```

```
      D=D27+DK1+DK2
      IF(DMIN.LE.D)GOTO 400
      DMIN=D
      K1MIN=K1
      K2MIN=K2
  400 CONTINUE
      WRITE(6,9009)DMIN,K1MIN,K2MIN
 9009 FORMAT(11H MINIMUM OF,F12.1,25H ACHIEVED WHEN 2 DEPOTS =,2I3)
      STOP
      END
      FINISH
****
```

TABLE 4.2 COMPUTER INPUT DATA

Region	No. of Repairs/ year in 1985	No. of Adjacent Region	Adjacent 1		Adjacent 2		Adjacent 3		Adjacent 4		Adjacent 5		Adjacent 6		Adjacent 7	
			Reg.	Dist. Km.	Reg.	Dist. Km.	Reg.	Dist. Km.	Reg.	Dist. Km.	Reg.	Dist. Km.	Reg.	Dist. Km.	Reg.	Dist. Km.
A	.004	3	P	4.5	D	5	B	3								
B	.016	3	A	3	D	4	E	5								
C	.029	5	P	3.5	Q	7	G	5	I	5	D	2.5				
D	.012	6	A	5	B	4	F	6.5	K	6	I	6	C	2.5		
E	.006	2	B	5	F	7.5										
F	.008	4	E	7.5	D	6.5	K	6.5	M	8.5						
G	170.117	4	Q	4.5	H	3.5	I	4	C	5						
H	209.719	6	G	3.5	I	4.5	J	2.5	T_1	2	Q	6	T_2	2.5		
I	323.170	7	C	5	D	6	K	2.5	L	4	J	4.5	H	4.5	G	4
J	267.528	5	I	4.5	L	2.5	U	2.5	T_1	2.5	H	2.5				
K	376.726	5	D	6	F	6.5	M	4.5	L	6	I	2.5				
L	284,662	6	K	6	O	4.5	BB	6	U	2.5	J	2.5	I	4		
M	203.119	3	F	8.5	K	4.5	O	5								
O	482.433	3	M	5	L	4.5	BB	2.5								
P	.004	3	A	4.5	C	3.5	Q	6.5								
Q	5.078	6	P	6.5	C	7	G	4.5	H	6	T2	5.5	R	6.5		

Region	No. of Repairs/ year in 1985	No. of Adjacent Region	Adjacent 1 Reg.	Adjacent 1 Dist. Km.	Adjacent 2 Reg.	Adjacent 2 Dist. Km.	Adjacent 3 Reg.	Adjacent 3 Dist. Km.	Adjacent 4 Reg.	Adjacent 4 Dist. Km.	Adjacent 5 Reg.	Adjacent 5 Dist. Km.	Adjacen 6 Reg.	Adjacen 6 Dist Km.	Adjacen 7 Reg.	Adjacen 7 Dis Km.
R	.008	4	Q	6.5	T2	6.5	CC	6.5	DD	6.5						
T1	177.418	4	T2	1.5	H	2	J	2.5	U	2.5						
T2	473.372	7	H	2.5	T1	1.5	U	4.5	V	5	CC	3.5	R	6.5	Q	5.5
U	698.193	7	T1	2.5	T2	4.5	V	2.5	Y	5	BB	4.5	L	2.5	J	2.5
V	951.570	6	U	2.5	T2	5	Z	5.5	CC	2.5	W	1.5	Y	3.5		
W	914.000	4	V	1.5	Y	3	X	3	Z	4.5						
X	22.052	4	Z	2.5	W	3	Y	3	AA	2.5						
Y	1797.650	6	W	3	U	5	V	3.5	BB	2.5	AA	3.5	X	3		
Z	.036	7	V	5.5	W	4.5	X	2.5	II	2.5	HH	2.5	DD	5	CC	5
AA	334.614	4	Y	3.5	BB	5.5	LL	2	X	2.5						
BB	307.142	6	L	6	U	4.5	Y	2.5	AA	5.5	MM	7	O	2.5		
CC	116.329	5	R	6.5	T2	3.5	V	2.5	Z	5	DD	5				
DD	.919	6	R	6.5	CC	5	Z	5	HH	5	GG	6	EE	4		
EE	.196	3	DD	4	GG	3	FF	6								
FF	.379	2	EE	6	GG	5.5										
GG	1.564	5	FF	5.5	EE	3	DD	6	HH	3	II	3.5				
HH	2.0571	4	GG	3	DD	5	Z	2.5	II	1.5						
II	4.396	5	GG	3.5	HH	1.5	Z	2.5	LL	3.5	JJ	1.5				
JJ	8.933	2	II	1.5	KK	2.5										
KK	0.708	3	JJ	2.5	LL	2.5	CO	4								
LL	323.90	5	AA	2	MM	3	KK	2.5	OO	3.5	II	3.5				
MM	53.246	4	LL	3	OO	3	NN	3	BB	7						
NN	123.44	2	MM	3	OO	3.5										
OO	25.375	4	KK	4	LL	3.5	MM	3	NN	3.5						

5. SUMMARY AND CONCLUSIONS

As I come to the end of this research paper, it is desirable to highlight the major findings of the study and the conclusions drawn therefrom, on a chapter by chapter basis; and finally end with a word of advice to the potential user of this study on how to utilize the findings.

5.1 Chapter One

In this chapter, we started by tracing the history of Nairobi (very briefly) from its establishment in 1899 as a railway depot to its present size and importance as a centre of commerce and industry for the entire country.

Secondly, it was shown that about 17% of the water supplied to the city is lost through leakages, and expressed in monetary terms, it means the City Council is losing revenue to the tune of 23 million shillings per annum. This loss appeared to be a reasonable justification for undertaking this study, whose findings if implemented would contribute quite significantly to the overall reduction of this loss. It was argued that, this loss can be reduced by building additional water repair depots so as to attend to leakages with minimum delay. The objective of the study was consequently stated as a search for the ideal location of one additional depot or at most two additional depots. By setting up additional depots, other important benefits are also expected to accrue from the reduced distance between the depots and the repair sites in terms of lowered - vehicle depreciation rate, fuel consumption and travelling time. Finally, it was stated that, less loss of water will result in an improved supply of water to the industries and other businesses and private households in the city, thus benefiting the country's economy in general, and city dwellers in particular.

5.2 Chapter Two

This chapter began by setting out the city's organisation for water repair right from the mayor, through the various departments and sections down to the smallest operational units.

Secondly, the water supply was traced right from the sources of supply through the entire reticulation system down to the consumer's terminal.

Finally, a brief analysis was carried out of the existing system of operations, where one of the most important finding was that on average 33% of the official working-hours are spent on travelling due to non-central location of the present depot. It was also argued that the idea of re-siting the depot in a more central location was out of question due to the enormous amount of funds already invested in the construction of this depot; and the only feasible alternative was to set-up additional depots.

5.3 Chapter Three

This chapter was devoted to the development of the prediction model, a model which was to be used later for predicting the number of leaks expected to occur in the various regions. The occurrence of the number of leaks was found to depend on three variables - length of piping, age of the pipes and the type of soil. It was not difficult to obtain directly the data for the last two variables, unlike the data for the length of piping which could only be obtained through an indirect means - by assuming that the length of piping is proportional to the number of houses in an estate, an assumption which was proved to be correct in the course of model construction.

The presence of soil effect in the prediction model meant that two prediction equations had to be developed - one for red soil areas and the other for black cotton soil areas. The two prediction equations were found to be:-

a) Red soil : $F = 10^{-6.3} H^{0.96} \times D^{3.7}$

b) Black-cotton soil : $F = 10^{-1.8} H^{0.96} \times D^{0.8}$

Where (in both (a) & (b)); F is the number of leaks per year

H is the number of houses in a region

D is the age of pipes in the region.

5.4 Chapter Four

In this chapter, the number of leaks expected to occur in each region by 1985 were forecasted through the use of the prediction equations developed in chapter three. The forecasted number of leaks were in turn used in an investigation of where the additional depots would be located. This investigation involved a considerable amount of computational work, and a computer program had to be designed to ease the computational burden.

The rationale behind our ideal locations of additional depots are those locations which minimize the total weighted distance (Distance x Number of leaks) from the depots to the repair sites.

The total weighted distance from the present depot (Kampala Road Depot) was found to be 49,253.5 Kms per year. It was also found that, given the total weighted distance, one would have multiply it by 10, to convert that total weighted distance into the estimated actual distance covered by the repair vehicles per year. The estimated actual distance covered, then, is half a million kilometers per year; at an estimated total fuel cost of Shs.672,000.

Two additional depots would have to be located in the City Centre and Eastlands, with a total weighted distance of 24,838.4 kms per year, which means by setting up the two additional depots, the transportation cost would be reduced by approximately a half, e.g. the total current fuel cost would be Shs.336,000 per year. Though, the idea of setting up two additional depots is left as an open possibility for the City Council to consider, one additional depot is recommended.

The ideal location (through the use of computer program) of one additional depot was shown to be in the City Centre with a total weighted distance of 31,688.9 kms per year, which represents a 36% reduction over the total weighted distance from Kampala Road Depot. The transportation costs would be reduced by approximately the same percentage e.g. fuel cost (current) would be reduced by Shs.240,000 per year.

It was finally pointed out that due to high cost of land in the City Centre, it may not be the best of the possible locations. Consequently, it is necessary to rank the the possible sites from best, second best etc., so that the City Council can compare the transportation savings with the cost of buying the land and building the additional depot in the City Centre . The result of this comparison plus any non-quantifiable factors which are peculiar to particular sites would then influence the City Council's final decision as to whether the additional depot will be located in the City Centre or in any one of the other possible sites.

5.5 Future

The findings and conclusions drawn in this study were arrived at under a set of prevailing conditions, and must be re-examined from time to time in light of any fundamental changes in these conditions.

Two areas, pregnant with potential change, must be watched with utmost care as we move into the future:-

1) It must be noted that the prediction equations have been developed for the existing type of piping, which is predominantly galvanised iron. If a different make of pipes is used in future these equations would cease to apply in those areas where such pipes would be laid and a new set of prediction equations would have to be developed.

2) The future will see the city grow in terms of intensification of density and opening up of new areas, and a direct consequence of such a pattern of growth will be the physical spread and the magnitude of the number of leaks occuring in the city. A great number of leaks spread over a large area will have to be serviced; necessitating the establishment of new depots and re-location of the existing ones. The growth process is bound to be an on-going process for quite a long time to come, and establishment of semi-permanent depots - which can be re-located with minimal financial expense - is definitely preferable over the establishment of permanent depots.

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