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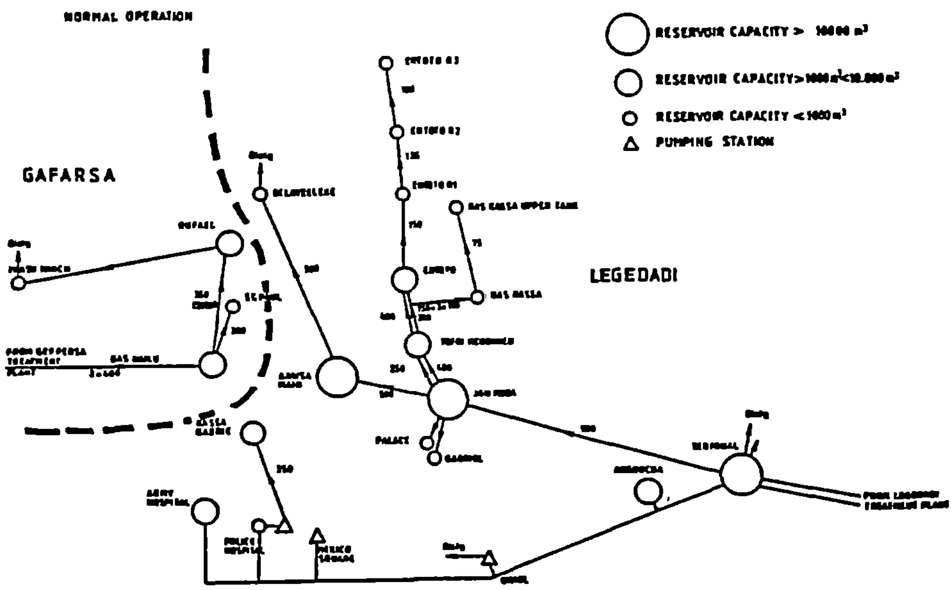

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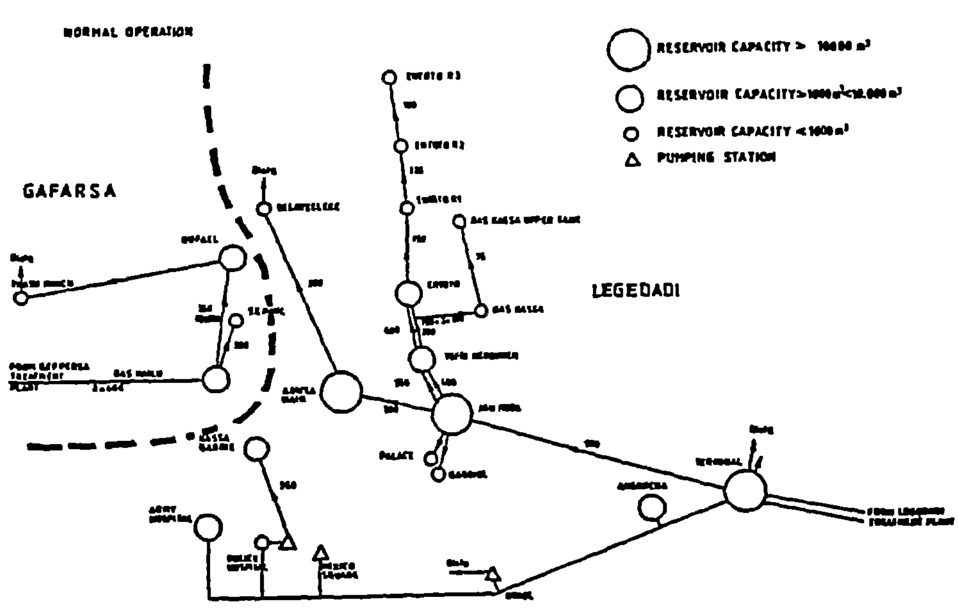

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LEAKAGE CONTROL IN WATER DISTRIBUTION SYSTEM OF ADDIS ABABA

by Azeb Asnake

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ABSTRACT

Leak detection and repair is an effective means of water conservation in any water utility. Some of the major benefits of a leak detection program are savings in water treatment chemicals and pumping energy, better system knowledge and public relations. Leakage control should be considered as equal in magnitude and importance as the development of new sources or enlarging the water supply system.

This study is carried out in Addis Ababa, Ethiopia. The Addis Ababa Water and Sewerage Authority (AAWSA) is the only water utility in the capital city which is responsible for supplying potable water, conservation and protection of groundwater from undue exploitation and pollution, and to ensure the sanitary disposal of sewage.

The lack of qualified personnel, proper administration and organization and, above all, financial resources prevent AAWSA from keeping ahead with the increasing demand. There is a widening gap between the quantity of water produced and the amount actually distributed to customers. The leakages in the network due to old age of pipes and lack of proper maintenance have made AAWSA unable to render sufficient services.

The main objectives of the study were estimation of percentage of leakages in the water supply system of Addis Ababa, identification of technical, organizational and economic problems that inhibit leakage control and the main causes of these problems. Comments on the existing situation, especially on the organization, job descriptions and managerial aspects are given. Proposals were made on what should be done to control the existing leakages, which were found to be 27 % from distributed water.

The methodology included the study of theory on leakages in relation to organizational and managerial aspects, producing data from publicized and unpublicized (but compiled) files at various offices in the authority, personal participation in the daily routines of departments and/or sections involved in leakage control, discussions and interviews with concerned individuals with their own notes and experience.

1 INTRODUCTION

As energy and treatment costs are rising all the time, the need to control leakage in water distribution systems arises to make the best use of resources. An awareness for the need of loss prevention and leakage control has existed for many years. Papers have been written for a long time on the importance of controlling water losses.

The leakage control policy adopted by a water undertaking can vary from simple, cheap but effective measures to more sophisticated techniques. It is clearly uneconomical to ensure that a system will never leak but it is also clear that there is an economical limit to the loss of water that should be tolerated through leakage.

Different types of leakages, factors causing leakages, various methods of leak detection and control, methods to repair leaks, and benefits that can be gained from leak detection and control programmes are discussed.

This paper also investigates all possible prevailing causes for unaccounted-for-water in general, and particularly in the water supply system of Addis Ababa. Further, the existing organization and management problems in leakage control are presented.

An attempt is made to estimate the prevailing leakage percentage in the water distribution system of Addis Ababa. Although, actual field measurements are not carried out, it is believed that these estimations will somehow give an insight on the extent of leakages in the system.

2 UNACCOUNTED-FOR-WATER

In a water supply system, the term unaccounted-for-water refers to the difference between the amount of water produced and the amount of water sold to customers.

Unaccounted-for-water may also be considered as a measure of the efficiency of the whole water supply system including distribution, metering and billing (Bays 1984).

The ever-increasing cost of water supply makes the losses worth of prohibiting. Unaccounted-for-water can range from 10 to 15 % where excellent loss control is practised, to greater than 80 % where little or no control is made. Smith (1986) noted that the major areas of water losses in all utilities include system leakages, inaccurate master meters, inaccurate commercial, industrial and domestic meters, unmetered use, and unauthorized connections.

2.1 System leakages

Kroushl (1984) noted that system leakages contribute to the most part of unaccounted-for-water. The underground distribution system comprising mains and pipes of varying age and material and numerous joints and fittings is a potential source of leakage. Whenever possible, an inventory should be made for the type and location of installed pipelines. They should be indicated on a map for determining where trouble spots are located, where to rehabilitate the system, and what type of pipe to use in a particular area. The water department personnel should be aware of the need of controlling underground leakage. Valves and hydrants should be listened with proper listening devices during the course of normal maintenance work.

2.1.1 Reservoir leakages

Leakages from service reservoirs are insignificant when compared with leakages from distribution and service lines (Twort et al 1985). Leakages from service reservoirs are usually caused by defective construction joints through which water escapes into underdrainage system, defective ball valves leading to reservoir overflow, and faulty outlet and washout pipework.

The usual method used to measure leakage from service reservoirs is to isolate them from their supply and to measure the change in levels over a suitable period of time (Bays 1984). The method is relatively simple where reservoirs are constructed with more than one compartment in which case supply will not be interrupted. It is important that every service reservoir has a regular inspection for water tightness. Observations should also be carried out on level controls to avoid overflows.

2.1.2 Trunk main leakages

Leakages from trunk mains are usually less significant than those from the distribution system (Twort et al 1985). There are different methods of measuring leakages from trunk mains. One simple commonly used method is carried out by means of a by-pass meter. Two selected valves should be closed, one upstream and the other downstream on the main line and a tapping on either side of the upstream valve should be made to connect the meter between the tappings. Any leakage on this section will be registered on the meter provided that both the upstream and downstream valves are fully closed. This method does not require any sophisticated equipment.

2.1.3 Distribution and service line leakages

Leakages from the distribution and service pipe connections are the major part of the total system leakage. These leakages cannot be measured directly, but they are accurately estimated from night flow measurements (Field 1983). At night the principal component of the flow will normally be the leakage since consumption is at a minimum. The minimum night flow indicates the existence of leakages in the system.

For valid minimum or net night flow assessment there must be no service reservoir in the system or large storages on consumers' premises which fill at night. Allowance must also be made for legitimate night demand by factories on night shift, hotels, hospitals, power-stations and airports, which remain active throughout the 24 hours (Twort et al 1985).

2.2 Losses from inaccurate master meters

All loss studies in a distribution system should start by checking the accuracy of the master meters. Because the data obtained from the master meters is the primary information needed to know if an unaccounted-for-water problem exists. A high unaccounted-for-water percentage may be due to a master meter over-registering. Although master meters will usually under-register the flows, some examples show that some meters can over-register as much as 25 %.

Inaccuracies in water meters will normally occur in the measuring chamber due to existence of foreign elements such as sand, debris or minerals. This increases the tolerances in the chamber as time goes on and allows more water to pass through than is recorded.

Master meters should be tested in place with a pitometer or comparative flow meter. A volumetric test can be performed by filling or emptying a reservoir through the master meter and comparing volumes (Kroushl 1984).

2.3 Losses from inaccurate consumer meters

One of the efficient methods of distribution system control and conservation is the use of accurate water meters because then the customers pay for the actual water use (Hutchins 1984). They are early warning devices for piping leaks and they reduce billing estimate errors.

Industrial and commercial meters

Sizes of meters for industrial and commercial use range from 13 mm to 75 mm. These meters are often the most neglected ones. Some of the reasons for this are: their weight which makes the handling difficult, their inaccessibility as in many cases they are installed in stores and apartment buildings and lack of adequate facilities for testing. In many communities this group of meters, although relatively small in number, is responsible for a high percentage of the water consumption. Thus the operation of these meters must be checked properly (Kroushl 1984).

Smith (1986) stated that domestic meters are the principal revenue producers in most water distribution systems. Inaccuracies of domestic meters usually occur due to incorrect sizing. Water meter sizing should be based only on flow requirements. The maximum, average and minimum consumptions should be determined for correct sizing. Oversizing of meters leads to a higher degree of under-registration at low flows.

2.4 Unmetered use

Unmetered use includes water consumed for fire fighting, routine fire hydrant checking, municipal uses such as watering green areas, fountains and temporary supplies for governmental institutions. The consumption for watering green areas in hot climates may be particularly high. Unmetered public use of water is exposed to abuse through wastage and carelessness (Twort et al 1985).

2.5 Unauthorized use

Unauthorized use is made through illegal connections before water meters, reinstalling of the water meters in the reverse direction and removing the water meter for the theft of water. The theft usually occurs in the domestic connections and can be controlled by enforcing a strong ordinance relating to illegal connections before meters and breaking of meter seal wires (Kroushl 1984). Provision should be made for regular inspection and reading of meters so that any fault found be rectified.

3 FACTORS AFFECTING LEAKAGES

3.1 Corrosion

Corrosion of iron pipes takes place both internally and externally depending on the quality of the treated water conveyed and the surrounding soil around the pipe. Corrosion causes severe damage on the structural integrity of the pipe so that it is exposed for pitting and breakage resulting in extensive leakage.

Corrosion of materials in plumbing and distribution system increases the concentrations of metal compounds in the water which are possible health hazards. Aesthetical deterioration and undesirability of the water for consumption can also result from corrosion (Kirmeyer and Logsdon 1983).

Internal corrosion

The internal corrosion of iron pipes depends largely upon the acidity (low pH values) or carbon dioxide (CO_2) content of the water. The CO_2 content must be sufficient to keep the dissolved calcium by carbonate in equilibrium with solid calcium carbonate ($CaCO_3$). If the amount of free CO_2 is more than sufficient, the water will tend to dissolve any protective covering of solid $CaCO_3$. On the other hand, when the water is deficient in free CO_2 it will tend to deposit some of the calciumbicarbonate which it holds in solution, thus creating a protective coating (Twort et al 1985).

External corrosion

O'Day (1982) stated that external corrosion of iron pipes occurs depending on the type of soil in which the pipes are laid. In general clays and highly organic soils can be corrosive. Even mixing sand and clay as backfill material creates a galvanic reaction that will slowly corrode the pipe.

The risk of corrosion increases when the soil conditions are altered by replacing clay with sand, due to maintenance of the distribution network or laying down lines of other underground services (Friis and Baekkegard 1988).

Corrosion of pipelines can be inhibited to some extent with different kinds of methods which are discussed in Section 4.3.

3.2 Pipe installation faults

High degree of leakages can be caused by faults made during pre-installation and installation works. Manufacturing, transporting and storing of pipes are the main pre-installation works in which care must be taken. The pipe quality in manufacturing should be checked before the pipes are delivered to sites. During transportation of the pipes to construction sites, proper lifting and loading should be practised to avoid damage of the external coatings. Polyvinyl chloride (PVC) pipes suffer a certain loss in strength when exposed to direct sunlight for long time, thus care should be taken by covering them when stored in the open area.

During the installation of pipes big boulders in trenches should be avoided. Especially when laying PVC pipes the trench bottom should be free of sharp stones and proper bedding material must be used (Twort et al 1985). The circularity of larger diameter PVC pipes can be distorted if the backfill is not evenly compacted in equal layers, on both sides of the pipe. This can cause distortion at the joints and lead to leakage.

Joints between the pipes can also be the sources of leakage when mechanical joints are improperly tightened or gaskets are displaced. When using PVC pipes, if the application of solvents or glue is not done properly, the high coefficient of expansion and contraction of the pipe with change of temperature may cause a breakage of the solvent joint and hence substantial leakage (Twort et al 1985).

3.3 Excess supply pressure

The control of excess pressure throughout the system is of great importance in reducing leakage problems (Bays 1984). Pressure variations should be avoided so that surges cannot cause leakages. The reduction of pumping heads, setting up of pressure zones from service reservoirs and the introduction of break pressure tanks or pressure reducing valves are some of the measures to reduce pressure. Reduction in pressure reduces the rate of leakage and it is the simplest and most immediate way of minimizing leakages.

Figure 1 shows the relationship between pressure and leakage graphically. The curve demonstrates that pressure reduction reduces leakage and also that the effect is greater at higher pressures (Goodwin 1980).

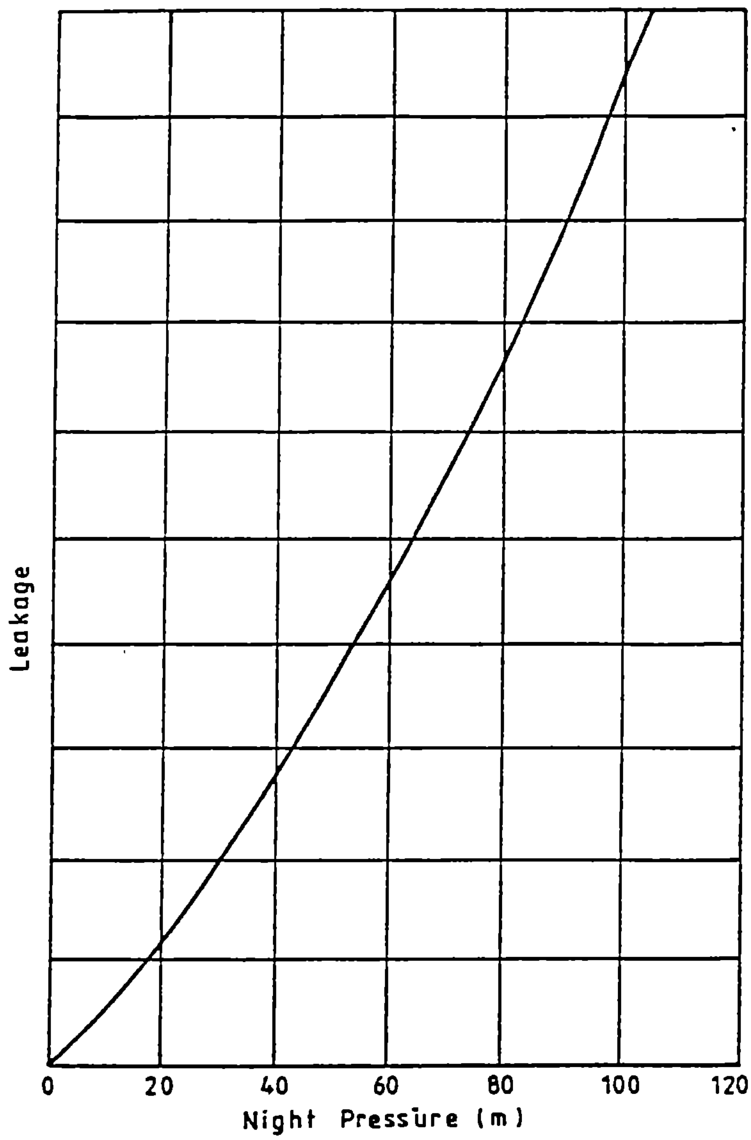

Figure 1. Relationship between leakage (net night flow) and pressure (Ridley 1982).

3.4 Pipe material selection

Factors such as corrosiveness of water, required pressure and flow, soil characteristics and water temperature influence the type of pipe material to be selected. Moreover, the suitability of any type of pipe in a given situation is influenced by its availability and cost.

The common pipe materials in use are the polyvinyl chloride (PVC), galvanized steel and asbestos cement. According to Twort et al (1985), the main advantage offered by PVC piping is its resistance to corrosion. Generally its light weight, flexibility, and ease of installation encourage its wide use.

Steel is frequently used for trunk mains where pressures are high and pipes are large. Steel is seldom used for distribution mains, because steel pipes are not adapted to withstand external loads, while a partial vacuum caused by emptying a pipe rapidly may cause collapse or distortion (Steel and Terence 1979).

Asbestos cement pipes are resistant to corrosive conditions, except in the case of sulphated soils which attack the cement (Twort et al 1985). Because the pipes tend to be brittle and liable to be easily damaged by shock, they require careful handling and laying. Asbestos cement pipes should preferably not be laid beneath roads carrying heavy traffic and be subject to vibration.

3.5 Lack of proper record-keeping and updated maps

All water undertakings should have updated maps and records. Since practically most components of water distribution systems are buried, maps and records are vital for proper operation and maintenance.

Maps and records are also valuable in planning future developments. They are important management information systems in which significant data is stored, maintained, and displayed. Updated records also help to maintain good public relations by allowing efficient response to interruption of water supply and other related problems.

The most common and important records to be maintained by each utility are data on mains, hydrants, valves, meters, service lines and spare parts. Failure to accurately locate an underground distribution component which needs repair, can result in unnecessary excavation expenses, wasted man hours and increased amount of water loss.

During leak occurrence information on its location, cause and repair must be forwarded to the responsible section in good time for map updating and recording purposes. Moreover, general records on supply facilities, water billings, customer information, and financial information must be kept (Brown 1986).

3.6 Public awareness

The consumers should be trained for conservation of treated water. Careless use of water leads to high amount of loss. A regular campaign should be arranged for this purpose and it may take various forms such as articles in local newspapers, posters at public places, seminars and discussions, lectures by water specialists, radio talks, and television programmes (Rangwala 1986).

4 CONTROL, DETECTION AND PREVENTION OF LEAKAGES

4.1 Leakage control methods

After estimating the amount of leakage in a system from the production and consumption figures, the next step is naturally to locate the leaking areas. Methods widely used to identify leaking areas include district metering, waste metering, combined district and waste metering and passive control.

4.1.1 District metering

District metering involves installation of meters at strategic points within the distribution system so that the water consumption of an area of about 5 000 properties is supplied through a meter and the flow into each area measured. These meters should be read at regular periods, typically weekly or monthly and a note made of areas which show significant increase. Any district indicating unusually high consumption should be sounded by inspectors at locations of valves, hydrants, stopcocks, etc. (Bays 1984).

4.1.2 Waste metering

In the method of waste metering a small part of the distribution system of about 1 000 properties is valved off so that the supply into it is provided through one main only. A by-pass containing a recording flowmeter (waste meter) capable of recording the low flow rates that occur in the early hours of the morning is installed. The meter is normally read quarterly or half yearly and unexpected increase in the minimum night flow rates is investigated. Then by stepwise shutting of valves throughout the waste district, the point of leakage can be pin-pointed to a particular small section for sounding and location (Twort et al 1985 and Bays 1984).

4.1.3 Combined district and waste metering

This method combines the two methods of district and waste metering where the district meters are installed to measure the flows to areas of about 5 000 properties and when an increase is noted, waste meters are used to determine more precisely the location of leakage (Ridley 1982).

4.1.4 Passive control

In this method only the leaks that become apparent will be repaired. They include the ones appearing on the surface of the ground, those found as a result of complaints of low pressure, of no water or of noises in the internal system and those discovered by the water undertaking personnel while carrying out other tasks (Bays 1984).

4.2 Leakage detection techniques

4.2.1 Sounding techniques

This method establishes the presence of a leak by its sound. A listening rod (1 - 5 m long) of solid metal is used. The listening device helps to hear characteristic noise of leaking water from valves, hydrants and other fittings (Twort et al 1985). Figure 2 shows the sounding rod in use.

Figure 2. Sounding rod in use.

4.2.2 Correlation techniques

This technique involves the use of a leak noise correlator (Figure 3) with two microphones for pin-pointing the position of underground leaks by comparing the signals using the process of correlation (Grunwell and Ratcliffe 1981). The noise produced by a leak is detected at two positions along the main line on either side of the leak. The difference in time taken for the noise to reach the two positions is determined by the correlator. From the time difference, the distance between detection points and the velocity of sound in the pipeline, it is possible to determine the exact position of the leak. This device has many advantages, such as more accurate location of the leak, less dependence on operator interpretation, and possibility to use in areas with a high background noise, thus allowing leak location during the day in areas of busy traffic.

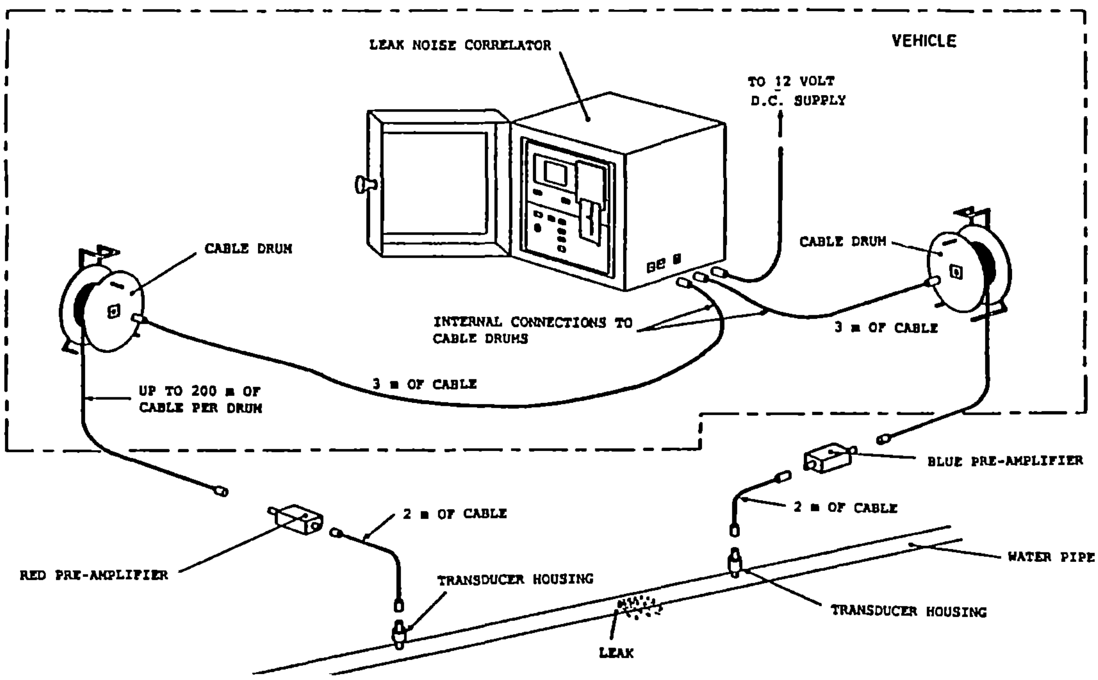

Figure 3. The leak noise correlator (Iikkanen 1988).

4.2.3 Tracer techniques

In areas where leakage is known to exist, but the noise is undetectable by any of the sounding methods, tracer technique can be used. The principle of tracer technique is that a substance is injected into the main, where it will either dissolve or mix in the water and some of which will leave the main line at the location of the leak (Francis 1988). A detector is then used to search for the substance that escapes from the main, thus the position of the leak is found. Sulphur hexafluoride (SF_6) and nitrogen oxide (N_2O) which are soluble in water, non-reactive, non-toxic, odourless and tasteless are suitable tracers for use with potable water. In most cases the physical properties of SF_6 make it more effective as a tracer than N_2O.

4.3 Leak repair methods

The restoring of leaking pipes can be done by repairing the pipe point by point, by renovation and by replacing. The choice of the remedial measure depends on many factors such as structural condition of the pipe, hydraulic capacity requirement, water quality criteria, life cycle costing, disrusption of traffic roads etc. (Lofthouse and Buldleigh 1984).

4.3.1 Point repair methods

Point repair activities can be done using clamps, dresser couplings and welding works. Clamps are used to repair small leaking holes, cracks and shear breaks. Dresser couplings are also applicable in some cases. Cutting off the damaged section of a pipe and welding a new section is another way of maintenance where repair clamps are not applicable (Merlo 1986).

4.3.2 Pipe rehabilitation

Methods of renovation fall broadly into two categories, usually known as structural and non-structural renovation depending on the type of the problem (Reed 1980). Structural renovation comprises the insertion of plastic pipes through a leaking pipe of bigger diameter. In non-structural renovation cement mortar or epoxy resin coating is placed on the old pipe for structural strength. Non-structural renovation requires the new lining and the old pipe to be integral so that they act as a composite unit. Figure 4 shows the structural and non-structural methods of pipe renovation.

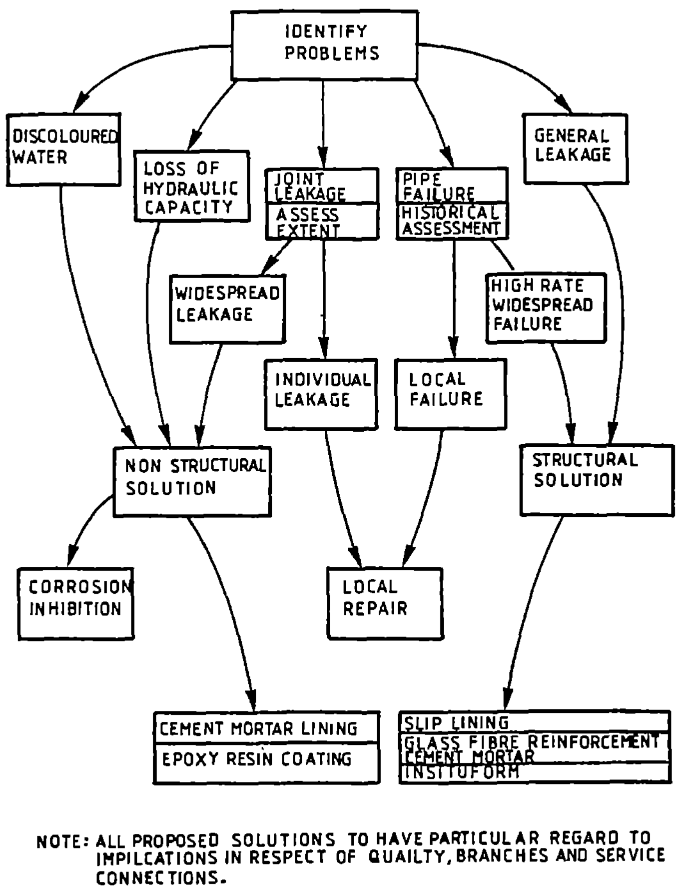

Figure 4. Water main rehabilitation methods (Reed 1980).

4.3.3 Pipe replacement

The need for pipe replacement at any time results from physical and functional ageing processes of the pipe. As pipes age, the breakage rate tends to increase and the pipes become likely candidate for replacement. Replacement decisions are based on the amount of leak or the degree of possible breakage of the pipe due to old age. During a replacement there will be a tendency to choose larger pipes, because the additional costs are not very significant and hydraulic conditions usually need to be improved in water supply networks (Walski 1987).

4.4 Leak detection and repair benefits

4.4.1 Resource conservation

The value of the water that is no longer wasted is the immediate benefit gained as a result of leakage survey. As leaks are located and repaired, the annual consumption will begin to decrease resulting in immediate cost savings on power and chemical expenses. The life time of the existing system will also be extended.

Flows to wastewater treatment plants can also be reduced if the water leaking into the sewers is avoided. Thus the wastewater treatment costs are getting lower and the need of expanding the sewer system is avoided to some extent (Kroushl 1984).

Reducing legal claims paid for water damages and insurance fees is also considered as a benefit for water undertakings. Incidents caused by water main and plumbing leaks (such as earth movements which completely destroy public works, homes and property; ruined floors and home furnishings; damage to automobiles and injury to drivers because of holes in street surfaces) can be avoided by systematically surveying the water system for leaks and either repairing these leaks or replacing badly deteriorated mains (Kingston 1979).

4.4.2 Improved system control and knowledge

According to Greely (1981) the distribution system information generated by a leak detection and repair program is an important benefit. Co-ordination of field conditions with map information provides an opportunity for up-dating the system.

Brainard (1979) noted that personnel regularly engaged in leakage surveys quickly becomes proficient in the art of leakage detection and becomes aware of the characteristic of the system.

4.4.3 Improved public relations

By attacking leakage and water loss, rather than reacting just in case of complaints, a water utility can impress upon its customers the utility's commitment to a high standard of service and the importance of water conservation (Greely 1981). An undertaking that solves its leak problems enhances its image as a good organization, giving it greater credibility when asking users to make conservation efforts as well.

If the leak detection team has a vehicle with a name to identify it, the community becomes aware of the work, that something is being done to conserve water resources. Moreover, the detection crew generally interacts with water customers in a positive role when locating leaks occurring in the customers' premises (Kroushl 1984).

5 ORGANISATION AND MANAGEMENT IN URBAN WATER SUPPLY SYSTEMS

5.1 Management structure

The common types of water organizations are city departments, water authorities and private companies. Public utilities are under direct or indirect control of government, often as a government department. The management to these utilities can either be by city municipal authority or water company (Grigg 1986).

Regardless of its organizational form, the public utility must be subject to procedures which ensure its adherence to government objectives. The supervisory ministry (for example Ministry of Water) usually appoints board of directors to oversee the utility functioning. The board of directors is to establish operating objectives and targets within government guidelines and to monitor activities and progress of the water authority (Powell 1987).

A generalized internal organization of water and wastewater utility proposed by Grigg (1986) is shown in Figure 5. This structure can apply whether the utility is private or public.

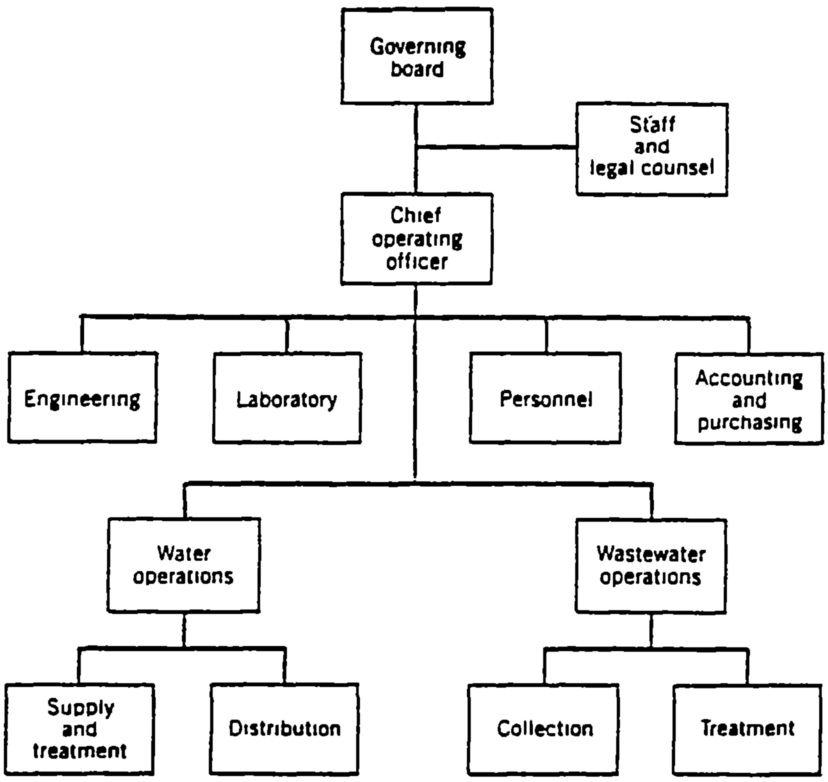

Figure 5. Generalized water and wastewater utility organization (Grigg 1986).

In this structure, various study and design functions can be accomplished by the engineering department. Depending on the size and complexity of the water utility, other staff can be distributed around the organization. In larger utilities there may be a need for a separate and permanent training department if the problem of reducing wastage of water is to be tackled efficiently. A measurement and loss control department is advisable in the larger utilities to ensure effective loss control (Twort et al 1985).

5.2 Management of public water supply systems

5.2.1 Management inefficiencies

Consequences of inefficient management

Inefficient management in water supply systems can be reflected in one of the following conditions (Franklin 1983):

a) Shortage of water available to customers

Shortage due to excessive leakages often results in intermittent supply with consequent low pressures in parts of the distribution system. Negative pressures can cause a danger of pollution being drawn into the system through defective pipes, joints and fittings. A good management would ensure proper functioning of the system by maintaining positive pressures in the distribution network.

b) Loss of supply capacity

This is caused by excessive leakage and poor maintenance of the system, inefficient use of water sources, etc. If the supply capacity of a system is decreasing so that demand exceeds the supply, an extension should be constructed or the existing system has to be rehabilitated earlier than the anticipated design period.

c) Illegal connections

Unauthorized and often unskilled connection with the system for the theft of water is reflected in water supply systems where necessary discouraging action on defaulters is not taken. A good management would track down illegal connectors and take proper measures to avoid the loss of revenue and possible pollution of the system due to unskilled tampering.

d) Loss of revenue

In most water supply systems the majority of the income is from the sale of water. When there is a reduction in the ability to meet demand, there will be a reduction in income. A management which cannot maintain the output of water is unlikely to be effective in collecting all the revenue even for the low level of service it renders. A reduction in revenue may be acceptable if there is a corresponding reduction in expenditure, which is improbable with poor management. When the revenue keeps decreasing the water utility could face the possibility of seeking subsidies to meet its commitments.

e) Increased expenditures

Repair costs tend to increase when management is not able to ensure that works are run properly. If preventive maintenance becomes neglected, the more expensive emergency maintenance system gradually develops.

f) Public health and spread of diseases

The most serious result of poor management arises in deteriorated water quality which affects the public health. Water-borne diseases such as typhoid, cholera and various enteric infections can be caused by polluted water supply, poor water works operation and management. Lack of water with intermittent supply can also affect the public health.

g) Loss of staff qualification

The accident rate, sickness and absenteeism would all tend to rise if management is poor. Recruitment may be affected as word quickly spreads about organisations which are difficult to work for. The qualification of applicants would be lower than would apply to a good management. Training requirements also would appear to increase and yet there would not be improvement in performance which should follow good training.

Causes of inefficient management

a) Inadequate training

Inadequate training and education of staff concerned with the management and operation of waterworks leads to inefficient system (Franklin 1983).

In most cases manpower will have to be trained and re-trained to meet the goals of the utility. A careful analysis of training needs is very important because training is often wrongly applied as a solution to problems that do not in fact, respond to training. In addition to the achievement of the goals of the organization training will become an increasingly more important and prevalent activity both in providing new forms of service and improving the use of existing facilities (Carefoot and Gibson 1984).

b) Inadequate appreciation of objectives

Managements unclear about their objectives will not understand the implication of not meeting the objectives and will not be aware of their shortcomings (Franklin 1983).

c) Organizational structure

The organizational structure may be a cause of inefficient management. In some cases, efficient management is not possible within the framework of rules governing the operation. Changes in the organization and procedures usually help to have flexible management system where re-staffing according to changes in circumstances is possible (Franklin 1983).

5.2.2 Improvement of management

a) Assessment of magnitude of tasks

Analysis on the number of different categories of workers required to complete the works within the allocated time must be made after the frequency of performing each task and picture of the total work load is decided (Franklin 1983).

b) Manpower planning

Franklin (1983) stated that in developing personnel policies one of the first steps is to examine the essential tasks to be done and the manpower required to complete them. The manpower available is then compared with that required and solutions worked out to correct any deficiencies thus obtaining and maintaining a balance. Manpower planning should be linked with the development of the organizational structure. Where certain categories of workers do not exist, or are numerically inadequate, it may be necessary to amend the organization structure to ensure that essential tasks can be completed by the available workers.

Availability of excess manpower should also be avoided, because it will be difficult to define the level or responsibilities and delegate power at various stages. It will also be difficult to set clear job descriptions for the excess manpower so that payment of salaries for non-productive personnel does not affect the economic condition of the organization.

c) Job descriptions

The purpose of a job description is to provide data which is useful in defining the performance required of an employee. Job description explains to the employee his authority, i.e. his right to make decisions and his responsibility: the duties and objectives he is expected to accomplish. Job descriptions are one way to help distribute tasks among a group. The distribution of work among the members of an organization is one of the most important tasks of a manager. When work is distributed unfairly it may cause dissatisfaction; when distributed unclearly, people lack information about who will solve problems, and are unclear about their own areas of freedom (Carefoot and Gibson 1984).

Franklin (1983), noted that job descriptions should be prepared once the manpower requirements are known. The work to be done, information on special tools and equipment to be used, working hours, relationships with other jobs in the organization and special training requirement should be clearly outlined by the job description. Skills and experiences necessary in the job and the characters required of the employee such as education and training should also be stated in the job description.

d) Correcting imbalance of skills needed and available

When there is a discrepancy between the skills needed and available such as in the case of gross overmanning the remedy would seem to transfer some workers to other departments, dismiss some, arrange for some early retirements or retrain some to categories where there is shortage. The type of organisation and the rules under which it is operating will influence whether the first three alternatives could be adopted. Retraining, on the other hand, would be dependent on the availability of funds, training facilities and a need for additional workers in some other categories (Franklin 1983).

e) Organization amendment

In organizations exhibiting symptoms of poor management a critical evaluation is necessary to determine the reasons for this state of affairs. The organization is not static but should change with the development of the utility, increment of service coverage and service requirement. During organization amendments increased power must be delegated to key personnel.

Another key factor in any organisation amendment is the communication system. Necessary information and instruction should be transmitted freely and clearly in the right and shortest directions (Franklin 1983).

f) Management audit

Franklin (1983) noted that a regular systematic management audit can be of great help in avoiding some of the undesirable effects of poor management. Any of the management audit team should not be regular members of the undertaking's staff. An independent outsider's view is most effective. Suggestions for improvements should be given by the management auditors in addition to pin-pointing inadequacies. A management audit should be conducted at least once a year.

6 WATER SUPPLY SYSTEM OF ADDIS ABABA

Addis Ababa (the name means "new flower" in the official language, amharic) was founded in 1887. It is situated in the central part of Ethiopia roughly between latitudes $8^{o}45''$ - $9^{o}10''$ north of the equator, and between longitudes 38^{o} - 39^{o} east at a maximum altitude of about 2 800 m and a minimum altitude about 2 200 m .

The climate of Addis Ababa is governed by its location as the geographic centre of Ethiopia. Temperatures are rather mild and relatively constant throughout the year with an average value of $16^{o}C$. The characteristics of rainfall and temperature contribute to a moderate climate to the region. There are two rainy seasons, the main one occurring generally from mid-June to the end of September accounting for most of the annual rainfall (750 mm out of 1 200 mm on an average). The small rainy season takes place usually between February and April.

Addis Ababa is a fast growing African city. In addition to being Ethiopia's political and economic capital, it is also the seat of various national and international organizations. The latest population census of Addis Ababa dates back to May 1984. The population of the city was estimated to be 1.4 million that time. Taking an average annual growth rate of 4 %, the number of population in 1989 was about 1.7 million (Anon 1987).

On the other hand unpublished reports from the Central Statistical Authority (CSA) show the number of population in Addis Ababa at the end of 1989 to be 2 300 000. This population increment is due to the expansion of the boundary of the city in every direction so that other regions are becoming part of the city. The total number of population with the newly expanded area is given in Appendix 1.

6.1 Development of the water supply system

Before the construction of the original Gafarsa dam, in 1943 with its treatment facilities and capacity of 5 000 m^3/d, the main sources of drinking water were springs and wells. Owing to the fast growth of the city population, the capacity of Gafarsa plant was raised up to 15 000 m^3/d and the first 400 mm transmission mains to the city were constructed in 1955. Then in 1960 the capacity was doubled.

The second water scheme (known as the Legedadi water scheme), was constructed in the late sixties to give an initial capacity of 50 000 m^3/d (BCEOM 1982). A water priority programme was implemented by the water supply authority in 1973 as a first stage of a new water supply project. The project dealt with the improvement of the water distribution system including the construction of reservoirs and pumping stations, laying of primary and secondary lines and the rearrangement of the water distribution system into 13 sub-systems based on the topographical situation.

As the population in the city grows rapidly, the combined daily total water production (about 76 000 m^3/d) from the two treatment plants could not cope with the increasing demand. To overcome the acute water shortage the second water supply project has been implemented, in two stages A and B. Stage II A was primarily to gain extra water into the supply by increasing the capacity of the Legedadi plant to 150 000 m^3/d and by rehabilitating the Gafarsa treatment plant. The construction of new storage tanks, pumping stations and transmission lines were commenced by the stage II A project in 1986. Stage II B project is still undergoing and is primarily concerned with sorting out the distribution zones and reinforcing the secondary distribution systems.

It is expected that the completion of the water project II B in early 1990 will solve the shortage of the distribution lines and consequently boost the water supply approaching the demand. The increase of supply into the existing old distribution system after the completion of the project II A has caused a higher percentage of leakages. In the following years after the pipes are put into service, the leakage in the system will be minimized provided that the execution of all pipes, fittings and appurtenances is satisfactory. In addition to new pipe layings, the rehabilitation of the old existing pipes will contribute to the total decrease of water loss in the system.

As statistical studies revealed, the population of the city is increasing tremendously in 1990's. To cope up with the demand, the authority, through the Canadian consult, Associated Engineering Service Ltd (AESL), made a Water Resources Study within 40 km radius of the city. The study is known as Water III Project (AAWSA 1988 a).

Currently detailed feasibility study and preliminary design is done by a French consulting firm Seureca in collaboration with Sir Alexander Gibbs, a consulting firm from the United Kingdom. According to the terms of references for the feasibility study and design, the main objectives of the Water III Project are the following (AAWSA 1989 a):

- to re-assess and update the water demand trend for the city up to the year 2020

- to study in more detail the hydrological and hydrogeological aspects of the surface and groundwater resources within 40 km radius

- to study and estimate the cost of various water supply alternatives and to compare economic, social and technical aspects of the alternatives and to select and design the most appropriate project to be constructed

- to prepare a master plan of staged projects, investigate their financial viabilities and recommend on management and organizational aspects

- to propose a water tariff.

Currently the interim reports are prepared and submitted to the authority for recommendation. Presently there are no activities going on concerning leakages, except the routine pipe maintenance carried out by the authority. In the beginning of 1980's leakage survey was done by the AESL (1982). Recommendations for establishing leakage control and meter maintenance programmes to reduce levels of unaccounted-for-water, and to maintain losses at minimum levels, were given. These programmes of detection and loss control, have not been fully put into operation despite training of some technicians in Canada and the supply of detection equipment mainly from Japan.

Italian experts carried out a technical mission in Addis Ababa in late 1986 to investigate the present leakage problems and their solutions.

Further agreements were made between the Ethiopian and the Italian governments concerning a leakage detection project which was to commence in June 1988.

6.2 Existing condition of the water supply system

Figure 6 shows the location of the distribution system components.

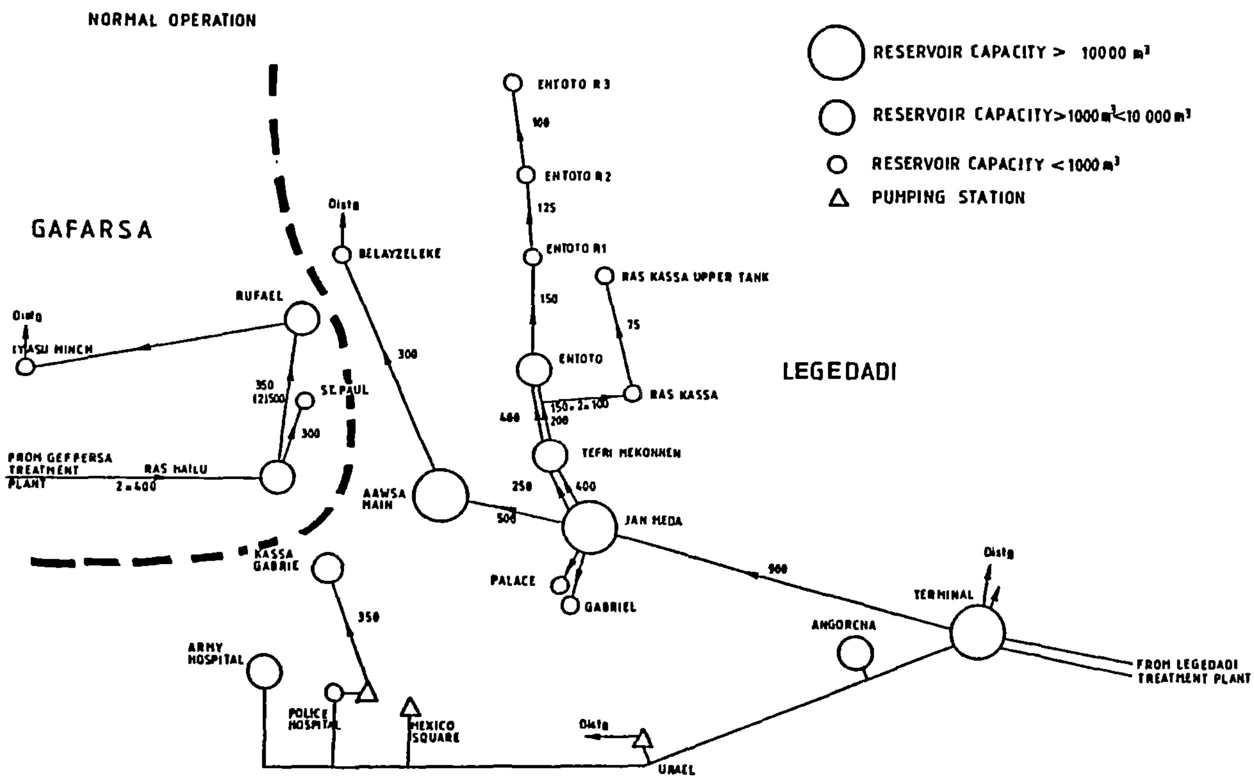

Figure 6. Location of the water distribution network components in Addis Ababa.

6.2.1 Treatment plants

The Legedadi Treatment Plant

This plant is composed of a reservoir with capacity of 47 million m^3 and surface area of 40 km^2. The reservoir feeds two treatment plants, the older one being constructed in 1970 and the new one in 1986. The main treatment processes in the plant are pre-chlorination, coagulation/flocculation, settling, filtration, pH adjustment and disinfection. The new plant has rectangular settling tanks of the clarifloc type and rectangular filters with a bed composed of siliceous sand. Aluminium sulphate was used for flocculation but recently it is found out that Superfloc-575 is more economical in the purification process as it substitutes aluminium sulphate and lime. Chlorine is used for disinfection. The treated water is conveyed to the city reservoirs by gravity through two bitumen coated steel pipe lines of 900 mm and 1 200 mm. The average daily production of the plant currently is about 95 000 m^3/d (Yohannes 1989). The existing situation of the plant is generally good even though regular inspection and maintenance is required.

The Gafarsa Treatment Plant

The water source of Gafarsa plant is a dam built in 1950's, adjoining a reservoir with a capacity of 7 million m^3. The treatment plant consists of two circular settling tanks of the accelerator type and rectangular filter beds of sand. Currently the general condition of the plant is very poor. Its designed capacity of 30 000 m^3/d is not being reached owing to deterioration caused by the effort made to satisfy the increasing demand.

The treated water is conveyed to the city by gravity main through two cast iron pipe lines of about 14 km in length and 400 mm diameter. Due to encrustation, the capacity of the pipe lines is reduced (Yohannes 1989).

6.2.2 Service reservoirs and pumping stations

Currently 39 reservoirs with a total storage volume of about 77 400 m^3 are in service in the system. Their capacity ranges from 30 m^3 (upper Raskassa reservoir) to 10 000 m^3 (Terminal reservoir).

The age of the oldest reservoir is about 50 years, while the new ones were constructed in 1983 during the Water II A Project. The general condition of the reservoirs seems good, except the two old Janmeda reservoirs of 1 250 m^3 capacity each constructed in the beginning of 1970's, and those of Raskassa reservoirs with capacity of 500 m^3 each, constructed in 1963. The main causes for the deterioration of the reservoirs are cracking of the base slabs and porous foundation concrete. At Janmeda reservoirs several cracks are visible and the water is poured out to the drains Also the level recording equipment in most of the reservoirs is out of order and immediate repair action must be taken. Otherwise the volume of water lost through overflow cannot be controlled.

According to the leakage survey by AESL 1982, amount of leakages in the service reservoirs is only about 0.4 % of production. This percentage is determined from the tests made for only 14 reservoirs out of the total 38. The survey was not carried out fully, mostly due to the various size of valves and valves not closing tightly or having broken spindles. Table 1 illustrates the level of leakage in 14 tested reservoirs during the survey.

Table 1. Reservoir leakage in Addis Ababa water distribution network (AESL 1982).

Reservoir[1)]		Leakage (l/min)
Janmeda	left	12.5
	right	5.4
Entoto	3rd	0
	4th	0
Entoto R_1	left	0
	right	2.2
Entoto R_2	left	0
	right	0
Entoto R_3	left	0.4
	right	0
St. Paul	left	0.8
	right	0.4
Ras Hailu	left	3.3
	right	5.3
Total leakage		30.3

Note [1)] reservoir side as viewed from main valve chamber.

Therefore it is suggested that the reduction of leakages in the reservoirs requires the replacement of faulty valves so that the remaining tanks may be inspected and tested. It also requires regular testing and cleaning of the tanks, regular valve exercising and maintenance of float valves, and installation and/or maintenance of level recording devices on all reservoirs and continued monitoring to prevent overflows.

According to the Interim report of the Water III Project, there are about 52 pumping units in operation including stand-bys and 14 pumps kept for emergency use. The pumps are derived by five different suppliers. The majority of the pumping stations are mechanically in good condition except some leakage at the glands on the drive shafts. These leakages at a number of pump glands are quite

insignificant compared to the total production.
Some peripheral equipment such as the counters for hours and number of operations are also missing or not functioning. There are also very few reliable pressure gauges.

Moreover, it seems that proper recording system for the pumps is lacking, despite its usefulness for operation and maintenance. Thus it is suggested that regular maintenance of the electrical parts and pressure gauges must be done. Proper recording systems should be practised as it is not only assisting in good management of the system but it also ensures that any failure will be brought to notice as soon as it occurs.

6.2.3 Network

The existing network length in the Addis Ababa water supply system is about 3 500 km. Different pipe materials (galvanized steel (GS), cast iron (CI) and polyvinyl chloride (PVC) are used in the network. It is estimated that the oldest pipes in the network were laid about 50 years ago. Pipes of older age with wide usage are mainly the GS and CI. PVC pipes for distribution lines have been used since 1975 (Senay 1989).

Internal and external corrosion problem has resulted in the deterioration of the network. According to the observations made during leakage repair works, the pipes are pitted both internally and externally with widespread tuberculation.

The treated water from both treatment plants is aggressive and results in internal corrosion. Proper pH adjustment must be done in the treatment plants to avoid internal corrosion which results in excessive leakage.

The soil condition in the city of Addis Ababa is rather corrosive (Central Laboratory and Research Institute 1982, unpublicized) because of low pH values and soil resistivity. Thus reasonable measures must be taken to reduce the losses due to external corrosion. These measures include external coating or galvanization of iron pipes, wide use of PVC or polyethylene (PE) pipes, and proper bedding and cover in the pipe zone to reduce the contact of metallic pipes with moisture.

6.2.4 Water meters

In the water supply system of Addis Ababa there are different types of meters from various manufactures in use (Table 2). This has resulted in difficulties with maintenance and especially with spare parts.

Table 2. Types of water meters in use in Addis Ababa water distribution network.

Model	Country of manufacturing	Type[1)]
Astra	Italy	W, C
Bosco	Italy	W, C and D, S
Maddalena	Italy	W, C
Zacchi	Italy	W, S/C
Kent	England	D, S/C and D, S, M
Predom	Poland	D, S, M
Mapo	Korea	W, S/C
Schlumberger/ Doris	France	D, S
Arad	Israel	W, C and W, S/C
Prema	Czechoslovakia	D, S

[1)] C - clock-dial register
D - dry register
M - magnetic drive
S - straight reading register
S/C - combined straight reading and clock-dial register
W - wet-register

The four main types of meters in the system are Mapo (28 %), Schlumberger Doris (21 %), Bosco (10 %) and Arad (8 %) (AESL 1982).

7 LEAKAGES IN THE WATER DISTRIBUTION SYSTEM OF ADDIS ABABA

The level of leakages in the system was estimated by AESL in 1982. According to the study the total unaccounted-for-water in the system was estimated to be 22 %. This includes 15 % of leakages from the distribution system and 7 % of metering and billing losses. The breakdown of these losses is given in Table 3.

Table 3. Losses in the water distribution system of Addis Ababa (AESL 1982).

Types of losses	Percentage of production
Leakages (system losses)	
Supply mains	0.5
Service reservoirs	0.4
Pumping stations	0.1
Distribution mains	5.6
Service connections	8.4
Subtotal	**15.0**
Metering and billing losses	
Incorrect sizing of meters	2.0
Assessment losses	4.5
Unauthorized connections	0.5
Subtotal	**7.0**
Total losses	**22.0**

Leakages have not been studied after 1982, even though considerable changes (like expansion of service area, increased production and consumption) have been made. From general observations the water supply system is highly sensitive to leakages because of its old age, lack of proper maintenance, and poor management. Thus it is high time for the authority to plan leak detection and repair programmes and to implement proper leak repair and maintenance techniques.

7.1 Determination of the existing leakage percentage

The existing amount of leakage in the system is determined from the difference between the unaccounted-for-water and unmetered uses. The unaccounted-for-water is estimated as shown in Table 4.

Table 4. Estimation of the unaccounted-for-water use in Addis Ababa (Plan Programme and Budget Office, Annual Reports, unpublicized).

Year	Production	Metered consumption	Unaccounted-for water	
	1000 m^3/a	1 000 m^3/a	1 000 m^3/a	%
1984/85	28 400	21 300	7 100	25.0
1985/86	29 900	21 900	8 000	26.8
1986/87	34 270	23 990	10 280	30.0
1987/88	37 460	26 220	11 240	29.0
1988/89	37 600	26 400	11 200	29.8
Average				30.0

The average value is taken only for the 1986/87, 1987/88 and 1988/89 values, because the percentage of unaccounted-for-water increased significantly after the new expansion of the Legedadi treatment plant (1986/87).

The unmetered consumption in the Addis Ababa water supply system consists of the following:

- municipal consumption
- firebrigade and other institutions using unmetered fire-hydrants as their source
- faulty water meters
- reservoir cleaning and overflows
- flushing of transmission lines.

The unmetered consumption of water due to unauthorized connections is not taken into consideration in this study, because the number of cases reported are very negligible so that the unmetered volume of water is insignificant when compared to the total production of treated water in the system.

Municipal consumption

The municipality of Addis Ababa uses water for gardening in public parks, public fountains and for different institutes such as pension houses, childcare organization and military camps. The municipality has got three trucks: one 3 000 l capacity and the other two 8 000 l capacity. The consumption of water is shown in Table 5.

Table 5. Municipal water consumption in Addis Ababa.

Volume of truck l	Average frequency of fetching water per day	Volume of water used l/d
8 000	4	32 000
8 000	4	32 000
3 000	7	21 000
Total		85 000

The average volume of water consumed in a year is about 26 500 m^3 considering six working days per week. But the data obtained from the Recreations and Parks Division shows the unmetered consumption for 1987/88 and 1988/89 is 30 800 m^3 and 31 500 m^3 respectively including the unmetered uses from distribution lines. Thus the average of these values (31 200 m^3/a) is taken for the years where data is incomplete.

Consumption for firefighting

The existing number of firehydrants in the city is about 145. The hydrants are under the control of the firebrigade. Water meters were installed for the new type of hydrants but currently most of the meters are out of order due to lack of proper protection and maintenance (Figure 7). Thus the consumptions are unmetered and the firebrigade is not paying for its use. Figure 8 shows the old type of unmetered firehydrant.

Figure 7. Condition of an unprotected metered fire hydrant in Addis Ababa, December 1989.

The firebrigade uses water for firefighting and other purposes such as consumption by other governmental institutions.

Figure 8. Old type of unmetered fire hydrant in Addis Ababa.

The water consumption by the firebrigade is given in Table 6.

Table 6. Consumption of water by the Addis Ababa firebrigade.

Year	Consumption		
	Firefighting m^3/a	Governmental institutes m^3/a	Total m^3/a
1984/85	800	1 100[1)]	1 900
1985/86	3 600	1 100	4 700
1986/87	900	1 100	2 000
1987/88	900	1 100	2 000
1988/89	3 500	1 100	4 600

1) Average value given by the firebrigade

Faulty meters

The estimation is made separately for domestic faulty meters (usually 25 mm and less) and for industrial and commercial meters (larger than 25 mm).

Data for small meters is obtained from the water meter laboratory and for the larger ones from the Network Inspection and Loss Control Section.

a) Domestic water meters

The following assumptions are made when calculating the volume of water lost by faulty meters:

- the water meters to be examined were in the same condition three months (90 d) prior disconnection
- one water meter serves one family with five members
- a specific consumption is 80 l/cap/d.

The results are shown in Table 7.

Example: With the above assumptions, the amount of unmetered water resulted from scrapped meters (small meters $\leq$ 25 mm) for the year 1984/85 is calculated as follows.

Volume of water per year

$$= 2\ 860 \text{ meters} \times 80 \text{ l/cap/d} \times 5 \text{ cap/meter} \times 90 \text{ d/a}$$
$$= 102\ 960 \text{ m}^3\text{/a} \quad 103\ 000 \text{ m}^3\text{/a}$$

Table 7. Unmetered volume of water resulted from scrapped water meters in Addis Ababa (AAWSA 1988).

Year	Total number of water meters			Unmetered water
	Examined	Reinstalled[1)]	Scrapped (out of use)	m^3/a
1984/85	6 623	3 763	2 860	103 000
1985/86	4 479	1 655	2 824	101 700
1986/87	4 482	2 133	2 349	84 600
1987/88	4 482	2 133	2 349	84 600
1988/89	4 482	2 133	2 349	84 600[2)]

1) Re-installed after adjustment and corrections
2) Based on a four month thorough report in 1988/89, taken as an average for the years with incomplete data.

b) <u>Large meters</u>

The assumptions made in this case are the following:

- flow velocity of water in all meters is 1 m/s
- the meters stay faulty at least for two months, excluding the amount charged on an estimated average basis of the customer's consumption
- customer's consumption in hours per day.

Table 8 shows the volume of water in m^3/a that is lost from large meters.

Table 8. Unmetered volume of water from large water meters in Addis Ababa (> 25 mm) (Network Inspection and Loss Control Section, Annual performance reports submitted to the Engineering Division, unpublicized).

Size of meter	Unmetered volume, m^3/d				
mm	1984/85	1985/86	1986/87	1987/88	1988/89
25				25	
32		46	46		41
40	37	63	72	207	37
50	1 202	4 419	1 640	1 618	1 849
75	1 405	991	1 654	1 334	1 148
100	1 133	1 813	2 036	453	623
150		1 018			
Total	226 700	321 000	326 900	218 300	183 500

The list of customers, estimated consumption hours and total consumption is given in Appendix 2.

Reservoir cleaning and overflows

In this analysis it is considered that all reservoirs are cleaned once in two years. Reservoir cleaning includes blowing off (sediment discharge), cleaning and rinsing followed by disinfection (Mekuria 1989).

Assumptions

Depth of water needed for sediment discharge = 10 cm
Depth of water needed for cleaning and rinsing = 20 cm
Depth of water needed for disinfection = 20 cm

The total volume of water required is the depth of water multiplied by the surface area of the reservoir. The total water requirements for cleaning reservoirs is estimated to be 3 500 m^3/a. The detail calculation is presented in Appendix 3.

Since most of the reservoirs do not have properly working level indicators, overflow takes place often. Thus about 0.1 % of the volume of reservoirs is assumed to be lost per day (Mekuria 1989). The amount of water lost due to overflow is about 28 300 m^3/a. Thus total unmetered use from reservoirs cleaning and overflows is approximately 31 800 m^3/a.

Flushing of transmission lines

The transmission lines from the Legedadi treatment plant to the city reservoirs and from Gafarsa treatment plant with a length of about 18 km and 12 km respectively are assumed to be flushed six times/a. Fifteen min of draining and 1 m/s of velocity of water are assumed. The total flushing requirement is estimated to be 20 700 m^3/a. The detailed calculation is given in Appendix 4.

The total unmetered consumption from municipality, fire-brigade, faulty meters, reservoir cleaning and overflow, and flushing of transmission lines is summarised in Table 9.

Table 9. Unmetered consumption in Addis Ababa water distribution network.

Year	Unmetered consumption (1 000 m^3/a)						Total
	Munici-pality	Fire-brigade	Faulty meters		Reservoir cleaning	Mainline flushing	
			Small	Large			1 000 m^3/a
1984/85	31.2	1.9	103.0	906.5	31.8	20.7	10 095
1985/86	31.2	4.7	101.7	1 284.0	31.8	20.7	1 474
1986/87	31.2	2.0	84.6	866.6	31.8	20.7	1 037
1987/88	30.8	2.0	84.6	872.9	31.8	20.7	1 043
1988/89	31.5	4.6	84.6	813.3	31.8	20.7	987

Table 10 shows the leakage percentage for the five years study time.

Table 10. Determination of percentage of leakage in Addis Ababa water distribution network.

Year	Unaccounted-for-water 1 000 m^3/a	Unmetered consumption 1 000 m^3/a	Leakages 1 000 m^3/a	%
1984/85	7 100	1 095	6 005	21.1
1985/86	8 000	1 474	6 526	21.8
1986/87	10 280	1 037	9 243	27.0
1987/88	11 240	1 043	10 197	27.2
1988/89	11 200	987	10 213	27.2
Average [1])				27.1

1) This average value is only for three years after the new expansion of the Legedadi treatment plant is set operational.

In the year 1986/87, the new treatment plant at Legedadi, an extension of the existing plant, set operational which raised the water production substantially. As a result, the leakage in the distribution system, grew to about 27 % of the production.

7.2 Visible and invisible leakages in the system

This analysis may help the organization to control and give more attention to the type of leakage having serious effect on the system.

Because the data available was only for the years 1987/88 and 1988/89 the analysis is made accordingly.

Despite the effective communication system of the authority and the public awareness of visible leakages (reports by telephone), a six hour loss i.e. time taken until the loss is under control is considered for calculation purpose.

The leakage reports indicate that about 75 % of the cases reported are losses from private connections while the remaining 25 % are from the distribution lines.

The common size of pipe for private connections in the system is 13 mm. Therefore diameter of 13 mm is taken as the minimum and average size for private connections while, pipe sizes of 25 mm and 50 mm are taken as minimum and average sizes for distribution lines respectively.

Moreover, the average velocity in the pipes is assumed to be 1 m/s.

Thus the extent of visible leakages in the system is based on the previous facts and assumption.

The reported cases in the six zones are presented in Table 11 and Appendix 5. It must be noticed that these reported cases are not the only visible leakages in the system. Even intensive leak surveys can possibly miss some of the leakages.

Table 11. Number of reported leakages in Addis Ababa water distribution network.

Year	Number of reported cases					
	Zone 1	Zones 2 & 4	Zone 3	Zone 5	Zone 6	Total/a
1987/88	1 984	3 850	1 504	2 015	2 074	11 427
1988/89	2 720	3 584	901	2 176	2 272	11 653

Because zones 2 and 4 have the same branch office, the results are compiled together.

Table 12 shows the visible leakage percentage.

Table 12. Total volume of water lost due to visible leakages in Addis Ababa.

Year	Volume of water lost (m^3/a)					
	Private connection		Distribution lines		Total/a	
	Minimum	Average	Minimum	Average	Minimum	Average
1987/88	24 700	24 700	30 300	121 200	55 000	146 000
1988/89	25 200	25 200	30 900	123 600	56 100	149 000

Taking the total leakage amount which is determined before and shown in Table 10, the invisible leakage percentage is calculated as presented in Table 13.

Table 13. Invisible leakage percentage in Addis Ababa water distribution network.

Year	Total leakage		Visible leakage		Invisible leakage	
	1000 m^3	%	1000 m^3	%	1000 m^3	%
1987/88	10 197	27.2	146	0.4	10 051	26.8
1988/89	10 213	27.2	149	0.4	10 064	26.8

Tables 12 and 13 show that the authority has to pay more attention to the underground leakage which needs leak detection survey. The Network Inspection and Loss Control Section has to be reorganized and strengthened by adequate staff so that the available detection equipment are set in operation.

8 ORGANIZATIONAL, TECHNICAL AND ECONOMICAL ASPECTS OF LEAKAGE CONTROL IN THE WATER DISTRIBUTION SYSTEM OF ADDIS ABABA

8.1 Organizational aspects

8.1.1 Development of the organizational structure

Piped water services for Addis Ababa were started in 1902, about 15 years after the establishment of the city. Actually in the beginning the service was available only to the royal family. All activities pertaining to water supply remained to be the sole responsibility of the Ministry of Public Works until the water supply section was established under the municipality in 1942. The number of employees was 78, of which 70 were involved in technical work. 23 employees were Italians (AAWSA 1973).

The municipality of Addis Ababa started to provide drinking water from springs and wells. As the city was expanding and population increased, the water supply section was faced with the need for an additional source of supply and better service. The construction of the Gafarsa and Legedadi dams with their treatment plants, network expansion and reservoir construction activities were carried out.

Although much had been done by the municipality of Addis Ababa to improve and enlarge the water supply services in accordance with the growth of the city, the government of Ethiopia greatly felt the pressing need for a constant and adequate supply of water and a proper sewage disposal system. Therefore, the present Addis Ababa Water and Sewerage Authority was established as an autonomous government organization in 1972 (AAWSA 1973). Since then the main objectives of the authority have been (AAWSA 1989 a):

* to supply potable water for domestic, commercial and industrial use
* to conserve and protect the groundwater from undue exploitation and prevent it from contamination
* to ensure the sanitary disposal of sewage.

During the establishment of AAWSA the number of employees was about 500.

To discharge its responsibility in efficient and economical manner, the authority launched a re-organization and systems study. According to that study, the authority was divided into three departments: the Engineering Department, Finance Department and Administration Department.

Since the organization was growing unexpectedly large its structural set-up had to be improved to solve the prevailing administrative and technical problems. In 1979 an American firm, Public Administration Service (PAS) studied new organization chart, position classification manual, job descriptions, manpower assignments and salary scale. These were approved and put into practice in 1980. The organization chart studied by PAS is presented in Figure 9.

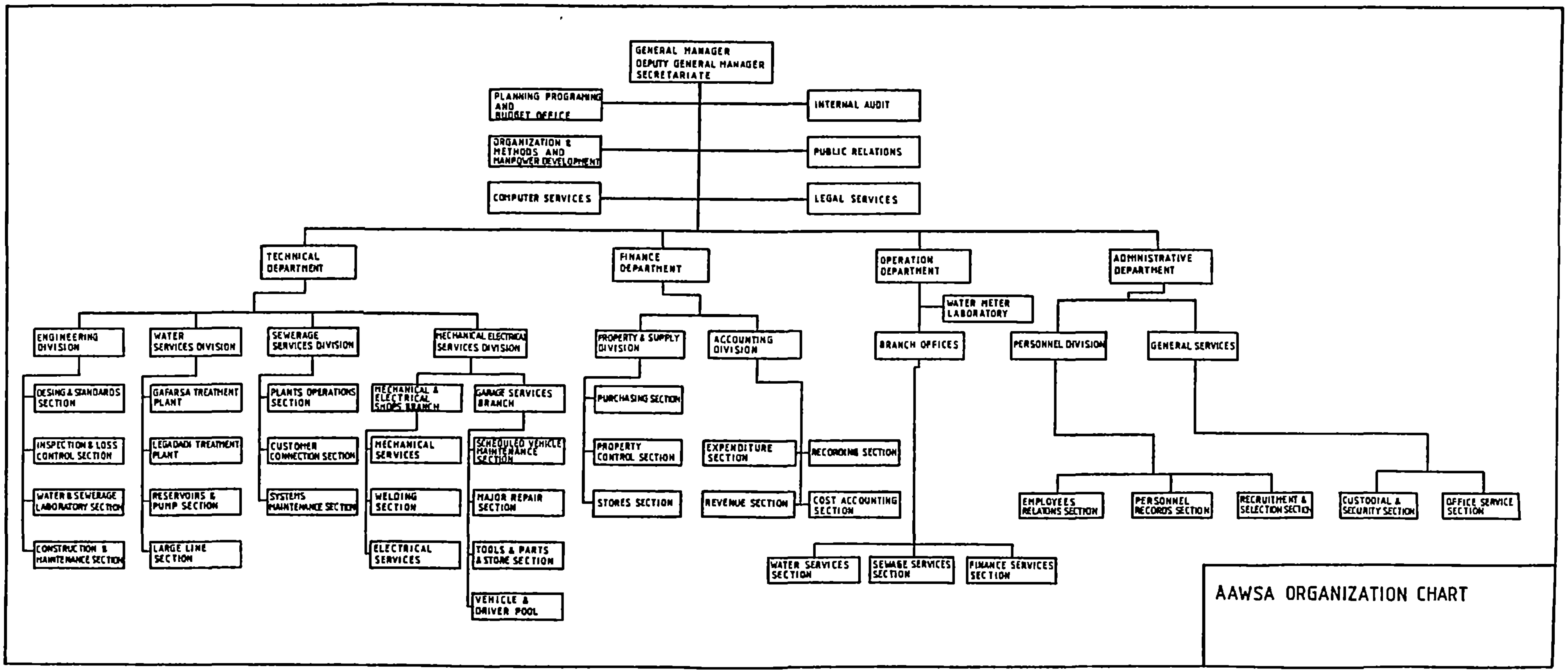

Figure 9. Organizational chart studied by the Public Administration Service (FAS) in 1979.

Currently AAWSA has about 1 200 employees involved in the technical, administrative and financial work. AAWSA is directed by the General Manager under the authority of a board of members from the Ministry of Health, the Ministry of Finance, National Water Resources Commission, and the Ministry of Urban Development and Town planning. The Chairman of the board is the Addis Ababa Region administrator. Policy formulation is the responsibility of the board of directors, while the General Manager has the executive authority (AAWSA 1988 a).

8.1.2 The existing organization and leakage control

As the city was growing faster and effective service was expected from the authority, minor modifications were necessary in the authority's organizational set-up. The improved existing organizational chart of the AAWSA is as presented in Figure 10.

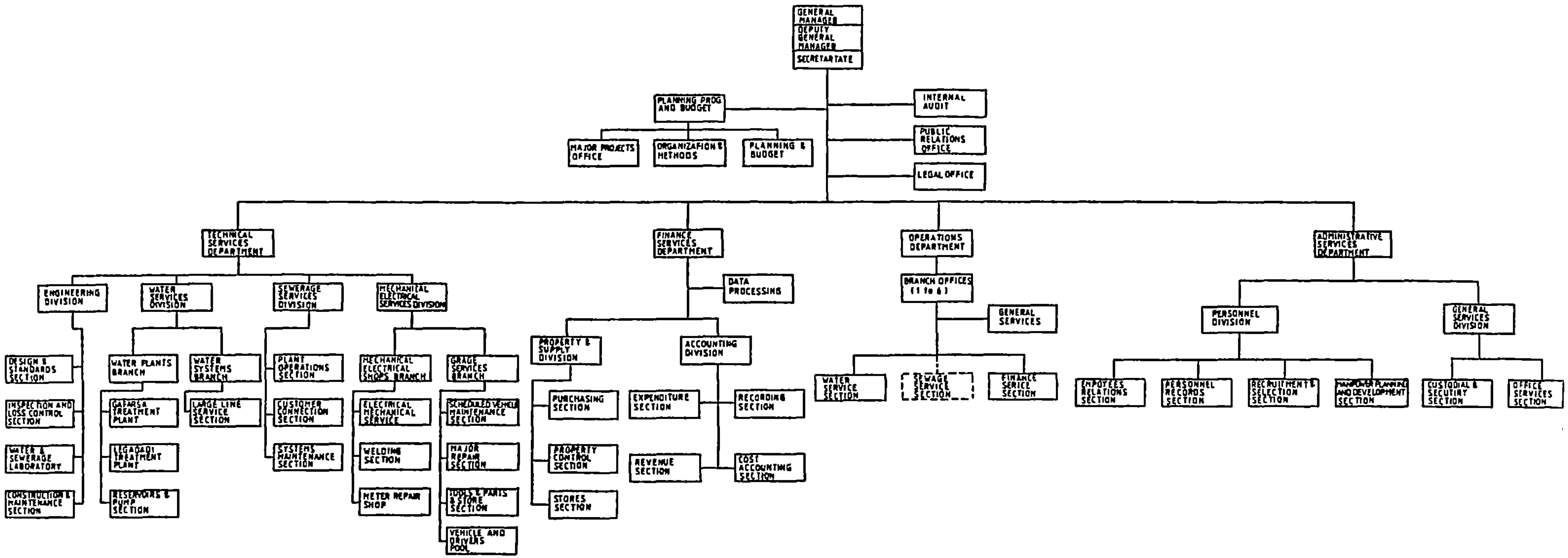

Figure 10. Existing organization of Addis Ababa Water and Sewarage Authority (AAWSA 1989 b).

Despite all the possible improvements done within the PAS studied organization chart, it is now high time for the authority to modify its existing organization set-up as Addis Ababa is growing to a metropolitan city with a very large service area and growing number of customers.

As shown in the organizational chart, the Network Inspection and Loss Control Section which has the responsibility to follow-up leakage detection and loss control is presently under the Technical Department. All distribution lines of the city up to 100 mm diameter inclusive, and the technicians who repair them and make pipe layings and connections of same sizes belong to the branch offices which are under the Operations Department.

In cases where leakages are detected by the inspection and loss control crew, the crew leader has to report to the Engineering Division and this division has to forward the case to the Technical Department. Further the Technical Department has to inform the Operations Department which later transmits the report to the concerned branch office. Finally repair instructions are transmitted to the technicians. This procedure takes quite a long time before the leak is repaired and in most cases the feedback is not effected. The worst case of flow of information is presented in Figure 11 to point out the unnecessary time consumption resulting from the present organizational set-up. The numbering shows the sequence of information before any activities are done following the customer's complaint.

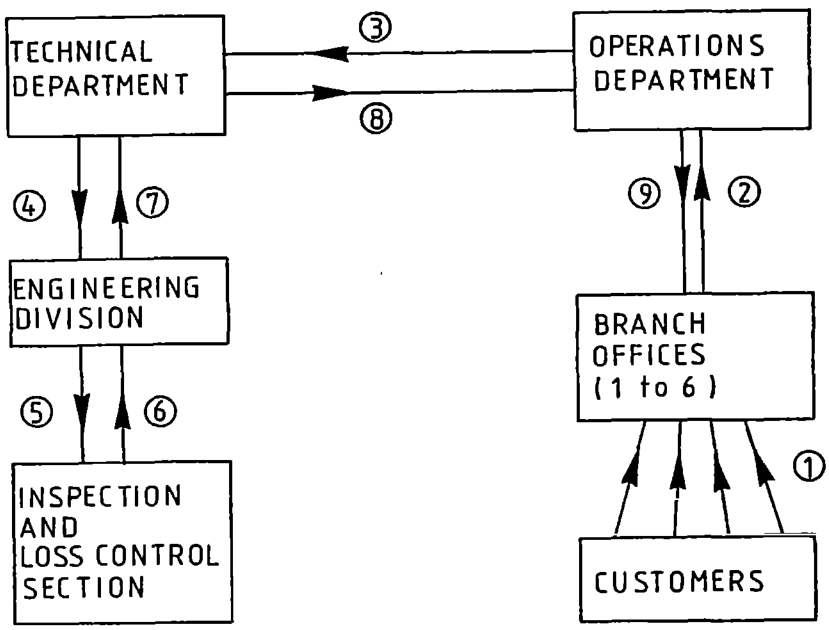

Figure 11. The information flow in Addis Ababa Water and Sewerage Authority might sometimes be quite slow including several steps.

The whole round from 1 to 9 exceeds three to four months especially with invisible leakages before appropriate measures are taken. In case of visible leakages, control is made by the branch offices in relatively shorter time without going through this lengthy channel. The bureaucratic bottleneck in this context could have been solved if the Network Inspection and Loss Control Section is organized under the Operations Department (Figure 12) where regional branch offices could easily contact it without any formal procedure.

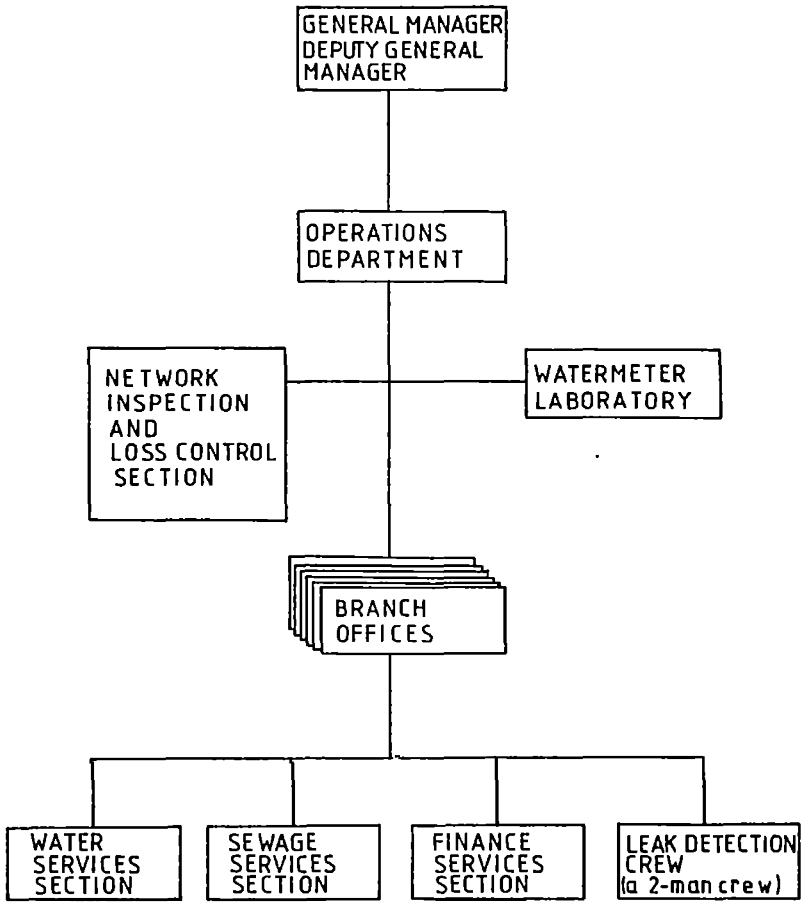

Figure 12. Proposed organization for the Network Inspection and Loss Control Section in Addis Ababa Water and Sewerage Authority.

The Operations Department or the Inspection and Loss Control Section would also have the possibility to assign trained technicians in leakage detection in the section as well as in every zonal offices as the AAWSA has quite enough leak detection equipment.

It is worth mentioning here the encouraging measure taken by the authority to minimize visible leakages. During the working hours the zonal technicians are ready to control and repair visible leakages mostly caused by breakage of old pipes and reported by the public. Outside the working hours, including the night, the authority has formed an emergency crew to take appropriate measures whenever there is a case reported. Besides guaranteeing the normal water supply, the crew maintains reported leakages as soon as possible. If the repair is beyond its capacity it makes only temporary control by closing valves to stop the loss and reports to the concerned zonal office the next working day.

To facilitate this operation, a radio and telephone unit is at service 24 hours. Additionally vehicles assigned to the technicians are equipped with radio units. These measures definitely have substantial contribution to minimize visible leakages.

8.1.3 Duties and responsibilities of departments, divisions and sections involved in leakage control

In the following description of duties and responsibilities of departments, divisions and sections, only the ones which are directly related to leakage are mentioned, even though every part of the organization has contribution one way or another in affecting the leakage control.

1) Departments

Technical Department

As this department is responsible, in addition to various tasks, for water distribution and laying of pipes with diameters more than 100 mm, it is also responsible for controlling detection of leakages, pipe repairs or replacements, condition of reservoirs and repair of leakages at pump gland, operation of water and wastewater plants and collection of sewage and laying of sewer pipes. Also during project implementation project preparation of specifications, bill of quantities and contract documents are accomplished by this department.

This department has four divisions: Engineering, Water Services, Sewerage Services and Mechanical-Electrical Services Divisions.

Operations Department

All customer connections and distribution lines with diameters up to 100 mm which are the responsibility of the branch offices are supervised by this central office. Moreover, activities of the meter repair shop, meter reading and billing are controlled by this department.

Finance Department

This department is responsible for the overall financial management. Duties carried out by this department include collection of revenues and effecting expenditures, procurement of goods and services, and record-keeping in relations with the financial activities.

2) Divisions

Engineering Division

This division supervises the conduct of auxiliary studies and assesses the technical requirements of all facilities, controls the preparation of engineering standards, designs and specifications for operations, maintenance and material supply and equipment procurement.

Water Services Division

The division is responsible for water production, treatment and distribution processes. The treatment plants, the large lines section and the reservoirs and pumping stations are under the control of this division.

Mechanical-Electrical Services Division

This division is responsible for maintaining the authority's vehicles, providing central motor tool services, central tool and parts services, welding services and mechanical and electrical workshops.

Property and Supply Services Division

The procurement of materials, equipment and service for the authority is the responsibility of this division. It also controls property and store services. It assures that adequate records of purchased materials are maintained, and assists in the pricing of short and long-term programmes for planning and budgeting purposes.

3) Sections

Network Inspection and Loss Control Section

The main duties of this section include:

- detection of invisible leakages
- control and inspection of bulk meters, firehydrants and pressure reducers of large lines
- pressure measurements for the purpose of new connections and installation of firehydrants
- field mapping of the distribution network
- transmitting proper reports on leakages and faulty bulk meters to the Engineering Division for remedial action by the concerned section.

Design and Standards Section

The duties of this section comprises of the following:.

- preparation of drafting and surveying works for small constructions to be accomplished by the authority
- up-dating of all water distribution network maps to facilitate the proper control of the water supply system
- designing standard details to be used by field personnel such as trench and house connection details
- designing new connections in the water distribution network for new areas of the city
- preparation of technical specifications for tenderers.

Large Lines Section

The construction of large lines greater than 100 mm and appurtenances is executed by this section. Repair of leakages on these lines and installation of bulk meters are effected by this same section.

Reservoirs and Pumping Stations Section

The duties of this section include:

- patrolling, recording and reporting of measurements from pumping stations and reservoirs of the distribution and collection systems
- reporting of leakages in reservoirs and pumping stations after close inspection for the concerned section.

4) Services and Others

Mechanical Services

The mechanical parts of treatment plants, reservoirs and pumping stations and repair of leakages at pumping stations are under the supervision of this section.

Branch Offices

Each branch office works under the general supervision of the Operations Department. Distribution, pipe laying and customers' connections, meter reading and bill collection as well as repair of leaking lines are accomplished by these offices.

Meter Repair Shop

Faulty meters are tested and repaired or put out of service by this section. This shop is under the supervision of the Operations Department.

Radio Unit

Any complaint of customers and visible leakages reported by the public by telephone or personal is received by this unit and information is transmitted to the concerned section or branch.

8.1.4 Interaction between the departments

a) Technical Department and Finance Department

The Technical Department prepares all technical specifications which facilitate the purchase of pipes, fittings and appurtenance, chemicals, equipment, etc. The quality of the imported items are technically checked by qualified personnel from the Technical Department (AAWSA 1982).

b) Technical Department and Operations Department

Proper design of distribution network, construction standards, water treatment and quality control are performed by the Technical Department, whereas water distribution and customer connections with the corresponding billings are carried out by the Operations Department.

c) Technical Department/Operations Department and Administration Department

As all qualified technical personnel are needed in the Technical and Operations Departments, the request for new employment is forwarded to the Administration Department. The request is usually partially treated as the budget allocation is limited and the bureaucratic process is time consuming. In addition, some technical personnel are promoted to higher administrative posts and no substitute of qualified technical personnel is effected for a very long time or not at all. This delayed action reduces the efficiency of crews, sections or divisions in question. For example, trained personnel in the Network Inspection and Loss Control Section were already transferred to other sections without any replacement in their former posts. As a consequence, the section has not at present enough qualified technical personnel.

Moreover, there are many vacant key posts and some sections without qualified responsible chiefs. Hence, there is no other option than assigning unqualified or semi-qualified temporary acting chiefs. This management weakness leads to reluctance or frustration of the temporarily assigned chiefs which result in lack of co-ordination and inefficiency of the staff.

8.1.5 Skilled manpower in the Network Inspection and Loss Control Section

The manpower anticipated a decade ago by the Public Administration Service (PAS) for this section was as follows (AAWSA 1982):

Number	Job title
1	Engineering Assistant III
5	Engineering Assistant II
3	Engineering Assistant I

However, only 30 % of the above mentioned manpower is employed at present. The available manpower currently is:

Number	Job title
2	Foremen
1	Technician III

It is easy to understand the inefficiency of the section with the available manpower as the service area is enlarged and the network is more complicated now than a decade ago. On the contrary, the manpower should have been increased to meet the ever-growing service requirement. By this time, trained technicians in leakage detection and control should have been assigned in every regional office to use the available detection devices and to tackle leakage problems effectively.

The manpower in the section could be strengthened by rearranging the excess manpower in some of the sections, or by returning back the qualified personnel who were transferred to other sections. Also combining sections with similar or related duties can help to use the available manpower effectively.

Job descriptions of personnel in the Newtwork Inspection and Loss Control Section studied by the Public Administration Service are as follows (PAS 1979):

<u>Engineering Assistant III</u>

Employee in this work classification performs miscellaneous and complex field and office work, usually with significant supervisory responsibilities. The employee plans and supervises the work of the central drafting room; applies standards to the preparation and maintenance of underground and facility maps of the water and sewerage systems, supervises and instructs junior employees in standards and procedures; plans, assigns, and co-ordinates the work of several survey crews; makes field inspections and interprets plans and specifications as needed.

The required qualifications are completion of technical school and several years of training in civil or sanitary engineering, and at least five years of progressively responsible technical experience in drafting, surveying, and/or construction inspection, or an equivalent combination of experience and training which has provided the following:

- thorough knowledge of the basic principle of using modern equipment in surveying and drafting
- considerable ability in planning and organizing, drafting, mapping, surveying and construction work
- ability in interpreting engineering plans, designs and specifications
- ability to maintain records and to prepare field notes and reports of work performed.

Engineering Assistant II

The nature of work to be performed by this group of employees includes the preparation of maps and tracings, preparation of plans for relatively simple standard projects, materials and fittings for extension, replacement, and new construction work. In construction inspection, carry out the inspection of assigned segments of the project, checking adherence to plans, designs, and specifications.

The required qualifications are completion of technical school supplemented preferably by some training in civil or sanitary engineering, and at least two years experience in mapping, drafting, surveying, construction inspection; or an equivalent combination of an experience and training which has provided the following knowledge and abilities:

- knowledge of the principles and practices of surveying and drafting and of the care and use of drafting and surveying instruments
- knowledge of common construction practices and materials in the construction of pipe lines and structures
- ability to maintain records and prepare field notes and reports of work performed, measurements taken, and inspection of findings
- ability to maintain good work relationships with other workers
- ability to instruct and train less experienced workers in mapping, drafting, surveying and construction inspection.

Engineering Assistant I

Engineering Assistant I prepares original maps, makes tracing and enters data on maps according to the standard procedures of the office; operates blue print or other duplicating machine in preparing copies of drawings and maps; files drawings. In construction work, employees in this classification assist in checking line grade; inspect trenching operations for adherence to requirements about depth, width and finishing of bottom and sides.

The required qualifications are completion of technical school in surveying and drafting; or an equivalent combination of experience and training which has provided the following abilities and skills:

- basic principles of surveying and drafting, use of surveying and drafting instruments
- ability to maintain records and prepare reports of work performed, measurements taken, and inspection findings
- ability to understand and carry out oral and written instructions where the user of basic survey, drafting, or construction inspection techniques are involved.

Foreman

This group of employees are classified either as water services foremen or water construction foremen.
Water Services Foreman is doing skilled and supervisory work in the maintenance, repair and extension of the water distribution system. Employees in this work classification are responsible for planning and supervising the work of several assistants and technical workers in carrying out varied assignments with water distribution system. Much of the emphasis of their work is on meter servicing, customer connections, and repairing and replacing smaller distribution lines (typically less than 100 mm diameter).

The required qualifications are completion of technical school, and at least five years of experience in water distribution system maintenance; or an equivalent combination of experience and training.

Water Construction Foreman is doing skilled and supervisory work in water distribution system maintenance and construction of large size lines (100 mm and large diameter) and the use of construction equipment. Employees in this classification are responsible for immediate supervision of crews trained in the repair and replacement of distribution lines and related elements and in extension of water line of large sizes.

The required qualifications are completion of technical school, and at least five years of progressively responsible technical and supervisory experience in major pipe construction and replacement projects.

Technician III is doing technical and skilled work in the installation, repair and maintenance of water distribution or sewage connection facilities. The work assignments to positions of this class vary, but typically they involve some combination of advanced skills in pipe work, knowledge of basic practices in surveying and drafting, ability to estimate material and fittings needed, etc.

Technician III serves on leak detection operations using equipment required to trace or locate water losses; operates water valves when necessary to carry out detection work; prepares sketches, memorandum and reports required to complete information on conditions of the system; prepares requisitions and work orders needed to complete repairs of the system.

Employees in this job classification also serve as a meter service men; receive work orders for meter cleaning, repair, replacement, installation, or removal and for related work at customers' premises; and carry out requested services, replacing meters as necessary and recording readings of meters removed and installed. Inspection of site and using maps or other references as the location of existing distribution lines; preparation of sketches of premises showing location of connection line, gate valves and meters are performed by technician III.

The required qualification are graduation from technical school or high school completion supplemented by basic training in surveying and drafting with at least three years of diversified and skilled work in collection and distribution system operation.

The job descriptions indicate that the Network Inspection and Loss Control Section has a lot to contribute to the well-being of the water supply system. As it is under-staffed it is unable to perform its assigned missions and to fulfil its responsibilities until at least the bulk of the designated numbers of qualified personnel have recruited and assigned.

8.2 Technical aspects of leakage control

8.2.1 Types of detection equipment available in AAWSA

AAWSA has got several types of leak detection equipment most of which are Japanese brand. Almost all the equipment are in good condition because some of them are brand new and not yet used.

The list of the available equipment is given in Table 14.

Table 14. Leak detection equipment available in Addis Ababa Water and Sewerage Authority (AAWSA 1989 c).

Description	Condition
Fuji iron pipe detector FL-81	In use and in good condition
Fisher's M-scope model TW-5, pipe and cable locator	In use and in good condition
Electronic survey and detection instrument from Pollard	In use and in good condition
Fuji box locator F-50 (a special detector for locating buried metal objects)	In use and in good condition
Fuji non-metallic pipe locator PL-101N type	In use and in good condition
Fuji simple water leakage examinator	In use and in good condition
Fuji boring bar	In use and in good condition
Fuji electric sound detector FSB-4L.4S	In use and in good condition
Heath Consultants Incorporated model Globe Geophone	In use and in good condition
Fuji water leak detector WL-91	In use and in good condition
Cartridge type Fuji portable pressure	
Recorder FJN-135	In use and in good condition
FJN-138	In use and in good condition
Fuji electronic sound detector model FSB-4L	Available, not yet used
Metrauib DF 3000 leak noise correlator	Available, not yet used
Detection device Triphone T.70 by Pont A. Mousson	Available, not yet used
Portable test pitometer by B.H. Cox Ltd.	Available, not yet used
Peart, ferrule inserting machine	Available, not yet used
Fuji Ontan pipe locator PL-130 by Fuji Tecom Inc.	Available, not yet used
Fuji leak noise correlator LC-1000 with instruction manual by Fuji Tecom Inc.	Available, not yet used
Advanced leak noise correlator DF 3000	Available, not yet used

Due to lack of spare parts, the equipment has to be sent to Japan for repair. The quantity of the equipment is quite enough to AAWSA, but the detection crew needs proper training as the devices are new in the authority.

Training of technicians in leak detection has been agreed upon by AAWSA and an Italian firm. This training will take place in Italy for two months when the leakage detection project is commenced (AAWSA 1988 b).

8.2.2 Record-keeping and documentation

The technical documentation in the authority, is unsatisfactory. For instance, all leakage reports from the public to the Radio Unit are normally transmitted to the concerned branch offices either in written form or per telephone. There is however, no feedback whether the repair is done or not. All leakage reports and measures taken are not kept properly. Similarly, no proper and reliable documentation of all repaired water meters is available. It is hard to find up-dated maps which give important information on the distribution network, thus the leakage control is much complicated.

As there is an acute shortage of transportation (cars) in the organizations, it is very difficult to maintain even visible leakages in a reasonably short time. In some cases technicians try to find isolation valves by trial and error because valves are not marked down on maps. The control and maintenance of some leakages takes several days as a result of either lack of information on maps, transport problems or shortage of proper pipes and fittings.

A detailed leakage report form was prepared during the leakage survey study by the AESL (1982) (Appendix 5). But this form is abandoned as it was found to be too complicated for general use, even when translated into the local language. Figure 13 shows the improved form.

LEAK DETECTION AND REPAIR RECORD FORM
ADDIS ABABA WATER SUPPLY & SEWERAGE AUTHORITY

Date ____________________

=======================MAP==============================

=======================LOCATION =========================

ZONE __________________ SUBSYSTEM ___________ PLAN NO.______

HIGHER ________________ KEBELE ______________

=======================DETECTION========================

METHOD OF DETECTION

PUBLIC REPORT

ROUTINE SURVEY

MECHANICAL DETECTOR

ELECTRONIC DETECTOR

ESTIMATED FLOW _________ l/min or m^3/d

=======================REPAIR===========================

PIPE SIZE ____ mm PIPE MATERIAL ____________________

JOINT TYPE ___________________________ PIPE AGE____________

CAUSE OF LEAKAGE

CORROSION INSIDE/OUTSIDE

VANDALISM

EROSION OF BACKFILL

ACCIDENTAL IMPACT BY __________________________________

TYPE OF REPAIR ____

=======================COST=============================

MATERIAL USED ____

LABOUR REQUIRED ____

PERFORMED BY ____

Figure 13. Leak detection and repair record form for Addis Ababa Ababa Water and Sewerage Authority.

Regarding records of water meters, a ready -made card shown in Appendix 6 is available, but this form is not properly used in the shop. Thus appropriate supervision and control is needed from the Operations Department. if the installation, test and maintenance records of the meters are kept in order, it will help the authority to know what is to be available in the stores.

8.3 Economical aspects of leakage control

8.3.1 Limited budget allocation

The limited budget allocation for the authority affects the purchase of necessary pipe material and appurtenance on time. As most of the required materials are purchased from abroad, lack of foreign currency creates a delay in leak repair activities.

The AAWSA has to get a subsidy from the government, because in most cases the revenue cannot cover the expenditures (Table 15).

Table 15. Revenues collected and expenditures paid by Addis Ababa Water and Sewerage Authority (AAWSA) (Plan Programme & Budget Annual Reports, unpublicized).

Year	Revenue ETB 1 000/a	Expenditure ETB 1 000/a	Deficit ETB 1 000/a
1984/85	12 191	18 643	6 452
1985/86	12 430	16 022	3 592
1986/87	11 924	15 441	3 517
1987/88	15 962	23 257	7 295
1988/89	13 803	18 091	4 288

The budget allocation varies with the revenue collected by the authority. The stagnant water tariff, reluctance of some governmental institutions to pay for their consumption, meter reading and billing inefficiency, and lack of proper incentives are the main factors contributing to limited revenue and consequently of limited budget allocation.

Stagnant water tariff

There has been no increase in water tariff (ETB 0.5/m^3) of treated water for about 47 years, even though treatment and distribution costs are increased substantially over the period. According to the information gathered from the Plan Programme and Budget Office, a proposal for the improvement of the water tariff to cover the operation and maintenance costs has been presented to the Council of Ministers for approval, but no decision is made yet.

The production cost of treatment is about ETB 1.10/m^3 and yet AAWSA is selling water for ETB 0.5/m^3 (Haile 1989).

Even though, the tariff improvement will affect the low-income group in the city, somehow the selling price should cover the running cost of the system.

Unwillingness to pay

Large consumers such as hospitals and governmental institutions are not willing to pay for water. Numerous former private organizations which were nationalized, and institutions which changed their former names are troublesome to the authority, due to change of ownership and misfiled contract number respectively. Due to these reasons the AAWSA has about ETB 5 000 000 uncollected money with its customers accumulated from the year 1942 (Haile 1989).

Meter reading and revenue collection inefficiency

Meter reading and revenue collection inefficiency have also a sound effect on the income of the authority. Some meter readers give average reading values from previously sold bills without actually reading the meters. Moreover, meter iaccuracies lead to incorrect reading values and discrepancies in the actual consumptions.

As noted by AESL (1982) in addition to meter inaccuracies, reading errors in the water supply system of Addis Ababa are caused by difficulty of reading meters having dirty glass, condensation under the glass, confusion with multiple clock-dial meters and reading of the wrong meter when several metes are used by a single customer. These facts lead to "over-charges" or "under-charges". In case of over-charges, customers normally complain and the corrections are made in due time. Computer records show that in January and February 1988, out of 95 000 customers 15 % were over-charged. Whereas under-charged customers never come to discuss with the authority. Both cases affect the determination of exact amounts of losses in the system and under-charges greatly reduce the level of revenue of the authority.

Proper supervision of the meter readers is suggested to diminish the existing problem regarding approximate reading values. As there are supervisors in each of the branch offices who are assigned to control the meter readers in addition to some other duties, they have to counter check reading values more often.

Lack of adequate incentives

Lack of adequate incentives to the personnel involved in bill collection has affected the revenue collection efficiency. Not only better salaries could be an answer to effective bill collection, but an introduction and application of attractive incentive, for example combined encouraging percentage per bill and per amount of money collected.

Presently in the AAWSA, one bill collector gets ETB 0.095/bill if he sells 99 - 100 %, ETB 0.085/bill if he sells 94 - 98 % and ETB 0.075/bill if he sells 75 - 93 % of the bills he received per month (AAWSA 1985). This amount of commission has been given since 1985. Depending on the economic level of the authority the amount of these incentives must be improved.

9 CONCLUSIONS AND RECOMMENDATIONS

According to the study results, the leakage amount in the water supply system of Addis Ababa is estimated to be 27 %. It was difficult and inconvenient to make actual field measurements on leakages, not only because the network is very large and complicated to handle, it was also almost impossible to get updated maps because record-keeping and documentation system of the organization is poor. Moreover, the time allocated for data collection was relatively short to carry out such measurements. Even if field measurements had been made, the results would not have been reliable, because isolation of a certain area is quite difficult as the location of valves, connections and even pipes is not clear. Additionally, several leak detection zones should be considered as there is a big variation in characteristics of consumption, topography and other relevant factors. Therefore, only a few leak detection zones could not be representative.

Management problems are often reflected in the authority. The existing qualified manpower in the Network Inspection and Loss Control Section is an example of poor management. The section has only one third of the recommended qualified staff despite that leakage problem is getting worse and needs more attention. One can easily understand the inefficiency of the section with the available manpower (two foremen and one technician). On the contrary the manpower should have been increased to control the widely growing and complicated network of the city.

As most of the necessary material for the system is purchased from abroad, shortage of foreign currency has caused a delay in repair of leakages. Moreover the lack of vehicular fleet and adequate incentives to personnel has affected proper leakage maintenance.

There has been no increase in water tariff since 1942. The tariff of ETB 0.50 (USD 0.25) per cubic meter for treated water has remained unchanged for about 47 years, even though, treatment and distribution costs have been increased substantially over the period. In fact, proposals for tariff improvements were presented to the Council of Ministers for approval. It is considered to have political implication and affect the meagre standard of living of the population. Thus AAWSA is forced to rely on subsidies which it gets from the Ministry of Finance and on grants from international donor agencies. AAWSA is too extravagant to collect water revenues from its customers in due time. It is estimated that about ETB 5 000 000 which is accumulated over the 47 years is uncollected. Lack of adequate incentives to meter readers and collectors, unwillingness to pay (especially governmental institutes), and in general management inefficiencies are some of the main reasons affecting revenue collection.

Considerable amount of water is lost due to the bureaucratic channel before a leak is under control. Information about leakages observed by the public is reported to the concerned branch office and then forwarded to the Operations Department, then to the Technical Department through which the Network Inspection and Loss Control Section is organized. After the location of the leak is identified by this section, the result is reported back to the concerned branch office for maintenance.

Recommendations

1) The leakage percentage (27 %), or unaccounted-for-water (30 %) estimated is relatively high and it has always a tendency to increase as the pipes are getting older. Immediate action to control leakages should be taken by AAWSA.

2) The Network Inspection and Loss Control Section, responsible for leakage control, must be strengthened with competent and skilled manpower. Manpower planning should be done properly, i.e. the management should be flexible to rearrange and transfer the excess manpower in some of the other sections and reassign the already trained personnel who are transferred to another sections.

3) As lot of detection equipment are available, establishing detection crews in each branch office after proper training may help to shorten the time gap between leak occurrence and control. Even though, it is a question of economy, at least occasional training is required to the staff in order to improve the use of the new equipment.

4) The bureaucratic bottleneck could be solved if the Network Inspection and Loss Control Section is organized under the Operations Department, where regional branch offices could easily contact it.

5) Updating of the revenue collection will help to investigate in due time any discrepancy in water production and consumption. Problems of over-charges and under-charges, the accumulation of uncollected revenue with customers, and to have actual values of unaccounted-for-water and especially leakages. Contribution of attractive incentives for meter readers would definitely result in more reliable meter readings.

6) Updating of water system maps with all important pipe lines and valves must be given more emphasis as updated maps are essential for leakage detection and control.

7) The stagnant water tariff has to be improved, so that at least the operation and maintenance costs are covered by the selling price.

8) Attention to pH control of the treated water must be given. pH adjustment of the treated water before it goes into the distribution system helps to avoid aggressiveness of the water to the pipes which definitely causes corrosion and consequently increase in leakages.

9) The record-keeping and documentation system of the authority must be improved. Repairs should be reported to the concerned section for proper documentation.

10) Pipe laying practices must be improved. Sufficient installation depth of the pipes must be used, especially for PVC pipes, proper external and internal coatings must be used for steel pipes. In corrosive soils sufficient sand bedding must be provided.

11) Pressure control is necessary to reduce the risk of leakages in any water distribution system. Therefore, one must be sure that the system is not over-pressurized to guarantee unnecessary breakage of joints.

12) As the problem of leakage is quite serious as this study shows, a wider and deeper investigation of leakage control must be carried out.

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APPENDIX 1

Addis Ababa Administrative Region with the newly expanded areas (Population estimates - 1989 Central Statistic Authority modified by the author).

Awraja	Awraja towns	Urban population (Awraja town)	Rural population	Total Awraja population
Addis-Ketema		159 600		159 600
Arada		151 100		151 100
Bole		87 100	5 300	92 400
Entoto		193 500		193 500
Gulele		144 400		144 400
Kechene		107 900		107 900
Kirkos		150 200		150 200
Kolfe		184 000		184 000
Lideta		158 600	4 700	163 300
Nefas Silk		116 500	3 100	119 600
Tekle-Haimanot		167 200		167 200
Yeka		112 100		112 100
Newly included Awraja towns:				
Akaki			45 500	45 500
Alemgena	Sebeta	15 100		15 100
	Alem-Gena	3 400	83 800	87 200
	Tefeki	2 800		2 800
	Awash-Melka	1 700		1 700
Bereh	Sendafa	4 200	65 300	69 500
Beseka	Beseka	67 400	7 100	74 500
Kotebe	Kotebe	14 600	10 400	25 000
Sululta			113 800	113 800
	Chancho	3 400		3 400
	Segno-Gebeya	900		900
	Derba	800		800
Welmera			73 900	73 900
	Holeta-Genet	15 900		15 900
	Gafarsa-Burayu	5 000		5 000
	Menagesha-Tefeki	1 900		1 900
Total population		1 869 300	412 900	2 282 200

APPENDIX 2 (1/6)

Unmetered volume of water from large (> 25 mm) faulty meters in Addis Ababa.

1) From quartely report of 1977 E.C. (1984/85 G.C).

Name of the customer	Size of faulty meter mm	Estimated consumption time h/d	Total consumption m^3/d
Boucher house (Abattoir)	50	14	99
Military Engineering Dept.	50	8	57
Bauna Hospital	50	16	114
Menilik II School	50	8	57
Political School	50	14	99
A.A. University	50	14	99
Fiat A.M.C.E	100	8	227
Police Hospital	75	16	255
Food Processing Centre	100	16	453
Ghion Hotel	75	10	160
Sahele Selassie Building	50	10	71
82 Apartment	50	10	71
Italian Embassy	40	8	37
Italian Embassy	50	8	37
Finfine Hotel	75	10	160
Finfine Hotel	75	10	160
Zewdity Hospital	50	16	114
Good Shephered	50	8	57
Pharmaceutical Co.	50	14	99
Army Hospital	75	16	255
Army Hospital	75	16	255
Ras Desta Hospital	50	16	114
Television Studio	75	10	160
Black Lion Hospital	100	16	453
Vela Hospital	50	16	114
Total in one quarter			3 777

For the whole year unmetered water

= 3 777 x 60* d/a x 4 quarters = 906 480 = 906 500 m^3/a

* It is assumed that the meters remain faulty 60 days in a year.

APPENDIX 2 (2/6)

2) From quartely reports of 1978 E.C. (1985/86 G.C.).

Name of the customer	Size of faulty meter mm	Estimated consumption time h/d	Total consumption m^3/d
Awash Tannery	75	14	223
Sibste Nefasse School	50	10	71
Cement Factory	100	16	453
A.A. Abattori	50	14	99
Military Engineering Dept.	50	8	57
Awash Winery	75	14	223
Pharmaceutical Co.	50	14	99
Balcha Hospital	50	16	114
St. George Beer Factory	50	14	99
AA Stadium	50	8	57
Ghion Hotel	50	10	71
82 Apartment	50	10	71
Finfine Hotel	75	10	151
Zewdito Hospital	50	16	114
Previous Parliament Office	100	8	227
Fiat A.M.C.E	100	8	227
Food Processing Centre	100	16	453
Ethiopian Airlines	150	16	1 018
Russian Embassy Res.	75	10	161
Black Lion Hospital	100	16	453
Saba Winery	75	14	223
Police Department	50	8	57
St. Paul Hospital	75	16	255
General Winget School	40	10	45
Pasteur Research Institute	50	14	99
Dir Oil Factory	32	16	46
Amede Market	50	4	28
Mercato Shopping Centre	40	4	18
Previous Ethiopian Workers Association	50	8	57
Sahele Selassie Building	50	10	71
Total in one quarter			5 350

For the whole year volume of unmetered water

$= 5\ 350\ m^3/d \times 60\ d/a \times 4$ quarters $= 1\ 284\ 000\ m^3/a$

3) 1979 E.C. (1986/87 G.C.)

a) From 1st half year report:

In the 1st half year report, 48 water meters with sizes greater than 50 mm were reported malfunctioning.

- taking an average size of water meter to be 75 mm
- an average consumption time of 10 hrs/day.

Then volume of unmetered water in 6 months time will be:

= area x velocity x consumption hours/day

$$= \frac{\pi (0.075)^2}{4} \times 1 \text{ m/s} \times 10 \text{ h/d} \times 3600 \text{ s/d}$$

$$= 159 \text{ m}^3\text{/d}$$

$$Q \text{ annual} = 48 \times 159 \text{ m}^3\text{/d} \times 60 \text{ d/a}$$

$$= 457\ 920 \text{ m}^3\text{/a}$$

b) 2nd half year report

Size of faulty meter mm	Quantity	Consumption time h/d	Quantity of water lost m^3/d
100	9	10	2 545
75	13	10	2 068
50	29	10	2 050
40	2	10	90
32	2	10	58
Total in half a year	55		6 811

For the whole year Q annual = 6 811 m^3/d x 60 d/a

= 408 660 m^3/a

N.B.: As the list of the customers is not available, an average consumption time in a day is taken as 10 hours.

Total unmetered volume for the year is 457 920 + 408 660

= 866 600 m^3/a.

APPENDIX 2 (4/6)

4) From quarterly reports 1980 E.C. (1987/88 G.C.)

Name of the customer	Size of faulty meter mm	Estimated consumption time h/d	Total consumption m^3/d
Ministry of Mines and Power	50	10	71
Good Shephered	50	8	57
Pharmaceutical	50	14	99
A.A. Quary	50	10	71
St. George Beer Factory	50	14	99
College of Teachers Education	75	14	223
82 Apartments	50	10	71
Political School	50	14	99
A.A University	50	14	99
Ministry of Defence, School of Communication	50	8	57
Main Post Office	50	8	57
Main Post Office	75	8	122
Cement Factory	75	16	255
A.A. Abattoir	50	14	99
A.A. Abattoir	40	14	63
Mekkanisa Winery	75	14	223
Coca-Cola Factory	50	8	99
Balcha Hospital	50	16	114
St. George Beer Factory	25	14	25
Elyas Papasinoss Distillers	50	14	99
Wabe Shebele Hotel	50	10	71
Train Station Custom	50	8	57
Fiat A.M.C.E.	50	8	57
Finfine Hotel	75	10	161
Finfine Hotel	50	10	71
Kechene Light & Power Authority Branch	50	8	57
Dir Oil Factory	50	16	114
Dir Oil Factory	40	16	72
Emanuel Mental Asylum	40	16	72
TV Studio	75	8	127
Saba Winery	75	14	223
Black Lion hospital	100	16	453
Total in one quarter			3 637

For the whole year volume of unmetered water

= 3 637 m^3/d x 60 d/a x 4 quarters = 872 900 m^3/a

APPENDIX 2 (5/6)

5) From quarterly reports 1981 E.C. (1988/89 G.C.)

Name of the customer	Size of faulty meter mm	Estimated consump- tion time h/d	Total consump- tion m^3/d
Sibster Negasse School	50	10	71
Good Shephered	50	8	57
Army Aviation	75	16	255
Police Department	50	8	57
Elyas Papasinoss Distillers	50	14	99
Ethiopian Transport Construction Authority	50	8	57
Wabe Shebele Hotel	50	10	71
Ethiopian Workers Association	50	8	57
College of Teachers Education	75	14	223
Fiat A.M.C.E.	100	8	227
Insurance Company	50	8	57
Women's Welfare Association	50	14	99
Salcost Building	50	10	71
Ghion Hotel	75	10	160
Zewditu Hospital	75	16	255
Addis Ababa University	100	14	396
Maritime Office	50	8	57
Italian Embasy	40	8	37
Kechene EELPA Branch	50	8	57
St. Paul Hospital	50	16	114
Pasteur Institute	50	16	114
Pasteur Institute	50	16	114
Asko Shoe Factory	32	14	41
Main Post Office	50	8	57
Army Hospital	75	16	255
Total in one quarter			3 058

For the whole year the volume of unmetered water

$= 3\ 058\ m^3/d \times 60\ d/a = 183\ 480\ m^3/a$

APPENDIX 2 (6/6)

A separate nine months' report shows 66 water meters with average size of 75 mm were faulty. Thus the volume of water lost in nine monthes is:

$$Q \text{ annual} = \frac{\pi (0.075)^2}{4} m^2 \text{ x } 1 \text{ m/s x } 66 \text{ x } 10 \text{ h/d x } 60 \text{ d/a}$$

$$\text{x } 3\,600 \text{ s/h} = 629\,811 \text{ m}^3\text{/a}$$

Then the total volume of water lost in the year

$$Q \text{ annual} = 183\,480 + 629\,811 = 813\,300 \text{ m}^3\text{/a}$$

APPENDIX 3 (1/2)

Computations on water consumption for reservoirs cleaning and overflows.

Example:

1) Terminal reservoir:

Surface area = 4 000 m^2
Water requirement:

* sediment discharging	= 0.1 m x 4 000 m^2	=	400 m^3
* cleaning and rinsing	= 0.2 m x 4 000 m^2	=	800 m^3
* disinfection	= 0.2 m x 4 000 m^2	=	800 m^3
Total volume of water		=	2 000 m^3

2) Janmeda new reservoir

Surface area = 1 176 m^2
Water requirement:

* sediment discharging	= 0.1 m x 1 176 m^2	=	117.6 m^3
* cleaning and rinsing	= 0.2 m x 1 176 m^2	=	235.2 m^3
* disinfection	= 0.2 m x 1 176 m^2	=	235.2 m^3
Total volume of water		=	588 m^3

Relationship, floor area : water requirement = 2 : 1

APPENDIX 3 (2/2)

Name of reservoir	Qty.	Capacity m^3	Surface area m^2	Water requirement m^3
Terminal	2	20 000	4 000	2 000
Angorcha	1	5 000	580	290
Janmeda old	2	2 500	250	125
Janmeda new	2	10 000	1 176	588
Raskassa	2	1 000	200	100
Teferimekonen old	2	2 500	500	250
Teferimekonen new	1	2 500	385	193
Entoto old	1	1 000	200	100
Entoto new	1	1 250	223	112
R_1, R_2, R_3	3	460	132	66
Main Office	2	10 000	2 500	1 250
Belay Zeleke	2	1 000	200	100
Rufael old	2	1 000	200	100
Rufael new	1	2 500	385	193
St. Paul	2	1 000	200	100
Ras Hailu	2	5 000	1 000	500
Kassa Gabre old	1	500	125	63
Kassa Gabre new	1	2 500	385	193
Army Hospital old	2	1 000	333	167
Army Hospital new	1	5 000	588	294
Gebriel	1	1 000	222	111
Police Hospital	1	250	63	32
Eyasu Spring	1	50	17	8
Palace	2	350	88	44
Raskassa upper	1	30	15	8
Total	39	77 390		6 987

$\therefore$ the annual water requirement $= \frac{6\ 987}{2} = 3\ 493 \approx 3\ 500\ m^3/a$

About 0.1 % of the volume of reservoirs is assumed to be lost per day through overflow.

Thus water lost = 0.001 x 77 390 x 365
= 28 248 m^3/a

Then total water lost for cleaning and overflow
= 3 500 + 28 248 = 31 800 m^3/a

APPENDIX 3 (2/2)

Name of reservoir	Qty.	Capacity m^3	Surface area m^2	Water requirement m^3
Terminal	2	20 000	4 000	2 000
Angorcha	1	5 000	580	290
Janmeda old	2	2 500	250	125
Janmeda new	2	10 000	1 176	588
Raskassa	2	1 000	200	100
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Rufael old	2	1 000	200	100
Rufael new	1	2 500	385	193
St. Paul	2	1 000	200	100
Ras Hailu	2	5 000	1 000	500
Kassa Gabre old	1	500	125	63
Kassa Gabre new	1	2 500	385	193
Army Hospital old	2	1 000	333	167
Army Hospital new	1	5 000	588	294
Gebriel	1	1 000	222	111
Police Hospital	1	250	63	32
Eyasu Spring	1	50	17	8
Palace	2	350	88	44
Raskassa upper	1	30	15	8
Total	39	77 390		6 987

$$\therefore \text{ the annual water requirement} = \frac{6\ 987}{2} = 3\ 493 \approx 3\ 500\ m^3/a$$

About 0.1 % of the volume of reservoirs is assumed to be lost per day through overflow.

Thus water lost = 0.001 x 77 390 x 365
= 28 248 m^3/a

Then total water lost for cleaning and overflow
= 3 500 + 28 248 = 31 800 m^3/a

APPENDIX 4

Flushing of transmission lines:

Assumptions:

* frequency of draining = 6 times/a
* duration of draining = 15 min/drain
* velocity of water = 1 m/s

a) Transmission line from Legedadi T.P to City reservoirs (Ø 900, 1 200, 1 400 pipes)

* number of drain valves = 40
* size of drain valves = 300 mm

$$\therefore \quad Q \text{ annual} = \frac{\pi \left(\frac{300}{1\ 000} \right)^2}{4} \text{ m}^2 \times 1 \text{ m/s} \times 40 \text{ drains} \times$$

15 min/drain x 60 s/min x 6 times/a = 15 268 m^3/a

b) Transmission line from Gafarsa T.P to City reservoirs (Ø 400 mm pipes)

* number of drain valves = 32
* size of drain valves = 200 mm

$$Q = \text{annual} \frac{\pi (0.2)^2}{4} \times 1 \text{ m/s} \times 32 \text{ drains} \times 15 \text{ min/drain} \times 60 \text{ s/min} \times$$

6 times/a = 5 429 m^3/a

Then total requirement = 15 268 + 5 429 = 20 700 m^3/a

APPENDIX 5 (1/2)

Computations to determine visible leakage amounts

1) For the year 1987/88

a. Private connection (75 %)

11 427 x 0.75 = 8 570 cases

size of pipe = 13 mm
velocity = 1 m/s

$$Q = \pi \left(\frac{0.013}{4}\right)^2 \times 1 = 1.33 \times 10^{-4}\ m^3/s$$

Then loss of water in six hours for all cases in the year

$$Q \text{ annual} = 8\ 570 \times 1.33 \times 10^{-4}\ m^3/s \times 6\ h \times 3\ 600\ s/h$$

$$= 24\ 620\ m^3/a = \underline{\underline{24\ 700\ m^3/a}}$$

b. Distribution lines (25 %)

Minimum volume:
- cases = 11 427 x 0.25 = 2 857
- pipe size = 25 mm
- velocity = 1 m/s

Then loss of water in six hours

$$Q \text{ annual} = 2\ 857 \times \left[\frac{\pi (0.025)^2}{4} \times 1\right] m^3/s \times 6\ h$$

$$\times\ 3\ 600\ s/h = 30\ 292\ m^3/a = \underline{\underline{30\ 300\ m^3/a}}$$

Average volume:
size of pipe = 50 mm

$$Q \text{ annual} = 2857 \text{ cases/a} \times \left[\frac{\pi (0.05)^2}{4} \times 1\right] m^3/s \times 6\ h$$

$$\times\ 3\ 600\ s/h = 121\ 169 = \underline{\underline{121\ 200\ m^3/a}}$$

APPENDIX 5 (2/2)

2) For the year 1988/89

a. Private connection (75 %)

number of cases = 11 653 x 0.75 = 8 740 cases
pipe size = 13 mm
velocity = 1 m/s

$$Q \text{ annual} = 8\,740 \text{ cases/a} \times \left[\frac{\pi(0.013)^2}{4} \times 1\right] m^3/s \times 6 \text{ h}$$

$$\times\ 3600 \text{ s/h} = 25\,108 = \underline{\underline{25\,200 \ m^3/a}}$$

b. Distribution lines (25 %)

minimum volume:
number of cases = 11 653 x 0.25 = 2 913
pipe size = 25 mm
velocity = 1 m/s

$$\text{Then } Q \text{ annual} = 2913 \text{ cases/a} \times \left[\frac{\pi(0.025)^2}{4} \times 1\right] m^3/s \times 6 \text{ h}$$

$$\times\ 3\,600 \text{ s/h} = 30\,886 \ m^3/a = \underline{\underline{30\,900 \ m^3/a}}$$

Average volume:
pipe size = 50 mm

$$\text{Then } Q \text{ annual} = 2913 \text{ cases/a} \times \left[\frac{\pi(0.05)^2}{4} \times 1\right] m^3/s \times 6 \text{ h}$$

$$\times\ 3\,600 \text{ s/h} = 123\,545 \ m^3/a = \underline{\underline{123\,600 \ m^3/a}}$$

APPENDIX 6

Leakage report form prepared by AESL, 1982.

WATER LEAKAGE STUDY - LEAKAGE REPORT

DATE..................ZONE............. SUBSYSTEM....................

LOCATION...

SOURCE OF LEAKAGE

☐ PIPE SIZE.................mm

MATERIAL: ☐ GALV.STEEL
☐ STEEL
☐ CAST IRON
☐ PVC

JOINT
BROKEN PIPE
BRANCH COLLECTION
SERVICE FERRULE

☐ GATE VALVE...................
☐ AIR VALVE....................
☐ OTHER VALVE..................
☐ METER........................
☐ PUMP.........................
☐ TAP..........................
☐ OTHER........................
☐ ABOVE GROUND DEPTH.........m.
☐ BELOW GROUND DEPTH.........m.
☐ IN CHAMBER/BOX
☐ IN ROADWAY PAVED/UNPAVED
☐ SERVICE CONN.BEFORE/AFTER METER

CAUSE OF LEAKAGE

☐ CORROSION FROM INSIDE/OUTSIDE
☐ NORMAL WEAR
☐ ACCIDENTAL IMPACT BY.........
☐ VIBRATION BY.................
☐ VANDALISM....................
☐ OTHER........................
....

METHOD OF LOCATION

☐ PUBLIC REPORT
☐ CASUAL OBSERVATION
☐ ROUTINE SURVEY
☐ VISUAL DETECTION
☐ MECHANICAL DETECTOR
☐ ELECTRONIC DETECTOR
☐ OTHER........................

LEAKAGE: ☐ NOT VISIBLE AT SURFACE
☐ NOT VISIBLE

QUANTITY:...................l/min.
..............................m3/d.

REPAIRS

CARRIED OUT-DATE.................

EXCAVATION
MATERIALS: ☐ PIPE...............
☐ FITTINGS..........
☐ VALVE.............

LABOUR
☐ TECHNICIAN
☐ WELDER
☐ LABOURERS

REMARKS/SKETCH OF LOCATION

SIGNATURE......................

Leakage Report Form

APPENDIX 7

ADDIS ABABA WATER & SEWERAGE AUTHORITY

WATER METER RECORD

1. INSTALLATION RECORD

Customer Name .... Meter No. ....

Address .... Size ....

Subsystem.. Make ....

Sector No. .... Service No.......................... Type ....

Contract No. .... Date Installed ....

ARTISTIC PRINTERS LTD 4414/4

2. TEST RECORD

BEFORE REPAIR							AFTER REPAIR						
Date	Test Flow L/min	Pressure Kg/cm²		Meter	Tank	P. C. Error	Date	Test Flow L/min	Pressure Kg/cm²		Meter	Tank	P. C. Error
		In	Out						In	Out			

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