Japan International Cooperation Agency
(JICA)

A Guideline for Operation & Maintenance System and Non-revenue Water Reduction for Baghdad Water Supply System (Draft)

PART I	Guidelines for Operation and Maintenance System
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PART I Guidelines for Operation and Maintenance System

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1. General

This document outlines guidelines for operation and maintenance of the water supply system using a Geographical Information System (GIS).

1-1 Basic Concept

1) Objectives of Operation and Maintenance

The main purpose of a water supply system is to supply safe drinking water to the user. This is achieved through appropriate planning, design, construction, and operation and maintenance (O&M). The purpose of O&M is to operate water facilities efficiently so that water is supplied in adequate quantities, at a suitable pressure, and to maintain the facilities' functions as they are designed.

2) Scope of the Guidelines

Water supply systems consist of intake facilities, treatment plants, distribution facilities, and service installations. This guideline focuses on using GIS for the effective maintenance of distribution pipelines and service installations.

3) Preventive Maintenance

Maintenance work is divided into two activities: preventive; and corrective. Preventive maintenance refers to scheduled maintenance. The aim is to eliminate or minimize breakdowns and to extend the useful life of the facilities. Therefore, preventive maintenance is one of the key elements for efficient operation of water supply facilities. Corrective maintenance refers to unscheduled maintenance when immediate repair action is required.

A proper maintenance program will enable a water utility to:

- Prevent facility failure.
- Detect and eliminate weak links in the system.
- Analyze how facilities endure during actual operation as a guide for future installations.
- Maintain the function of facilities as designed.
- Maintain good public relations by making necessary repairs before damage and suspension occur.
- Distribute work load more effectively.
- Reduce the cost of maintenance.

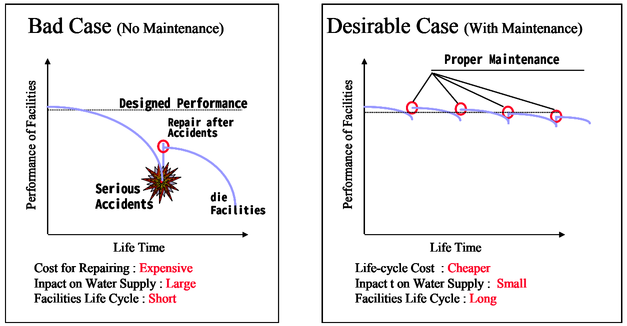

Fig. 1 Images of preventive maintenance and corrective maintenance

4) Maintenance Cycle

Maintenance activities repeat the cycle of Plan, Do, See, and Act. "Plan" refers to determining the cycle of inspections and checks for each facility. "Do" refers to undertaking the inspections in accordance with the plan. "See" refers to analyzing the inspection data, evaluating the functioning of the facilities, and deciding what kind of counter measures are required. "Act" refers to executing the counter measures. This cycle enables the facilities to operate efficiently and continuously.

GIS is a useful tool that can be used to undertake the above works efficiently. GIS enables recording and analysis of the inspection results. Also, information about new facilities can be entered into the GIS when the facilities are repaired or renewed. The GIS enables this new data to be taken into account for planning and inspections.

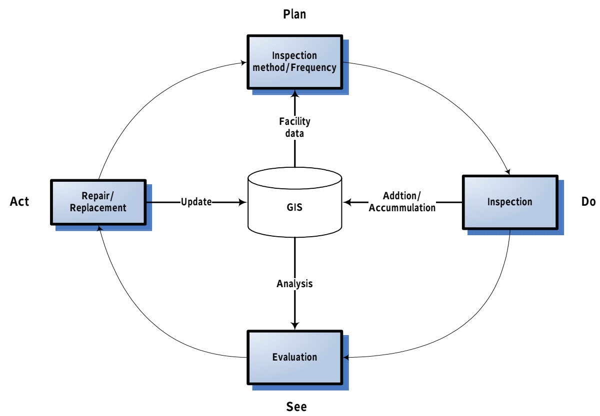

Fig. 2 Maintenance Cycle and Use of GIS

1-2 Outline of Preventive Maintenance

1) Inspection Plan

A properly planned inspection program (preventive maintenance) helps to ensure a continuous supply of water. Preventative maintenance requires consideration of the inspection frequency and inspection methods. The distribution facilities consist of many different types of equipment. The inspection frequency and inspection methods vary depending on the type of equipment. It is preferable for the inspection frequency and inspection method recommended by the manufacturers to be implemented. An inspection manual should be prepared for use by maintenance personnel.

2) Evaluation

In addition to inspecting the water facilities, the inspection results (data) should be evaluated periodically to identify the weak points in the facilities. It is important that the overall performance of the water distribution system is evaluated rather than just the individual facilities.

3) Rehabilitation

If the evaluation indicates poor performance, repair or replacement measures should be considered. Facility replacement should aim to improve the performance of the facility. However, large-scale improvement or replacement is expensive. Therefore, priorities for repair/replacement should be determined based on the facilities influence on the distribution system.

1-3 Data Management using GIS

A proper inspection plan requires significant information about the facilities, such as where it is installed, its function, etc. Also, when a facility's performance is evaluated, the inspection results need to be recorded. This large amount of data means paper based data management can result in mistakes. Using GIS will reduce the time spent on data management and will help with efficiently undertaking essential maintenance work. GIS is able to manage a significant amount of facility data using geometry and unitary position data. GIS is also able to searched or manipulate data. The "GIS plan" outlines the functional details of the GIS. However, these guidelines acknowledge the importance of deciding on the format of the inspection result data that is to be input to the GIS.

An example of a GIS for a water supply system (titled "Pipeline Management using GIS") is attached in Appendix-2.

1-4 Organization of Maintenance

Water utilities are organized differently from one another. This is a result of the history of each utility, its treatment processes, scale of the facility, population served, etc. The different types of maintenance works, complexities of each facility, and improvements in relevant O&M approaches should be considered in combination with the organizational structure and personnel.

To ensure proper maintenance, maintenance staff should understand the facility and the system processes. They should also keep up-to-date with current and emerging maintenance technologies. Periodic staff training will help to improve their maintenance ability.

2. Maintenance of Distribution Facilities

2-1 Functioning of Distribution Facilities

Distribution facilities consist of storage tanks, distribution pumps, pipes, and other apparatus to distribute water to the supply area. These facilities cover large areas and represent more than half of the facility construction costs. The functions of the different distribution facilities are described below:

- Transport and distribution function: to supply an adequate quantity of water at an appropriate pressure (to control water flow and pressure).
- Storage function: to provide for variations in water demand (storage volume).
- Water quality maintenance function: to maintain safe water (detention time).

1) Transport and distribution

Water flow and pressure influences the NRW ratio and the amount of water consumed. Therefore, these controls are especially important. The following methods are used to control water pressure and flow:

- Valve operation (open and close).
- Distribution and booster pump operation.
- Valve control for pressure or flow (adjustment of the degree of opening).

Two story buildings need at least 15m (0.15MPa) of dynamic water pressure in the distribution pipes to ensure a sufficient water supply. However, if the pressure is too high water leaks will increase. Conversely, if the pressure is lower than 15m, not enough water will be supplied. It is difficult to control water pressure for the entire service area using manual valve operation. Therefore a Supervisory Control And Data Acquisition (SCADA) system is recommended. This controls pressure and flow automatically.

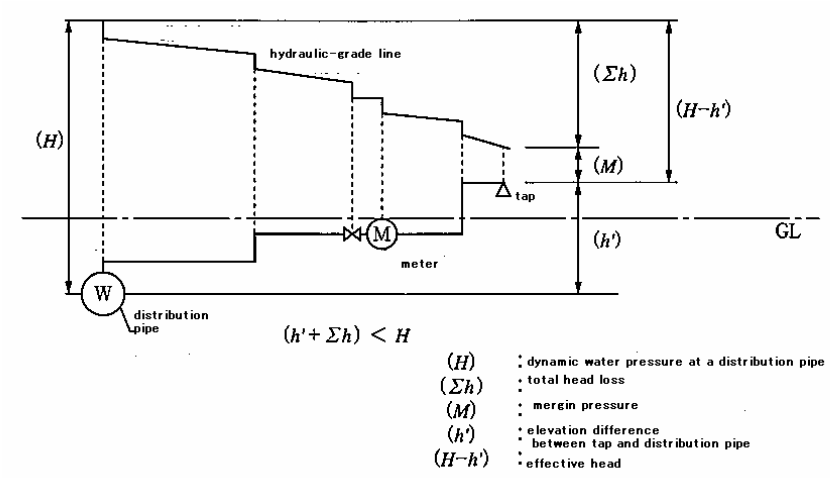

Fig. 3 Hydraulic gradient[1)]

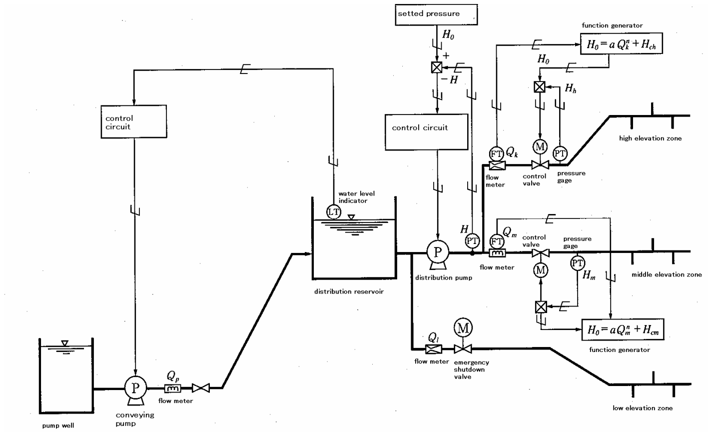

Fig. 4 Control of pressure[1)]

2) Storage function

Water consumption changes throughout the day. The highest consumption rates are during the morning and evening. The lowest consumption rate is around midnight. However, the treatment plant is operated to produce a constant water supply volume because this makes system control easier. It is therefore necessary to store some water to provide for the differences between the amount of water produced and consumed. It is generally desirable for a storage tank to have sufficient capacity to store six hours of the maximum daily supply.

The storage reservoir has other uses, such as providing stored water for fire fighting purposes and emergency water (e.g. following an earthquake or other disaster). Therefore, many cities have a storage capacity of 8 to 12 hours.

3) Water quality maintenance functions

The water supplied should be of a safe quality when it reaches the consumers taps. However the water quality is assumed to deteriorate gradually over time, due to chemical reactions between the distribution pipe materials and the treated water. The following water quality changes occur:

- Decreased amount of residual chlorine.
- Increased amount of THMs (Tri halo methane).

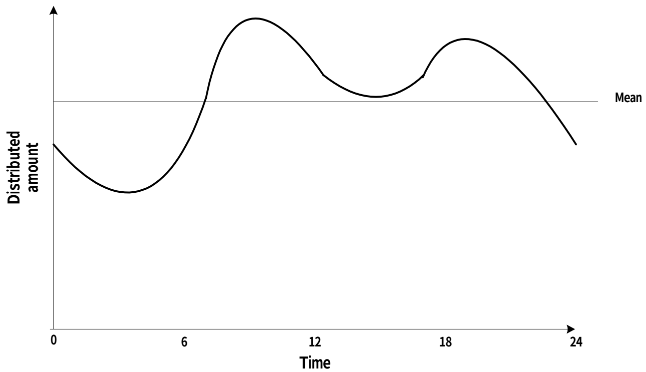

Fig. 5 Fluctuations in the amount of water distributed over time

These chemical reactions are accelerated if the water temperature is high and if there are long detention times. It is therefore desirable to provide for as short a detention time as possible, especially during the hot summer months. However, a reduced detention time will reduce the amount of water stored for emergencies. The following measures are used to assist with providing adequate water quality as well as emergency storage:

- booster chlorination occurs at the storage facility; and
- drainage occurs at the end of the pipe network.

It is also important to avoid sucking contaminated water into the system as a result of negative pressure. This is especially important where there are cross-connections with non potable piping systems such as air-conditioning. These systems in big buildings should be checked. Also, contamination backflows can be caused by negative pressure when a pipe fails or as the result of another accident. Therefore, adequate pressure should be maintained in the whole service area.

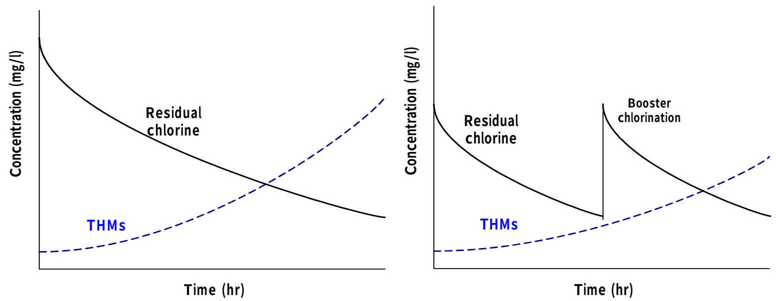

Fig. 6 Effect of booster chlorination (Image)

2-2 Inspection

1) Overview

It is important that the condition of the facilities is regularly checked to ensure the required functioning of the distribution facilities is maintained. The inspection items and frequency of inspections for the main facilities are as shown in Table1.

2) Visual observation

Since distribution pipes are laid underground, it is difficult to inspect them directly. It is therefore necessary to patrol for the following signs of deterioration:

- Leaks on the road surface.
- Changes to the ground shape due to a leak or an accident.

- Leaks from water pipe bridges (including air valve).
- Leaks from hydrants.

However, from a human resources and cost perspective it is not realistic to patrol all pipes. It is therefore recommended that pipes are inspected based on their importance (e.g. hydraulic influence, or damage that would occur to other facilities if the pipe breaks).

Table 1 Inspection items and frequency (examples)

	Daily	Weekly	Monthly	Annually	Every 2-3years	Every 5years	Remarks
Underground facilities							
Visual Observation for leaks	×						
Flushing				×			
Inspect/Operate Valve				×			
Fire hydrant inspection				×			
Leak survey					×		
Meter Accuracy test				×			
Water storage tank							
Exterior visual Observations		×					
Inspect general Condition				×			
Complete inspection including tank draining & check interior condition & for sediment						×	
Pump							
Check operation	×						
Pump effectiveness & performance test				×			
Valve inspection/operation				×			
Water quality							
Residual chlorine	×						
Turbidity	×						
Other drinking water standards			×				
Inventory of stock				×			

3) Valves

The following valve inspections are recommended:

- Confirm settings (open or closed).
- Check for rust and correct operation.
- Check for leaks.

Recording the inspection results in GIS is useful, because it makes comparisons with other data easier.

4) Measurement of flow and pressure

Data on water pressure, flow rates and water quality is essential for effective operation of the distribution

facilities. However without enough measuring points, it is not possible to determine the condition/status of distribution pressure. It is therefore recommended that the following points are measured at least once a year (Fig. 8):

- trunk/main pipe.
- typical point in the area.
- close to the end of the network.
- other key points where pressure is low or chlorine residual is low.

The following information about the measurement results should be stored in the GIS:

- data;
- location; and
- results (max, mean, min).

Fig. 7 Pressure gauge

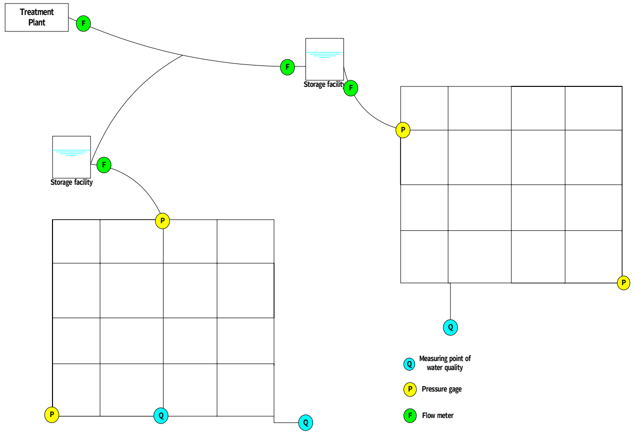

Fig. 8 Measurement points (example)

5) Flushing

When the water flow rate is low, suspended particles tend to settle. Also, rust tends to occur in cast iron pipes that are not lined. When the flow direction or flow rate changes rapidly sediment and rust can be dislodged from the pipe wall, causing red water or turbidity. Flushing can be used to prevent these problems by discharging the sediment and rust from a drain or a hydrant. GIS (pipe data and related complaints) can be useful when examining which pipes should be flushed. Flushing generally requires a flow rate of 1m/s to 3m/s with pressures of more than 15m to remove the sediments.

6) Leak survey

This section presents the leak repair data. An overview of the leakage survey process is explained in Part II “Guidelines for Non-Revenue Water Reduction”. The following items should be recorded in the GIS as a record of the repair (Fig. 9):

- Date
- Leak location: address, road name
- Person in charge
- Repairer
- Pipe data: Type (distribution/service pipe), diameter, material, earth covering, installation year
- Damage data: damaged part, damage level/contents, amount of leakage, site photo
- Repair data: repair method, cost
- Secondary damage: flood damage, water suspension, compensation cost.

7) Customer complaints

Customer complaints indicate where the water supply service is not satisfying customers. Water utilities should deal with the complaint to achieve the objectives of water supply and to satisfy the customers. The following items should be recorded as part of the record of complaint:

- Date
- Customer name
- Address
- Contents of complaint: water quality (red water, turbidity, taste and odor), pressure, leakage
- Result of correspondence.

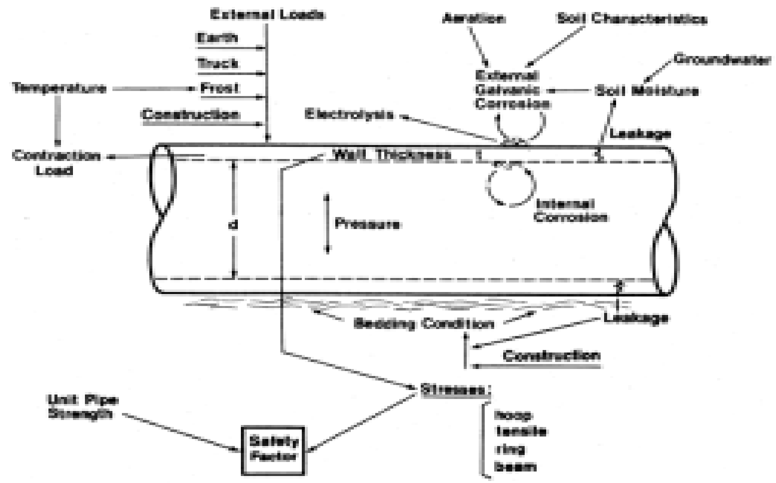

Fig. 9 Conceptual model of pipe structural condition[2)]

2-3 Performance Evaluation

It is important to undertake the following evaluations of the results of the inspections that were described in section 2-2:

- evaluate the whole distribution system
- analyze trends in specific areas and pipes.

1) Whole system evaluation

Target values for the following indices should be set to enable evaluation of the whole distribution system. When the results of the evaluation indicate that the target is not being achieved countermeasures should be examined.

Table 2 Performance Indices

Performance index	Data and calculation	Remarks
Pressure sufficiency	Area with a pressure of 15m or more(km²)/Service area(km²)×100	
Pipe breakages (no./100km)	No. of breaks/ pipe length(km)×100	
Equipment failure	No. of failed equipment/ total equipment	
Water suspension (days)	No. of days suspended each year	
Non-revenue water	Billed consumption (m³)/supplied water (m³)×100	
Complaints	No. of complaints/No. of supplied ×100	
Resolved complaints	No. of resolved complaints/total complaints×100	

2) Trend analysis

(1) Pressure distribution

Water pressure data and pressure complaints can be used in the GIS to estimate the pressure trends (distribution) in the service area. When there is an area with particularly high or low pressure, the cause should be examined based on other inspection results such as flow rate, diameter, etc. Low pressure is generally caused as a result of the following (note: the last two items can be resolved by maintenance works):

- Increased water demand (where demand exceeds capacity)
- Small pipe (insufficient to meet demand)
- Closed valve
- Sedimentation/turbidity.

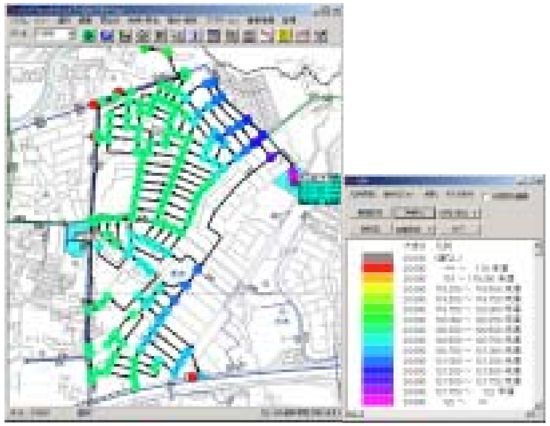

Fig. 10 Pressure distribution

(2) Quality distribution

Water quality data and quality complaints that are recorded in the GIS can be used to assess quality trends (to identify problematic areas) in the service area. If areas are identified as having residual chlorine levels lower than the drinking water standards or where red water is a problem, the cause should be examined. Poor water quality can be the result of a number of complex factors such as water quality problems in the water source, treatment process, distribution and service processes. The following factors can cause water deterioration in the distribution system:

- red rust in a non-lined pipe
- sediment/turbidity in a pipe
- suction/back flow of contaminated water due to negative pressure.

(3) Leakage Analysis

Leakage data recorded in GIS can be used to assess various leakage trends and to examine counter measures. The following analysis can be undertaken:

- analysis by pipe material
- analysis by region
- trend analysis by year.

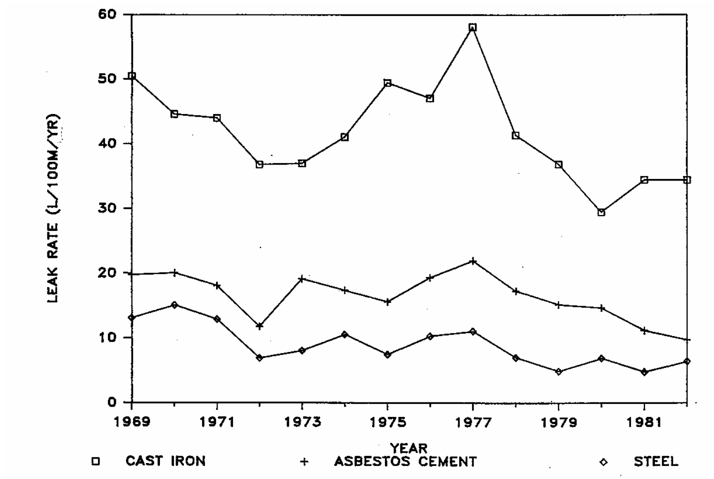

Fig. 11 Yearly trend[2)]

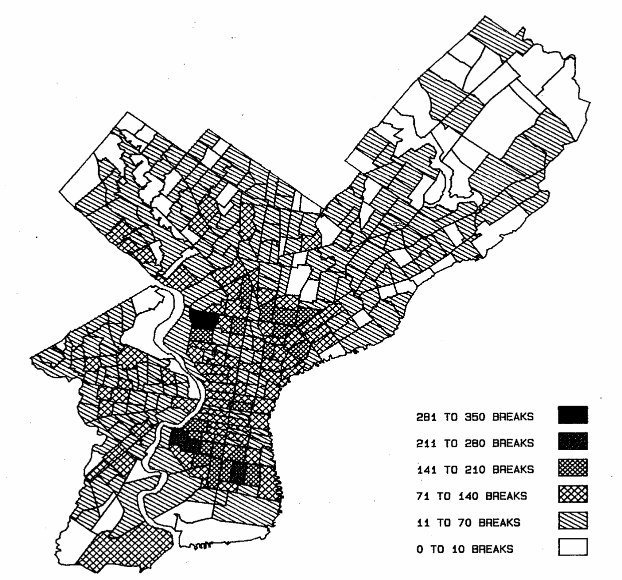

Fig. 12 Regional analysis[2)]

Fig. 13 Classification of pipe material

4) Water Audit (Formation of DMA)

When a service area is divided into multi distribution zones/blocks, it is desirable for each zone to have a flow meter at the zone inflow point to measure the amount of water being distributed in the zone. Non-Revenue Water of each zone can then be calculated by comparing the distributed amount with the billed water. Using this data is an effective way of determining priority leakage survey zones. This method requires that water meters be installed for every house.

2-4 Pipe rehabilitation

Pipe rehabilitation refers to the recovery of the pipe's ability to pass flow, which has been compromised due to sedimentation or rust. The normal rehabilitation method involves removal/cleaning of sediment from the pipe and lining the interior wall of the pipe with some non-corrosive material.

1) Cleaning

Tuberculation and sediment reduce sectional area of a pipe. As a result, the pipe friction grows and hydraulic pressure decreases. Also these materials consume residual chlorine. Moreover, the water quality trouble such as red water might be caused by the change for a rapid current. Therefore, it is necessary to remove sediment/ tuberculation by the cleaning.

The cleaning is executed by a Pig or a Scraper. A Pig is made of polyethylene and epidermis for rub is attached on the surface. They are moved from the inlet to the outlet in the pipe by hydraulic pressure. The excavation work is needed in both inlet and outlet point. However, it is considerably long between each

point. The use of Pig accompanies the large amount of sewage generation which should be mostly exhausted on the downstream edge of the pipeline.

If the metal of the pipe is exposed by the cleaning, even if rust and tuberculation are removed by the cleaning, the rust and tuberculation might be generated again. Therefore, the following rehabilitation or water quality improvements (pH adjustment and corrosion inhibitors such as phosphate and sodium silicate) are necessary to inhibit corrosion.

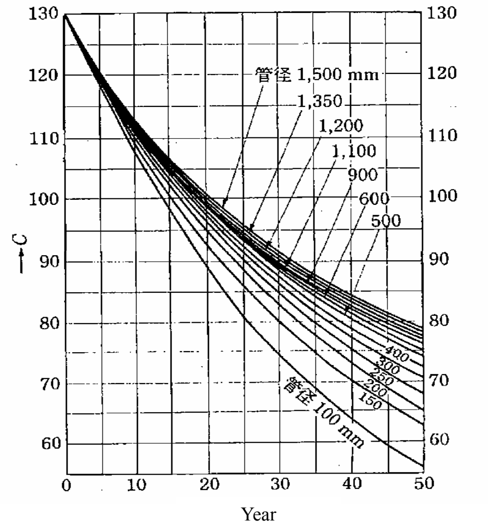

Fig. 14 Decrease in flow coefficient C[1)]

Sedimentation and rust reduces the cross-sectional area of the pipe, increases the pipe friction and reduces the hydraulic pressure. Also, these materials consume residual chlorine. Poor water quality (red water) results from rapid changes in current. Therefore cleaning is required to remove the sediment and rust.

Cleaning is carried out using a pig or a scraper. A pig is made from polyethylene. Epidermis to help scrub the pipe is attached to the surface of the pig. The pig is moved from inlet to the outlet of the pipe using hydraulic pressure. Excavation work is needed at both the inlet and the outlet. The distance between the inlet and the outlet can be a significant distance. Use of the pig is accompanied by large amounts of sewage generation. This sewage needs to be expelled at the downstream end of the pipeline.

If the metal of the pipe is exposed during the cleaning process, rust and sediment may be produced again. Therefore the following actions, related to water quality improvement, are necessary to inhibit corrosion in the future: ph adjustment and corrosion inhibitors such as phosphate and sodium silicate.

Fig. 15　Tuberculation

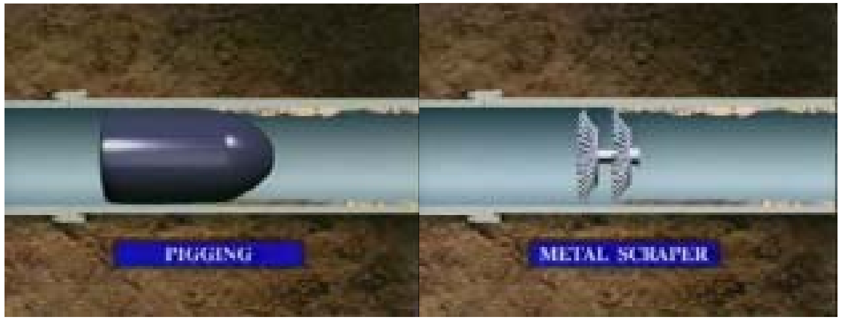

Fig.16　Cleaning equipment[3)]

2) Rehabilitation[4)]

(1) Overview

Rehabilitation refers to the process of lining the pipe with some anti-corrosive material after the cleaning process.　The advantages of rehabilitation are listed here:

- Rehabilitation can be applied to pipes that are difficult to excavate because they are located beneath roads.　This is because rehabilitation does not require total excavation.
- Construction costs associated with rehabilitation are less than the costs for open cut methods.
- Rehabilitation has a short construction period.
- Functioning of the existing pipe can be recovered for an interim period.
- Rehabilitation effectively prevents red water and recovers flow capacity.

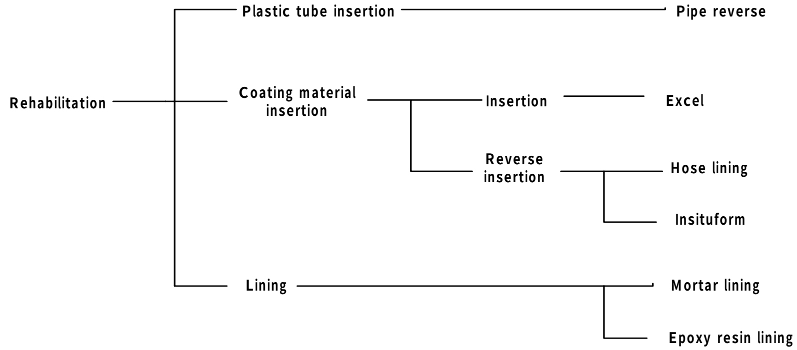

Fig. 17　Categories of rehabilitation

(2) Rehabilitation Methods

This section describes typical rehabilitation methods for pipelines.

<Plastic tube insertion> Pipe reverse

Method	A polyethylene pipe is inserted in the pipe.　This occurs after the pipe has been cleaned.　Cement milk is injected into the space between the pipe and the plastic.
Application range	Existing pipe:φ100mm～φ1200mm,cast iron, steel, hume, acp, Construction length:100m～ 150m
Characteristics	Effective if used to reinforce the pipe.

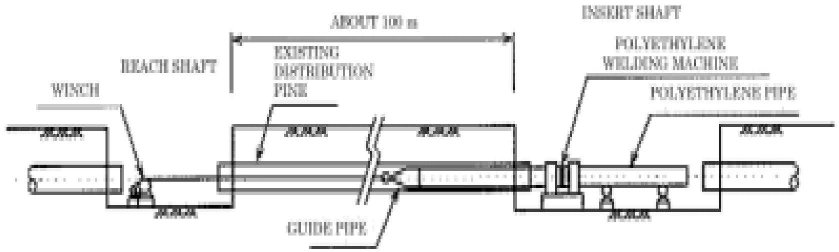

Fig. 18　Pipe reverse

<Coating metal insertion> Excel method

Method	A vinyl pipe is inserted and stuck to the existing pipe
Application range	Existing pipe:φ100mm～φ600mm,cast iron, steel, hume, acp, vinyl chloride Construction length:100m～ 150m
Characteristics	Effective if used to reinforce the pipe.

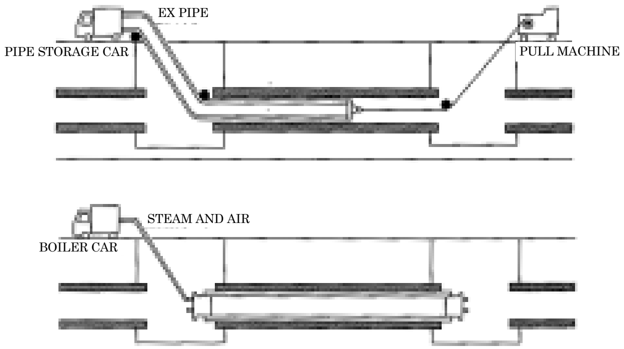

Fig.19　Excel method

<Reverse insertion>Hose lining

Method	A hose is used to spread adhesive inside the pipe. The hose is inserted under reverse air pressure.
Application range	Existing pipe:φ75mm〜φ1000mm,cast iron, steel, hume, acp, vinyl chloride Construction length: 200m
Characteristics	Effective if used to reinforce the pipe, prevent corrosion, or prevent red water.

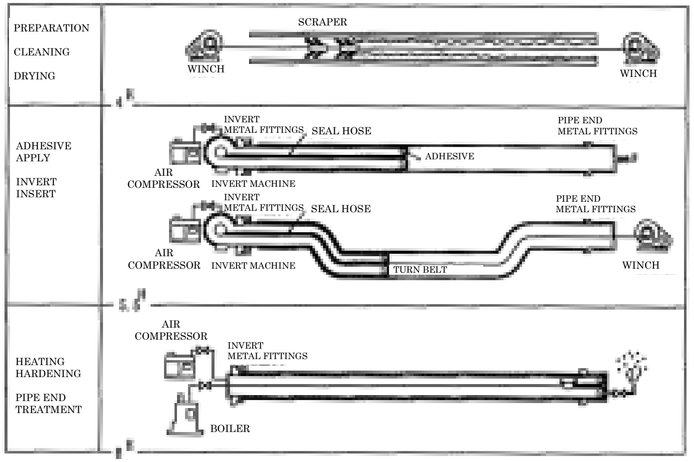

Fig.20　Hose lining method

＜Lining method>Mortar lining

Method	Cement mortar is sprayed in the pipe after cleaning.
Application Range	Existing pipe and construction length:φ75mm〜φ600mm(100-150m) φ700 and over (400-1000m)
Characteristics	Effective if used to prevent corrosion, red water, or to recover flow capacity.

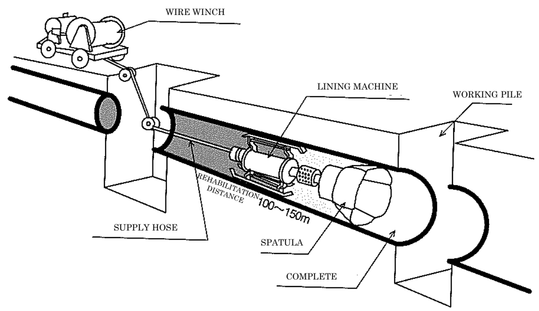

Fig.21　Mortar lining

＜Lining method>Epoxy resin lining

Method	The inside of the pipe is coated with epoxy resin after cleaning.
Application	Existing pipe :φ75mm〜φ300mm
Characteristics	Water can be supplied within eight hours of the work being undertaken. Temporary piping is unnecessary to provide for continued supply. Excellent safety, durability, and chemical resistance properties.

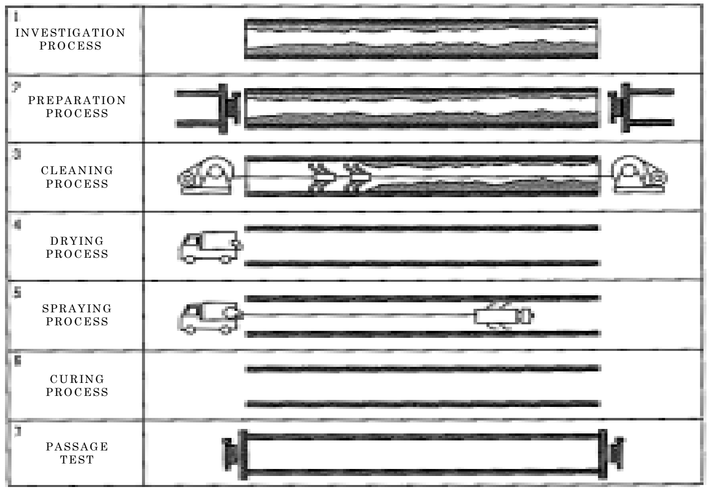

Fig.22　Epoxy resin coating

3) Considerations

The rehabilitation methods described above can only be used where the pipe has sufficient strength for continued use. Other methods may be required to rehabilitate bends in pipes, junctions, or valves. That is, the above rehabilitation methods are best suited to straight pipelines. Therefore, when selecting a rehabilitation method, the existing pipe should be investigated in advance to determine its characteristics. The method should be selected based on consideration of the purpose of the rehabilitation, the urgency of the rehabilitation, and the merits and disadvantages of each method. When selecting the appropriate rehabilitation method, the following characteristics should be considered. A GIS would be useful to manage this type of data.

- Material and diameter of pipe.
- Breaks and leaks in the pipe.
- Problems with water quality.
- Characteristics of the fittings and accessories.
- Location of the suction in the service pipe.
- Installation plan for the distribution pipe system.

4) Record

Following rehabilitation, the changes should be recoded on an 'as-built drawing' and the changed data should be registered in the GIS.

3. Service installation maintenance

3-1 Basic concept

Service installation is the responsibility of the user and the service should be maintained by the user. Accidents associated with service installation can affect other service installations because they are connected by the distribution pipeline. Therefore, maintenance of the service installation is very important.

3-2 Maintenance

1) Meter

Water meters are devices used to measure the quantity of water consumed by a household. Water meter readings are the basis for water rate calculations. Therefore, it is necessary to install accurate water meters for every household, and to ensure the meters are maintained in a condition that allows easy reading and replacement.

(1) Installation

Some users do not understand the important role that water meters play in providing the water supply service. The following list shows the order of priority for meter installation:

＜Priority by type of user>

- public offices,
- large users such as factories and departments, and
- citizens earning high incomes.

It is particularly important to have water meters installed for big customers because these customers are

sources of significant revenue.

<Priority by area>

- Regions where hydraulic pressure is comparatively high (i.e. water can be consumed), are high priority areas for meter installation.

The following issues should be considered at the time of installation:

- The water meter has a working life of eight years.
- The meter should be located in a position that is easy to check and replace.
- A straight pipe (three to five times the length of the water meter diameter) is required on the upstream end of the water meter, to ensure accuracy. Electromagnetic or ultrasonic wave water meters require a straight length of pipe that is five times the diameter on the upstream end of the meter, and three times the diameter on the downstream end.

(2) Inspection

The following inspections should be conducted when reading a meter:

- Check for leaks or breakages around the meter.
- Compare the water consumption with the last reading. If a significant difference between readings is noted, checks for water leakage and measurement of meter accuracy should be undertaken.

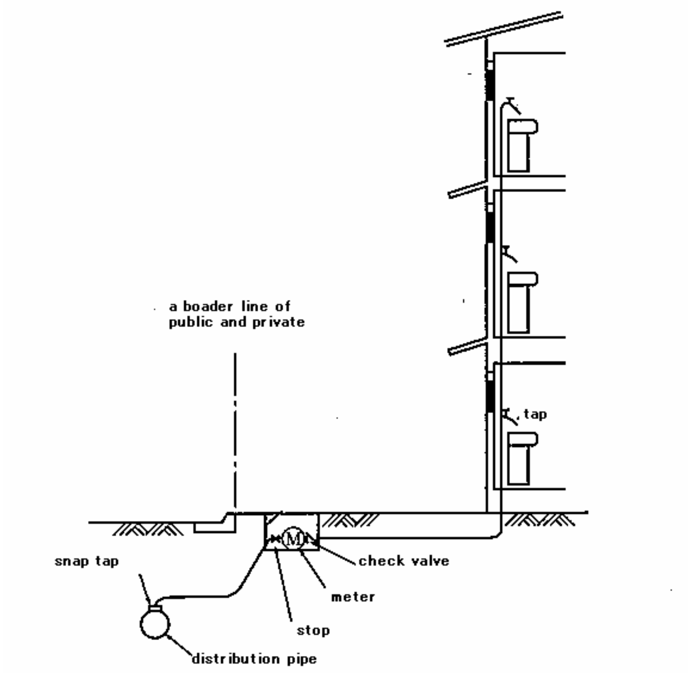

Fig.23 Direct connection system[1]

2) User management

<Big user>

Sometimes large users store water in a receiving tank with a ball tap. This can cause water hammering. Water hammering affects the water pressure (fluctuation) around the tank, and can result in sucking of contaminated water (such as sewage) through leakage holes when negative pressure occurs. In this case it is necessary to liaise with the user and undertake appropriate mitigation measures.

<Ordinary user>

Stopping water supply to users who connect illegally or refuse to pay their water bills, is not a realistic solution for addressing NRW, as it is too drastic. It is best to assess mitigation measures based on a thorough understanding of the cause of the NRW. Customers who do not receive sufficient water supply to meet their demand sometimes refuse to pay their water bills. Therefore, it is necessary to increase the supply capacity for both NRW and user management reasons. Refer to "Guidelines for Non-Revenue Water Reduction (Detailed Measures)" in Appendix-1.

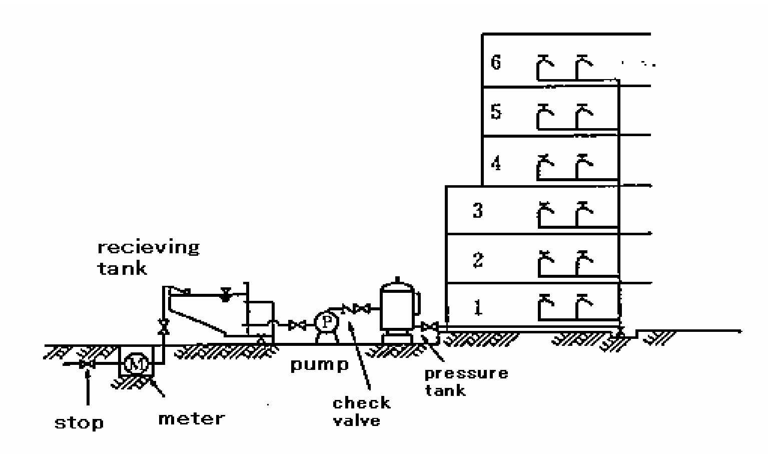

Fig.24 Pressure tank system[1)]

3) Map management

The amount of data associated with the water supply system is extremely large. This is because the number of service installations is usually equal to the number of customers supplied by the system. It is inefficient to manage such large amounts of data using a paper record system. It is more efficient to manage this data, as well as data associated with the distribution pipeline, using a GIS. It is common to manage meter and receiving tank service installation data with GIS.

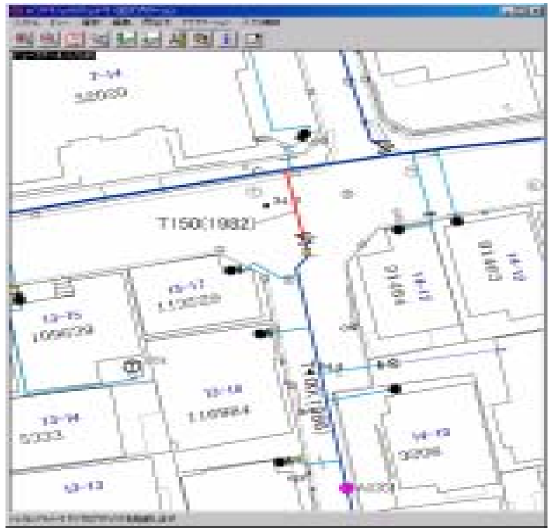

Fig.25 Example of managing service installations using GIS

4) Public Relations

The management of the service installation is the user's obligation. This means users are required to properly understand service installations to prevent accidents and to ensure safe use of water. Water utilities should therefore undertake comprehensive public relations exercises to educate users in the proper management of service installations. The following items should be included in the public relations program:

- User's management obligations.
- Standards for the structure and material used for service installations.
- Temporary treatment options, and contact details for use if leakages occur within a house.
- Reporting incidents of leakages noted on the road.
- Importance of water conservation and how to conserve water.

References

1) JWWA 2000 " Guidelines for Design of Water Facilities"
2) AWWA Research Foundation "Water Main Evaluation for Rehabilitation/Replacement"
3) AWWA Research Foundation, 2000, "Guidance Manual for Maintaining Distribution System Water Quality"
4) Japan Water Research Center, Mar.2001, "Planning Manual for Diagnosis and Rehabilitation /Replacement of Cast iron pipe"

PART II Guidelines for Non-Revenue Water Reduction

Table of Contents (UPDATE HEADINGS TO REFLECT ANY CHANGES IN THE DOCUMENT)

1. Introduction

The water supply system consists of a raw water storage facility, intake facility, raw water transmission facility, water treatment facility, treated water transmission facility and distribution and service pipe facilities. Proper management of these facilities ensures that a high quality and adequate quantity of treated water is supplied on a daily basis. A stable water supply is required to provide for basic human needs and normal functioning of urban and industrial activities.

Over recent years water related issues such as global water shortages and contamination of water resources have been matters of serious concern. Effective use of limited water resources has been identified as a priority worldwide. Reduction in non-revenue water will maximize the use of limited water resources and as such is an important consideration for water supply management.

This document outlines the general guidelines for non-revenue water reduction. More detailed guidelines are attached in Appendix-1.

2. Concept of Non-Revenue Water Reduction Measures

Non-revenue water is defined as ineffective use of treated water produced by purification plants. It is treated water that is not covered by water charges. Excessive amounts of non-revenue water can negatively impact water works financial management because the water treatment process is costly.

Reducing the amount of non-revenue water requires proper operation and maintenance of the water supply facilities, removal and reconstruction of old facilities, employment of qualified engineers, and water leakage accounts for most non-revenue water. Leakage prevention activities are the main measures used to reduce non revenue water.

To effectively implement non-revenue water reduction measures, it is important that accurate data on the distribution and use of water is collected. This requires water balance analysis which determines the amount of water produced compared to the amount of the produced water that is consumed. This requires collection of as much accurate data as possible about the water distribution and its components.

3. Non-Revenue Water Reduction Measures

Measures to reduce non-revenue water are presented in the following figure:

Non-Revenue Water Reduction Measures
- Water Balance Analysis
- Leakage Prevention Measure
  - Corrective measures
  - Preventive measures
  - Technical development
  - Others
- Employment of Engineers/Training of Skilled Workers
- Establishment on related regulations, prevention of illegal connections and strengthen of management system

Figure -1 Non-Revenue Water Reduction Measures

4. Water Balance Analysis

4-1 Water balance Analysis

Water balance analysis is used to determine the actual consumption of treated water. An example water balance analysis is shown in Table-1.

To determine the amount of water leaking from the system, an accurate analysis of each item is required. This information will help identify effective measures for water leakage control that should be implemented.

Accurate data about the distributed volume at reservoirs and each checking point needs to be collected. This means devices for measuring relevant data should be selected and used.

System Input Volume (Production/ Distribution Volume)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Non-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption (water used for fire fighting, etc)	**Non-Revenue Water (NRW)**
			Unbilled Non-metered Consumption (free water distributed at standpipes)	
	Water Losses	Apparent Losses (Non-technical or Commercial Losses)	Unauthorized Consumption (illegal use and connections)	
			Metering Inaccuracies - No meters - Meters not working - Meters not recording accurately - Meters misread	
		Real Losses (Technical Losses)	Leakage of Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connection up to Customers' Meters	

Source: IWA (International Water Association)

Table-1 Example Water Balance Analysis

4-2 Explanation of the Example of Water Balance

a) Revenue Water

Billed authorized consumption, that is, revenue earning water.

b) Unbilled Metered Consumption

A type of unbilled authorized consumption including fire fighting water, consumption by water agencies, etc.

c) Unbilled Non-metered Consumption

A type of unbilled authorized consumption including standpipe water which is free of charge, consumption by pipe laying works, etc.

d) Non-Revenue Water

Sum of unbilled authorized consumption and water losses.

e) Water Losses

Sum of apparent losses and real losses.

f) Apparent Losses

Apparent losses include illegal water use, meter related use problems, tariff collection problems, and water volumes that are deducted during settlement of bills due to occurrence of red water, delays in repairing leaks in houses etc.

g) Real losses

Real losses include overflows and leaks from water supply facilities.

5. Water Leakage Prevention Measures

5-1. Water Leakage Prevention Measures System

A water leakage prevention measures system includes corrective measures, preventative measures and technical development as shown on Figure-2

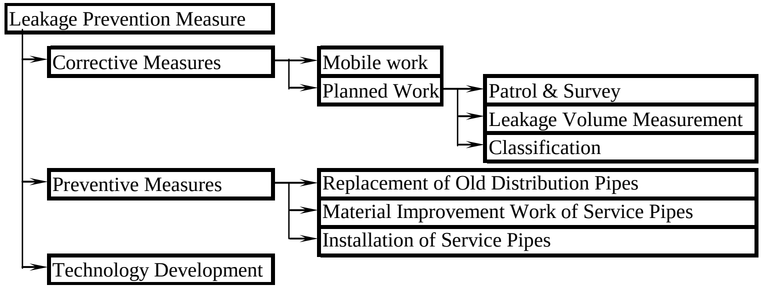

Figure-2 Water Leakage Prevention Measures System

5-2. Corrective Measures

Corrective measures include repair work that is undertaken immediately after leakages are detected, either underground or on the ground surface. In many case, the distribution pipes in the water supply piping network are publicly owned and maintained by waterworks authorities. However, service pipes belong to the individual consumers and therefore need to be privately maintained. However, maintaining underground piping is difficult for individuals, therefore repair of leakages located up to the customer’s water meter is normally undertaken at the expense of the waterworks. Corrective measures are classified as either mobile works or planned works.

1) Mobile Works

Mobile works refer to the repair of leaks on the ground surface; and leaks which are found and reported by residents, public officials such as police, fire fighters etc., and patrol staff working for the waterworks bureaus. Water leakages may occur accidentally at any time during weekdays as well as weekends, holidays, and either during the day or night. It is therefore necessary to establish an organization that can mobilize staff to repair the leak 365 days a year, 24 hours a day.

2) Planned Works

When underground water pipes break, treated water is lost on a continual basis. This type of leak cannot be stopped unless the location of the defect is found and repaired. The economic loss associated with these defects is significant and these costs cannot be recovered. An additional problem is that the leakages can cause big holes at the ground surface or cause land subsidence. This can result in accidents involving injury or loss of human life. Therefore it is important to regularly check for leaks based on a scheduled plan and to quickly repair broken pipes.

This planned repair work should include surveys to detect leaking pipes (the DMA district meter area distribution pipeline network should be divided into specified lengths so that surveys to detect water leakage can occur reliably). Major planned work items include: measuring the volume of water that is leaking to detect leakage trends, and detecting and repairing leaks through patrol and survey works.

(1) Leakage Volume Measurement

The leakage volume measurement is an estimation of leakage volumes and a confirmation of leakage trends. The confirmation process involves a targeted survey of an area which is the same size or less than the DMA. The minimum night flow rate is measured. This can be assumed to be the leakage volume. For Tokyo, the target area should be set at less than 700 house connections.

(2) Patrol and Survey

A patrol and survey consists of two (2) components; a) the sound of leaking water is checked at each customer’s water meter, and b) underground leaks are checked during the night by electric leak detectors. The following areas should be given priority for patrol and survey work: a) areas that are expected to have high leakage volumes based on measuring work and, b) areas where a lot of repair works are required.

5-3 Preventive Measures

Essential and effective preventative measures should be undertaken before leakages occur, to limit the number of leaks in the system and to minimize the leakage volume. Key preventive measures include; a) replacement of old pipes, b) improving the material quality of service pipes and, c) consolidation of service pipe material.

The integrity of water supply pipes are degraded as a result of aging and long term use, earthquakes, irregular ground subsidence, corrosion, traffic loading and construction works. In these situations leakage is likely to occur.

Although water leakages are repaired as soon as they found, the number of new leakages increases with time. This is referred to as the “repetition phenomenon” of leakage. Preventative measures are key to preventing this repetition phenomenon. Figure-3 explains the leakage repetition phenomenon.

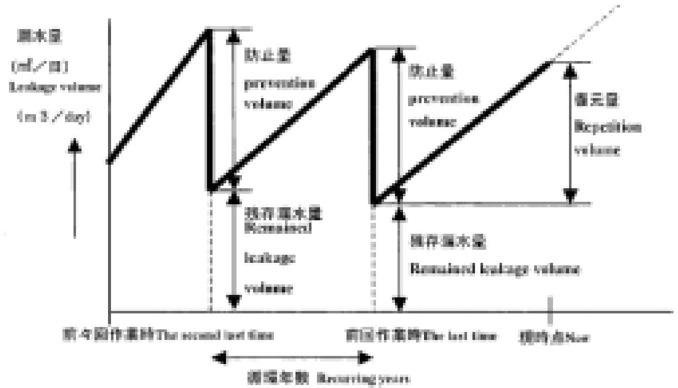

Figure-3 Leakage repetition Phenomenon

1) Replacement of Aged Distribution Pipes

The following pipes are classified as aged pipes:

a) Low strength cast iron pipes without cement mortal lining;

b) Asbestos cement pipes; and

c) Steel pipes that have been used for many years without a lining.

Aged pipes: a) easily leak and cause turbid water, and b) lack strength to withstand earthquakes. Therefore, aged pipes need to be replaced with new pipes that have sufficient strength and durability (e.g. ductile iron pipes, steel pipes and polyethylene pipes).

Replacement of aged pipes is a fundamental and important means of curbing water leakages. However, pipe replacement is very expensive and takes a long time. Therefore, replacement of aged pipes should be carried out in order of priority. The priorities should be based on adequate preliminary surveys.

2) Material Improvement of Service Pipes

The majority of leakage repair work is undertaken on service pipes. Therefore, implementing preventive measures for supply pipes can be very effective.

Many service pipes are constructed from lead and galvanized steel. These materials lack strength and deteriorate rapidly. It is therefore important that these pipes are replaced with pipes made from stronger materials that have anti-corrosive characteristics such as stainless steel pipes, polyethylene pipes and hard PVC pipes (rigid polyvinyl chloride pipes). This would ensure that leakages are reduced.

3) Service Pipe Length Adjustments

In many cities, service pipes that branch off from the distribution sub-mains are meant to be maintained and managed by customers. However it is difficult for customers to maintain and manage service pipes that are beneath the road. The length of service pipes beneath roads is quite significant. Due to the lack of maintenance, these pipes tend to have many leaks. To mitigate this issue, the unit service pipe length needs to be minimized. This would significantly reduce leakages.

4) Removal of Unused Pipes

Unused pipes that branch from distribution pipes are meant to be removed at the expense of customers. However many unused pipes still remain. Leakage detection (using the normal individual survey method) for these unused pipes is very difficult. Therefore leakages in these pipes continue for long periods, meaning a significant volume of water leaks from these pipes.

Pipes are unused because; a) houses are destroyed by war, earthquake and fire, b) roads are expanded, and old roads are replaced with new ones, c) land is acquired for large scale developments to provide for building of large malls and other facilities and d) housing programs.

5-4 Technology Development

Technology development in relation to water leakage prevention can be divided into three (3) categories: 1) early detection, 2) reinforcement of distribution pipe materials/joints and 3) improvement of service pipe materials and branching methods.

1) Technology Development for Early Detection

The following are newly invented technologies and devices developed for water leakage prevention.

a) Pipe Freezing

When work needs to be undertaken to repair a leakage in a small diameter pipe, the water in the pipe on the upstream side of the leakage point is frozen, which stops the water flow. The freezing is undertaken using liquid air (liquid nitrogen 80%, liquid oxygen 20%, temp.-191 degree C). This allows repairs to be undertaken without water suspension.

b) Electronic Leak Detector

Sensitive electronic devices to detect leakage noise from the ground surface are available. Even very quite underground leakage noise can be detected using electrical amplification.

c) Time Integration Leak Detector

This method identifies leaks by detecting intermittent leakage noise.

d) Correlative Leak Detector

This is a device that locates the leakage point and detects leakage noises occurring between two

(2) different points.

2) Technology Development for Reinforcement of Distribution Pipe Materials/Joints

This technology has been developed mainly by the private sector. Newly developed pipe materials include ductile cast iron pipes that are lined with cement, and polyethylene pipes that can withstand earthquakes. The new NS and S-type joints can be applied to ductile cast iron piping. These joints prevent and stop leaks from the joint. This joint technology was developed in Japan. Also, polyethylene pipes joints, constructed using electric fusion welding, are new types of joints.

3) Improvement of Service Pipe Materials and Branching Methods

Until recently, lead pipes were commonly used for house connections. Lead is susceptible to corrosion and has potential health impacts if the lead dissolves into the drinking water. Therefore, the lead should be replaced with other materials such as stainless steel, hard PVC, and polyethylene pipes.

For branch construction, snap taps are used. The saddle method, or drilling to the distribution pipe branch method, is used.

5-5 Leakage Survey

There are generally three methods for detecting leaks: 1) visual observation, 2) assessment of the distribution water volume and 3) leakage noise.

1) Visual Detection

Visual detection refers to visually observing leaks, such as water flowing out of the ground, springs, dampness and cave-ins.

2) Assessment of the Distribution Water Flow/Volume

Leaks are detected using this method if the effective water ratio decreases, the volume of water being distributed increases, or the measured consumption at house connections increases.

3) Detection of Leakage Noise

Leakage noise is commonly used to detect leaks. Leaks occurring through holes in pipes produce continuous vibration noise. The vibration noise results from conversion of the water energy as it flows through the hole to sound energy or mechanical vibration energy. The sound-level/sound-quality is influenced by the type of pipe materials, pipe wall thickness, water pressure and type of leakage holes. Many types of detectors that can recognize the difference in the noise caused by leaks have been invented. For example:

- Leak sound detection bar
- Electronic leak detector
- Correlative leak detector

- Time integration leak detector
- Others

4) Other Survey methods

Other methods of leak detection include: radar waves, tracers, electromagnetic waves, and water quality testing.

5-6 Leakage Repair

Leakage repair works can be divided into three categories; 1) emergency direct repair of leakage point, 2) repair of leakage point by retrofitting, and 3) repair by other methods.

1) Emergency Direct Repair of Leakage Point

(1) Distribution pipes

- Repair by divided collars: used for pipe breakages, leaks from service branches, pin-hole leaks, etc.
- Repair by cover joints: used for leaks from pipe joints.
- Repair by removal of the leaking pipe portion and replacement with a new section of pipe: used for leaks occurring through longitudinal cracks, leaks by corrosion, etc.
- Repair by bolt tightening: used for leaks from joints, sluice valves, fire hydrants, air valves, etc.

(2) Service Pipes

- Repair by union fitting & repair tape: used for leaks occurring from cracks, pin-hole leaks, leaks from joints, etc.
- Repair by bolt tightening: used for leaks occurring from joints including packing and nuts.

2) Repair of leakage point by retrofitting

(1) Distribution pipes

- Installation of expansion joint, bend pipes, etc.: used for leaks resulting from land subsidence, leaks resulting from detachment of pipes, etc.
- Repair by thrust blocks: used for leaks resulting from detachment of pipes, leaks through expansion joints, etc.
- Repair by inner banding: used for leaks occurring from joints in pipes with diameters larger than 800mm.
- Repair by anticorrosion materials: used for leaks resulting from corrosion of the pipes.

3) Other Methods

(1) Distribution Pipes

- Repair by pipe in pipe method: this requires the insertion of a steel pipe into the pipeline where the leaks are occurring.
- Hose lining method: this requires the installation of an elastic tube in the pipeline where the leaks are occurring.

(2) Service Pipes

- Installation of flexile joints.
- Relocation of branch points, service pipelines and water meters.

The methods described above are currently used to repair leaks. For further details refer to Appendix-1

6. Pipe Laying and Construction Supervision

Leakage prevention is a fundamental way of reducing non revenue water. As described in section 5.3 “Preventive Measures”, replacing aged pipes is considered to be an extreme option.
However, replacing aged pipes is recommended because it has many merits apart from preventing leaks. For example, it increases the pipe capacity, and provides protection against damage during earthquakes. Replacement of aged pipes is an important and effective way of preventing leaks and minimizing leakage volumes. Therefore, it is recommended that replacement of aged pipe be carried out using high-grade technology and appropriate skills.

For pipe laying, a detailed and through site survey must be carried out at the design stage. Based on the results of the site survey, suitable pipe material should be selected with consideration of the construction site. The construction methods should also be determined at this stage. It is important to establish an appropriate system of construction supervision to ensure construction progresses reliably.

6-1 Important Notes for Designers

The basic roles and responsibilities of the designer are listed below:

a) Prepare for unhindered construction works by obtaining relevant permission for occupying the road space during construction, coordinating with relevant organizations, and arranging for a detailed site survey.
b) Prepare functional designs based on relevant criterion and ensure the designs minimize construction cost.
c) Apply relevant criterion and standards by ensuing the designer has the necessary knowledge of objectives and contents.
d) Design construction works with full regard of safety requirements.
e) Estimate construction costs in accordance with applicable standards, ensuring the costs are fair and adequate.
f) Keep records of the design process progress.

6-2 Piping Design Process

The normal design process for pipe laying works is shown below.

planning → basic design → site survey → hydraulic study → detailed design → construction

6-3 Supervision System

Supervisors are required to make quick judgments; issue instructions and confirmations considering site conditions (such as time limitations associated with water suspension); and change construction methods due to obstacles (e.g. buried pipes/structures, existing service pipes, construction site situations and construction safety). In addition, the construction company needs to ensure someone is responsible for the proper control of the construction site, in accordance with the supervisor’s instructions. To ensure high quality pipe laying works, which are durable, water tight and safe, it is necessary to have sufficient supervision system capacity and to maintain appropriate conditions surrounding the construction site.

To provide for the above, preparation of general/technical specifications on pipe laying works, and skill enhancement of staff/contractors through training programs, should be developed. It is also necessary to ensure that someone is responsible for all the contractors at the construction site at all times. The water works staff must also confirm progress/condition of the construction works as required. To enhance the construction supervision system the following is require: control and confirmation of construction progress; and monitoring of the construction site condition and materials used by submitting of daily progress pictures/reports.

7. Training

The following measures have been identified as important for reduction of non-revenue water;
- proper maintenance of water supply facilities.
- implementing leakage prevention works.
- proper design of pipe laying works.
- enhancement of construction supervision systems.

To help ensure the above is possible recruitment of a number of qualified engineers is necessary. Also, training of skilled workers is essential. Therefore, the service training system for engineers/skilled workers should be enhanced. The following are examples of the types of technical training activities carried out in Japan. Section 7-1 provides an overview of the technical training activities undertaken in the Tokyo Metropolitan Water Works Bureau, and Section 7-2 provides an overview of the Japan Water Works Association.

7-1 Examples of training undertaken in the Tokyo Metropolitan Water Works Bureau

1) Water supply system engineering

Purpose	To train engineers in overall technical knowledge of the water supply system and to design future water supply works.
Subjects	Water works planning, hydraulics, civil structure analysis, civil/pipe materials, construction methods, water quality, water treatment facilities, transmission and distribution facilities, electric/mechanical equipment, and service facilities.
Duration	ten (10) days

2) Hydraulic engineering

Subjects	Study of hydraulic simulation for designing water supply facilities, analysis of distribution network systems, and water quantity and pressure controls.
Duration	Two (2) days

3) Civil structure

Purpose	To provide engineers with the skills to design civil structures and supervise construction.
Subject	Lectures on design/construction concepts associated with water supply facilities, geology and soil conditions, and temporary construction/sheeting for underground structures.
Duration	Three (3) days

4) Construction supervision

Purpose	To improve engineers' capability for construction supervision.
Subject	Lectures on the roles of supervision, the recent move towards public construction works, safety construction management, progress inspection, examples of past experiences.
Duration	Three (3) days

5) Explanation of guidelines for water works technical management

Purpose	To develop knowledge in the field of water works technical management (operation and maintenance).
Subject	Lectures on the guidelines for water works technical management.
Duration	Three (3) days

6) Corrosion/corrosion control

Purpose	To develop knowledge in the field of corrosion/corrosion controls.
Subject	Lectures on corrosion control mechanisms, examples of corrosion and countermeasure, and cathode protection systems.
Duration	Three (3) days

7) Field training for pipe laying

Purpose	To provide staff, chiefs, and subsection chiefs who are newly assigned to the project construction office from another division with appropriate skills.
Subject	Lectures on design of pipe laying and construction supervision, including field training.
Duration	Four (4) days

8) Water treatment practice

Purpose	To acquire skills and knowledge of treatment system technology.
Subject	Lectures on technical management of water treatment facilities, water treatment engineering, water quality management, analyzing devices, and electrical/mechanical equipment.
Duration	Two (2) to five (5) days

9) Service facility

Purpose	For new staff to obtain required knowledge of the service facilities in the distribution division of the water works.
Subject	Explanation of the condition and problems associated with the service facility, design/construction standards, and cost estimation.
Duration	Two (2) days

10) Service facility technology

Purpose	To obtain skills related to house connection techniques.
Subject	Lectures on the mechanisms in water meters, installation of saddle branch/drilling, installation of service pipes, field operation of buried pipe detectors and leakage detectors.
Duration	One (1) day

11) Seminar for contractors

a) Seminar for chief engineers of contractors

Purpose	To improve skills in management to ensure proper, safe and effective construction.
Subject	Chief engineers are required to control/manage technical aspects of field construction.
Duration	Three (3) days

b) Seminar for plumbers

Purpose	To gain a basic understanding and skill level in the preparation of drawing pipes, and field installation work.
Subject	Plumbers are required to have two (2) years experience.
Major items	Lecture on different aspects of pipe design drawings, how to prepare drawings, piping methods, pipe calculations, several types of connections (such as cutting pipe, sleeve, dismantling, and T-connection), alignment, location tape, and polyethylene sleeve protection. After completing the pipe connection work, detection of leaks are undertaken using water pressure tests.

7-2 Example of training undertaken in the Japan Water Works Association

The Japan Water Works Association implements seminars for municipal water works staff and contractors across the country to improve their understanding of technology and their water supply engineering techniques.

1) Seminar for water supply engineers (introductory course/advanced course)

Purpose	To learn about basic/newly developed technology associated with planning, construction and maintenance/management of treatment/transmission and distribution facilities, as well as leakage prevention.

2) Respective seminars for specialized subjects

Purpose	Seminars are provided for the following six (6) subjects: electrical/mechanical/instrumentation facilities, water treatment facilities, construction/maintenance/management of transmission/distribution facilities, water supply equipment facilities, water quality control, and advanced treatment.

3) Seminars for acquiring water supply engineers with qualifications that are authorized by the Minister for Health, Labor and Welfare

Purpose	To ensure staff are able to employ suitably qualified technical administrators[1] for the water works.
Subjects	Seminars and on the job training to obtain knowledge of technology associated with the general aspects of water works engineering.
Duration	Thirty (30) day.

Note: [1] The required qualifications for the technical administrator of the water works is prescribed in the *Water Works Law*. This Law states that a technical administrator for water works needs to be employed to manage waterworks in Japan.

4) Seminar for water leakage prevention

Purpose	Promotion and development of engineering capability of engineers engaged in water leakage prevention.

5) Skill enhancement- seminar for plumbers

Purpose	To acquire knowledge/skills related to piping/couplings, including earthquake-resistant couplings. This training is for water works staff and employers of companies that undertake pipe laying work.
Registration	Certificate: participants who pass the leakage test, which includes practical skill field training, are issued with a certificate which enables them to become a licensed plumber once they register on the list of qualified distribution engineers.

6) Seminar for pipe design

Purpose	To acquire basic knowledge of pipe design and cost estimation for design company engineers and water works authority. This is based on practice.
Registration certificate	Participants are issued with a registration certificate which states they attended the pipe design seminar.

Appendix-1

Guidelines for Non-Revenue Water Reduction (Detailed Measures)

Appendix-2

Pipeline Management Using GIS