A GUIDE TO THE CONTROL OF WATER LOSSES IN PIPE NETWORKS

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Based on a report for the

WATER RESEARCH COMMISSION

prepared by the

UNIVERSITY OF PRETORIA
Division of Water Utilization Engineering
and Environmental Science

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SYNOPSIS

Water lost from a water supply distribution network can account for a considerable percentage of the total volume of water supplied. As this loss is paid for by consumers, a reduction in the amount of water lost could lead to a decrease in water tariffs, smaller pipe sizes and reduced water purification capacity and a delay in the need for increased storage.

Various fields of study were incorporated into the investigations. An investigation concerning water meters, their accuracy, probable life-span and their use in determining water losses was undertaken. It was found that meters now in use are not very reliable and that meter readings must be studied with care before being accepted as such.

Pipe materials and construction methods were also studied. It was found that the various pipe materials which are SABS approved are of a high standard and are also very reliable. Thorough consideration must however be given to the types of soil the various pipe materials are laid in so as to obtain the maximum life-span from a specific pipe material. As far as construction methods and field installation are concerned, it was found that such work was not always being carried out according to the specifications and that a considerable number of pipe failures are due to unsatisfactory workmanship.

Various methods of leak detection and water loss prevention were studied and field investigations were carried out in a number of test areas. A combination of leak detection methods would seem to be the most suitable for water loss control in pipe networks. The economic implications of water losses from pipe networks were studied. A more extensive study would however be necessary in order to obtain an estimate of costs involved.

FOREWORD

There is no doubt that the availability of sufficient water supplies is vital to the welfare of a community or of a country as a whole and South Africa is no exception.

As the domestic and industrial centres of the country have grown so too have the demands on water, to such an extent that it is expected that by the turn of the century these sectors could account for some fifty per cent of total water usage compared to the present figure of around thirty per cent.

The storage, purification and distribution of water requires energy and manpower, and involves large sums of capital investment. Obviously, therefore, it is to everyone's advantage to use water economically and not to waste valuable resources.

The transfer of water from its source to the place where it is needed, is an intrinsic part of the water supply industry. Water escaping from such networks represents a total loss and in some cases can account for fifty per cent of all water entering the network. It is desirable, and indeed essential, to reduce these losses to acceptable levels, both from the economic and the water conservation points of view.

By applying water loss control programmes, the life-span of existing resources will be extended, thus delaying the necessity of implementing other more drastic measures to stretch our limited water supplies.

I trust that this document will succeed in focusing attention on this particular aspect of water saving and help to generate a consciousness to conserve water.

MR Henzen
Chairman
Chief Executive Officer
WATER RESEARCH COMMISSION

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The South African Bureau of Standards
The Thames Water Authority: (Metropolitan Water Board — London)
The Severn-Trent Water Authority

In addition five pipe manufacturers, various consulting engineering firms and six construction sites were visited as well as Hydrotronic, whose trip to Italy to evaluate their specialized sonic equipment was valuable.

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A GUIDE TO THE CONTROL OF WATER LOSSES IN PIPE NETWORKS

INTRODUCTION

An agreement was entered into between the University of Pretoria and the Water Research Commission during October, 1974. The term of the agreement was for a period of three years during which time the University would undertake research work concerning water losses from pipe networks.

The investigations entailed a number of tasks divided into two phases. The first phase covered investigations into water losses and associated problems and the second phase included ways and means of preventing losses as well as the economic implications involved.

As the project progressed, it became clear that despite limited water resources, not enough was being done in South Africa concerning the actual implementation of water loss control programmes. The reasons were probably that not enough was known about the problem and secondly, that bulk meters tend to under-register, giving a false sense of security.

The terminology "losses in pipe networks" is very generally used. The so-called "losses" are defined more accurately as the unaccounted for water (UAW) for the network. UAW actually consists of four components. Firstly, the actual losses from the network, which are economically reparable and also traceable by various methods; secondly, the unavoidable losses which will always occur and are generally not traceable; thirdly, meter losses on the delivery side; and finally, unmetered draw-offs that occur via hydrants etc.

UAW is determined by metering a network on both the bulk supply and delivery side and subtracting these two summations from one another. UAW for networks is known to vary between 6% and 60%, of the total volume of water drawn from storage.

Various factors have a direct influence on the quantity of the UAW. Incorrect meters can dramatically change the UAW, while inferior pipe materials and methods of pipe installation can cause an increase in the UAW. Furthermore, if an active programme of leak detection and water loss control is implemented, the UAW will invariably be reduced.

In order to investigate the UAW more fully, it is necessary to know the size and order of importance of the various components. Once they are known the task of reducing the total UAW is made much simpler.

In general, it can be stated that actual water losses which are of major importance, can be reduced in two ways. Firstly, leakages can be prevented and depend on the quality of the materials used and installation methods. Secondly, losses can be reduced by the implementation of an effective leak detection and water loss control programme.

DEFINITIONS

Leak

The undesirable discharge of water from a defect in the pipe network.

Connection pipe

A connection pipe is the pipe conveying water from the water supply authorities main to the consumer's premises.

Unmetered draw-off

This represents draw-off via a hydrant or a flushing valve and does not include draw-off from connections that are not metered. All connections are to be taken as metered.

Pipe network system (12 — 300 mm diameter)

A pipe network system starts at a central meter position (bulk meter) and ends at multiple meter positions. Connection pipes (usually 12 — 15 mm diameter) are also part of the network but *only* to the outlet side of the stand meter.

Combined pipe network system (12 — 300 mm diameter)

This is a pipe network system which also includes all pipes inside the stand if the stand is supplied from the network system.

Network meter

This is a bulk meter and takes up the central metering position in a pipe network. All the water supplied to the network passes through this meter.

Loss

Loss means water that runs to waste via a leak in a pipe network.

Loss flow (LF)

This is the volume of water that passes into a network system through a supply point or points per time unit when all draw-off points have been closed off. These supply points are fitted with network meters. Loss flow can be expressed in $\ell\ min^{-1}\ km^{-1}$.

Minimum night flow (MNF)

This is the minimum flow that will enter a combined network system during a 24-hour period. MNF usually occurs during the hours 02h00 and 04h00. The MNF can be expressed in $\ell\ min^{-1}\ km^{-1}$.

Unaccounted for water (UAW)

The UAW of a network consists of four components:

$$UAW = a + b + c + d \quad (1)$$

a = actual losses due to leaks that are economically reparable

b = unavoidable losses caused by small leaks which are not economically reparable and cannot be traced. These leaks can amount [1,2,3,4] to 1,5 — 4,5 $\ell\ min^{-1}\ km^{-1}$ pipeline and are independent of the pipe diameter.

c = apparent losses caused by slow stand meters on the delivery side. (The network meters[5] are taken to be correct.)

d = unmetered draw-offs via hydrants and flushing valves. Values for these draw-offs[1,6] vary between 0,3% to 1% of the average monthly flow.

The UAW can be determined by means of network meters on a monthly basis. Components a and b are determined by taking loss flow measurements using network meters or waste detection meters. Component d can be measured and thus component c can be calculated by means of equation (1).

UAW can be expressed in various terms:

(i) in $\ell\ min^{-1}\ km^{-1}$ of pipeline (this includes connection pipes up to the outlet of the stand meter and is independent of the pipe diameter);

(ii) in ℓ/min per connection;

(iii) as a percentage of the average monthly flow to the network.

(i) and (iii) are most suitable for investigations in residential areas. Distorted values for (iii) can however result when mixed areas with a number of large consumers are monitored. (ii) is not very useful as stand sizes vary tremendously in South Africa.

TYPES OF LEAKS

Leaks can be classified[4] into three categories

Type I

Small leaks which represent the unavoidable losses. It is not economical to find and repair such leaks.

Type II

Medium sized leaks which can make a considerable contribution towards the UAW. These leaks usually develop from Type I leaks and seldom appear above ground, depending of course on the porosity of the soil.

Type I and II leaks develop spontaneously and are not caused by external shock loads.

Type III

These are big leaks usually caused by external shock loads and nearly always appear above ground because of the massive amount of water that is discharged immediately after the break occurs.

In general, it would appear that most leaks occur on the connection pipes and not on the mains. Figures for the "Newcastle and Gateshead Water Company" for the period 1969—1972 confirm this[7]:

(i) mains = 256 leaks

(ii) connections = 1 207 leaks

Leaks that appear on the connections are mostly of Types I and II whereas those on the mains are mostly of Type III.

WATER METERING

Water Metering in Pipe Networks

Water meters, their accuracy, maintenance and probable life-span have a definite influence on the UAW of a network. With accurate meters on both sides of the network the actual losses can be determined.

Water metering elsewhere

Very little use is made of metering in England, especially in residential areas. In the United States of America and Europe most authorities meter water supplied to the various consumers. Israel meter extensively but apply a uniform tariff structure throughout.

Meter Accuracy and Maintenance

(a) Residential meters (26 mm diameter)

The Metering Committee of the AWWA reports[8] as follows:

'Out of a total of 1,2 million meters, 5% on average, were out of order at any one time. Furthermore

39,9% were replaced within a 10-year period. In another instance where meter maintenance was of a high standard, only 1,5% of the meters were out of order at any time.

With a maintenance[8] interval of 10 years, 93% of all meters measured within 96—107% of the actual flow at the medium flow range as against only 49% with no periodic maintenance.'

A survey[9] done in 1959, in Germany indicated that on the average 1,38% of the total number of meters (1,09 million) had to be replaced annually.

It was found in the city of Mankato[10] that it was economical to replace, rather than repair small meters in their maintenance programme. In general[9] it would be better economics to repair, rather than to replace meters, when the cost of repair is ⅓ of the cost of replacement. In many instances[11] however, the capital and labour costs for repair amount to more than the replacement cost.

(b) Industrial and bulk meters (larger than 26 mm diameter)

Research done in the United States of America and other countries makes it clear that maintenance[12] of bulk meters is essential if meter accuracy is to be maintained. It is fairly common to service a meter if it has reached 70% of its estimated life-span. Such service would include:

- periodic inspections carried out in-situ
- replacement of working parts and recalibration
- documentation of all maintenance work undertaken.

The documentation on meters would include the following aspects:

- manufacturer, purchase price and date
- type, model, size and serial number
- date and address of installation as well as reading on instrument
- failure date and meter reading on failure
- type of repair and total cost involved to recalibrate
- results of tests done on inaccurate meters after removal

Various factors can cause meters to fail or slow down; these include:

- corrosiveness of water
- sediment or sand in the pipeline
- lime build-up in meter body
- volume of water measured before service or replacement (5 Mℓ maximum for 20 mm meters)

Water Metering in South Africa

Universal metering is standard practice in South Africa today. Certain exceptions are still found especially in black townships.

A very limited amount of literature concerning meters is available in South Africa. Gebhardt suggests[6] a meter error of 5,5% at low flow rates, which he calls "meterslip". Two towns in the Witwatersrand area have 14 000 and 7 800 meters with 5,36% and 1,79% respectively of these meters out of order at any given moment. The first of these towns had UAW figures of 12,20% and 6,06% for 1973 and 1974 respectively. This reduction in UAW was due to an increased meter maintenance programme. For the second town the reduction was from 28% in 1960 to ± 4% in 1968, also attributable to such a programme.

Mr. J.E.L. Hampton, former chief Engineer of Pinetown found that the accuracy of meters depended more on the amount measured than on age.

Meters are tested for accuracy by Cape Town on receipt of complaints from consumers. It was found that 79,5% of these meters measured within 98—102% of the actual volume when tested.

Types of Meters Available

In South Africa there are only two meter manufacturers compared, for example, with the 14 meter manufacturers in Germany. In general two groups[13] of mechanical water meters can be distinguished i.e. displacement and velocity meters.

Four types of positive displacement meters are:

- oscillating piston
- semi-rotary disc (SRD)
- oscillating disc
- helix and other types

Three types of velocity meters are:

- single and multi-rotary
- turbine
- horizontal and vertical propeller

Combination meters are also available. This is a large and small meter in parallel with a changeover device to isolate the large meter at times of low flow. The object is to improve low flow accuracy and they are especially applicable where large flow variations are encountered.

Magnetic meters are also available but are not generally used in domestic water metering.

Only one type of residential meter smaller than 26 mm diameter, has been approved in South Africa, this being the semi-rotary disc type. These meters must measure accurately to 100 ± 2% before they can be approved and sealed with the required mark.

Various types are available in the larger than 26 mm diameter category. In South Africa the SRD, turbine, propeller and combination type meters are manufactured with the propeller or full flow type the most popular. When large flow ranges are required a combination meter is usually used having a range of 1000:1.

Maintenance cost for this type of meter can however be high compared with the turbine[14] meter. Combination turbine meters on the other hand only have a flow range of 60 to 80:1.

Accuracy requirements for new meters

The accuracy requirements[15,16,17,18] for positive dis-

TABLE 1 STANDARD FOR METER ACCURACY (%)				
Flowrate	Accuracy %			
	RSA 15–25 mm ϕ	England 15–25 mm ϕ	Netherland 17,5–46 mm ϕ	USA (AWWA) 15–150 mm ϕ
High	98–102	98–102	95–102	98,5–101,5
Medium	98–102	98–102	95–102	98,5–101,5
Low	97–102	98–102	95–102	95–101,5

placement meters for four countries are given in Table 1.

In general new meters have accuracies of 100 ± 2%.

Accuracy of used meters

The town of Mankato, United States of America, with 6 700 residential meters, found[10] that only 68% of water pumped into the network was being paid for. This is a UAW of 32%.

Accuracy tests conducted[19] in Malvern England on 1 000 meters after being in use for 10 years indicated that only 8,1% were still measuring to the required accuracy.

Quality does have an influence on meter accuracy and life. Brown[20] compared two makes of meters in the USA over a period of seven years (see Table 2).

TABLE 2 COMPARISON BETWEEN TWO MAKES OF METERS		
Reference	Make A	Make B
Purchase price	\$29,31	\$32,34
Number of years in service	7	7
% incorrect meters after 3 years	28%	3%
% incorrect meters after 7 years	52%	4%

In a test carried out by the Rand Water Board on three 100 mm diameter full flow (FF) type meters and three 40 mm diameter semi-rotary disc (SRD) meters it was found that the 100 mm diameter meters were all running fast (see Table 3). These meters had only been in use for 9 months.

TABLE 3 COMPARISON OF METER ACCURACY AT VARYING FLOW RATES			
Type of Meter	% Error		
	Low flow rate	Medium flow rate	High flow rate
40 mm ϕ SRD	+ 3,00	+ 3,15	+ 1,90
40 mm ϕ SRD	+ 2,35	+ 2,15	+ 1,15
40 mm ϕ SRD	+ 2,80	+ 2,80	+ 1,05
100 mm ϕ FF	+ 7,13	+ 9,09	+ 8,83
100 mm ϕ FF	+ 13,95	+ 7,48	+ 9,39
100 mm ϕ FF	+ 7,14	+ 10,10	+ 10,26

It can be seen from Table 3 that the SRD meters tested were more accurate than the FF type. If the fact that these meters had only been running for 9 months before being tested, is taken into account, it would appear that meter accuracy is far from ideal. One of the above meters was thoroughly cleaned and retested and found to be accurate again. A build-up of lime in the body of the meter was responsible for the inaccuracy.

Generally it can be stated that, if high meter accuracy is required, an appropriate maintenance programme is essential. Furthermore, a high meter accuracy generates a higher income in the short term without changing the unit cost of water.

A STUDY OF PIPE MATERIALS AND CONSTRUCTION METHODS

The quality and standard of pipe materials, specifications for their installation, and the actual installation have an influence on the UAW.

Pipe materials

Various pipe materials are available to the engineer today. The main requirements that influence the choice of a pipe material are as follows:

- sound basic pipe design
- ability to withstand internal and external loads with the required safety factor
- quality control during manufacture
- compliance with SABS requirements
- availability of simple jointing methods with a large range of joint pieces
- ease of installation with little bedding preparation
- corrosion resistance
- water tightness
- ability to tap connections while the pipe is under working pressure
- long life expectation

Virtually all pipes manufactured today satisfy the above requirements.

In South Africa various pipe materials are available: reinforced concrete[21] (only large diameters), asbestos cement[22.23.24] (AC), cast iron[21.25] (very seldom used), steel[26.27.28] and plastic.[29.30.31.32.33.34.35]

Ductile iron is very popular in the United States of America and reinforced glass fibre[36.37] pipes are currently being manufactured and installed.

A comparative study[38] on failure of various pipe types was carried out in Sweden (see Table 4). It can be seen that ductile iron compares very favourably with the other types.

TABLE 4
COMPARATIVE STUDY OF PIPE FAILURES[38]

Pipe Type	Number of Failures		Pipe length in km	Failure per km
	Trunk mains	Networks		
Reinforced concrete	1	—	296	0,003
AC	1	1	46	0,054*
Cast Iron	193	164	3 585	0,100
Ductile iron	2	3	333	0,015
Steel	23	32	488	0,113
PVC	49	55	302	0,344

*Sample too small to be representative

Construction methods and procedures

A high quality pipe material is not always successful if installed in adverse soil conditions for which it was not designed. Various factors have an influence on pipe life:

- soil conditions such as acidity, watertable, heaving characteristics and the possibility of stray electric currents
- type of corrosion protection prescribed
- choice of the correct pipe strength for the required internal and external pressures
- basic design of sluice and airvalve boxes
- the handling of pipes and fittings
- bedding conditions
- the correct installation of the pipe
- backfilling with a suitable material as well as compaction thereof.

The first four factors are basic design requirements and were not investigated. The other factors were investigated and the specifications of various bodies were compared with a combined specification (see Table 5). As can be seen, specifications as stipulated by various bodies appear to be quite satisfactory.

TABLE 5
A COMPARATIVE STUDY OF SPECIFICATIONS FOR PIPE LAYING

Body	SPECIFICATION REQUIREMENTS			
	Handling	Bedding	Correct installation	Back-filling
1	satisfactory	good	satisfactory	satisfactory
2	satisfactory	good	good	good
3	satisfactory	satisfactory	good	good
4	satisfactory	satisfactory	good	good
5	poor	satisfactory	satisfactory	satisfactory
6	poor	satisfactory	satisfactory	satisfactory
7	satisfactory	poor	good	poor

As can be seen from Table 5, specifications as stipulated by various bodies appear to be quite satisfactory.

Field investigation concerning pipe materials and construction methods

A total of five manufacturers were visited and it was found that the manufacturing processes and quality control were good. Handling of pipes on the premises as well as in transit to the various sites were satisfactory.

The results of investigations concerning construction methods were, however, not altogether satisfactory. Actual installation methods were compared to those required by the specifications (see Table 6).

TABLE 6
CONSTRUCTION METHOD INVESTIGATIONS

Construction Site	% Success according to combined specifications			
	Handling	Bedding	Correct installation	Back-filling
1*	87	84	92	88
2*	93	80	92	84
3*	90	72	96	60
4	93	48	88	88
5	83	70	84	92
6	68	36	72	84

*Areas situated in Cape Town where all the bedding material consisted of sand.

In general the execution of bedding requirements was carried out in an unsatisfactory manner. The seriousness of this is very clear because few pipes can withstand a sagging foundation.

INVESTIGATIONS CONCERNING WATER LOSSES AT VARIOUS CENTRES

Various centres were visited and UAW figures obtained are listed in Table 7.

TABLE 7
UAW FOR VARIOUS CENTRES

Year	UAW as a % of the Total				
	Pretoria	Johannesburg	Cape Town	Pinetown	Pietersburg
1968	—	10,9	—	14,2	—
69	12,3	7,6	—	11,8	—
70	11,1	9,7	7,2(11,6)*	12,5	—
71	9,5	10,6	9,8(15,7)*	13,9	15,3
72	12,3	10,1	10,1(16,6)*	14,5	22,0
73	13,3	10,5	8,2(13,8)*	16,4	21,4
74	15,1	15,3	9,6(16,9)*	10,7	20,1
75	10,8	14,7	7,2(12,6)*	13,6	20,7
76	—	18,0	3,7(6,7)*	9,4	18,6
77	—	15,6	—	11,9	13,5

*Cape Town is a bulk supplier of water to smaller municipalities. The figures in brackets represent the UAW of Cape Town itself and exclude the bulk supplies. A UAW figure of below 10% is very exceptional and is a clear indication of a very well maintained network. However, one must not be misled by low UAW figures. Incorrect bulk metering can even yield a negative UAW figure, that is, more apparently flows out of the network than is put into it.

INVESTIGATIONS CONCERNING LEAK DETECTION METHODS AND APPARATUS FOR THE DETERMINATION OF PIPE NETWORK LOSSES

There are various methods of leak detection:

- visual
- sonic testing[39,49,41,42,43]
- nitrous oxide injection[44]
- waste detection meters[44,45,46,47]
- scanning pipe interiors[48]
- network metering
- a combination of the above methods

It would appear that a combination of methods should produce the best waste detection and water loss control results. Visual methods are an essential ingredient of any leak detection programme and can be carried out by meter reading personnel or other municipal staff as well as the general public. Sonic testing assists greatly in the pin-pointing of leaks and it can be carried out with a variety of devices, from the very simple listening rod to the highly specialized motor transported unit.

Waste detection meters are very useful to monitor suspect networks, especially where soil conditions are adverse and where the porosity of the soil is high. In a porous soil, leaks very seldom appear above the ground and therefore go undetected.

Feasibility of sonic devices in South Africa

A whole range of sounding devices are available in South Africa or can be imported. The sophisticated devices are more sensitive and can therefore pick up less audible sounds. On the other hand they also pick up many more external noises like aircraft, dogs barking, vehicles etc. Because of external noise, a lot of sounding, especially pin-pointing, has to be done at night when the noise level is greatly reduced.

Sounding devices are very suitable for use under South African conditions, especially in residential areas which are in general fairly quiet throughout the day.

The cost of these devices vary considerably from R10 for a simple device to R3 000 for a very sophisticated type.

Field investigations concerning network losses

It was decided to determine the UAW for various networks ranging in length from 3 — 12 km. The networks also differed in type of pipe material and age. At the same time the actual components of UAW were also investigated.

A sonic testing device, bulkmeters and waste detection meters were purchased and used in the investigation. The bulkmeters were installed for periods of three months in each selected area of the network. A number of leaks were located by means of the sounding device, the largest being in the order of 4 000 ℓ/h. Table 8, gives in condensed form, the results of the various surveys. It can be seen that unavoidable losses (b) seem to be considerably more serious than the actual losses (a). It should be stated however, that the test periods were only for three months at a time.

From the results of the various surveys, recommended maximum acceptable figures for unavoidable losses were determined for different pipe materials within three age ranges (see Table 9).

TABLE 8
UAW COMPONENTS FOR SIX TESTS

Pipe material	Age years	UAW ℓ min⁻¹ km⁻¹	Component a* ℓ min⁻¹ km⁻¹	Component b* ℓ min⁻¹ km⁻¹	Component c* ℓ min⁻¹ km⁻¹	Component d* ℓ min⁻¹ km⁻¹
AC	3	1,08 (7,6%)	0,21 (1,5%)	0,50 (3,5%)	0,33 (2,3%)	0,04
AC	30	11,80 (45,0%)	0,00 (0,0%)	1,66 (6,3%)	10,14 (38,6%)	0,00
Cast Iron	35	13,00 (36,9%)	0,19 (0,5%)	2,01 (5,5%)	10,72 (30,9%)	0,08
AC	3	3,86 (8,9%)	0,15 (0,3%)	1,13 (2,6%)	2,49 (5,7%)	0,09
AC	25	5,18 (13,5%)	0,37 (1,0%)	3,63 (8,3%)	1,18 (3,1%)	0,00
Steel	25	9,98 (22,3%)	2,01 (4,5%)	1,49 (3,0%)	6,48 (14,5%)	0,00

* UAW = a + b + c + d where:

a = actual losses due to leaks that are economically reparable
b = unavoidable losses caused by small leaks which are not economically reparable and cannot be traced
c = apparent losses caused by slow meters on the delivery side
d = unmetered draw-offs via hydrants and flushing valves.

TABLE 9
RECOMMENDED MAXIMUM VALUES FOR UNAVOIDABLE LOSSES (ℓ min⁻¹ km⁻¹)

Age years	Pipe Material		
	AC	Steel	Cast Iron
0–10	0,5–1,5	N.A.	N.A.
10–20	1,0–2,0	N.A.	N.A.
20	1,5–2,5	1,5–3,0	1,5–3,0

Waste detection meters were installed in two networks in Johannesburg and step-tests were carried out. Certain branches of the networks were isolated and the corresponding drop in minimum night flow (MNF) recorded. At the same time the drop in the MNF was compared with changes in network pressure, and it became very evident that reducing pressures to the order of 270 to 400 kPa could mean a large reduction in MNF and therefore the UAW (See Figure 1).

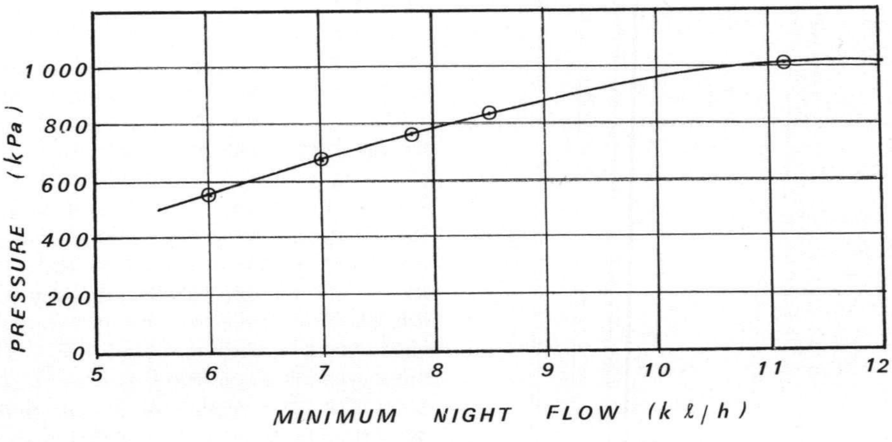

FIG. 1: Minimum Night Flow (MNF) with pressure variation

BENEFITS OF LEAK DETECTION

One of the major functions of a water supply authority is to provide the best service to the community at the lowest possible cost. As the community must pay for water lost from the system there is an economic responsibility on the supply authority to prevent waste. In addition, the water supply authority accepts a moral responsibility to prevent wastage.

A programme of leak detection and repair costs money. Some of the benefits which can be weighed against the costs of such a programme are listed below.

Water saved on the network side of the meter

By subtracting the amount of water sold to consumers from the bulk-metered water supply (and after making due allowance for other unmetered draw-offs such as from fire hydrants etc), the UAW is determined. As the leak detection/repair programme progresses the actual savings can be determined by the reduction in UAW. It is essential that the bulk-meter be calibrated before and after the exercise.

Water saved on the consumer side of the meter

The supply authority should encourage leak detection and water thrift by its consumers. The short term loss of revenue will be offset against the premature need for additional capital expenditure to extend treatment facilities, storage and pumping installations.

Reduced damage to public and private property

Even small leaks in domestic plumbing can ruin floors and furnishings while leaks in the network not only damage streets through the formation of potholes but also damage motor vehicles and on rare occasions cause injury to occupants.

Energy saved

All water supplies require energy for treatment and distribution. If leakage finds its way into the sewer system additional energy is wasted in treating the excess at the sewage treatment plant. Reduced leakage from pumping mains means reduced energy costs at peak periods.

Money saved

Leak detection and repair costs money, but this will be more than adequately offset against savings in the long run.

Capital deferred through deferred facility construction

New works or extensions to existing works can be delayed, thereby making capital available for other purposes.

Maintenance crew savings in time and therefore money

Ideally leak detection and leak repair will be undertaken by separate crews. Leak detection crews using sophisticated electronic sounding equipment soon become very skilled in using the equipment. They will pinpoint leaks which are often a long distance away from the surfacing water (if the water surfaces at all) thus saving the repair crew considerable time in locating leaks.

Experience

Knowledge and experience gained by a well organized leak detection and repair programme not only enables a more rapid survey of the total network but also provides management with better information on which to base decisions and business judgements.

Metering improved

A leak detection and repair programme invariably forces the supply authority to review consumer and bulk meter accuracy. Resulting from such a review, metering policy and meter maintenance programmes could be changed.

Public Relations

Public relations can be greatly enhanced if the leak detection programme is extended onto consumer properties. Detection crews often locate leaks under driveways, foundations or concrete yards.

Network Control

Control of the network is improved through familiarity and the entire distribution system can be reviewed. Documentation is continually updated.

DETERMINATION OF THE ECONOMIC IMPLICATIONS

Considering the economic implications of leak detection, the question arises as to how a nett value can be calculated for the input as against the savings due to this effort.

To determine this, it would be necessary to study a large scale operation for quite a length of time. Therefore the results obtained during the investigations reported here, are not adequate for this purpose.

The costs associated with leak detection and repair are threefold, namely:

Equipment and Labour costs

The highly sophisticated and specialized electronic sounding equipment is very expensive and could possibly only be afforded by contracting to a firm of specialists. Once the initial survey is completed using this equipment the water supply authority can continue with the programme using less sophisticated equipment. A leak detection crew is usually a small unit and costs should include labour, operation, maintenance, personnel training and administration and also depreciation of the equipment (vehicles, waste detection meters, sounding devices).

Costs of repairing leaks

The number of leaks found will be high initially but once a programme becomes established the number should stabilize around a statistical mean. This mean will be largely dependent on the type and age of the network, soil conditions, pressure, water quality and state of development. (The more branches and fittings there are, the more leaks that will occur.)

Cost of meter maintenance

Meters malfunction and have to be replaced without actually leaking due to grit and lime deposits. They can either stop altogether or slow down. Some authorities have adopted a regular meter replacement programme with periods varying from five to twelve years depending on local conditions, such as water quality.

To determine the actual saving in cost is far more complicated. Considering a city as a whole, and assuming that the metering system is accurate, the reduction in UAW from one year to the next can be valued and compared with the costs.

On the other hand, a value can be estimated for a specific leak repaired. The size of the leak can be measured but not the length of time it would have gone on discharging if it had not been found.

By making use of the recommended maximum acceptable unavoidable losses, for instance 2,5 $\ell\ min^{-1}\ km^{-1}$, and knowing the total length of pipeline, the maximum allowable loss flow for this pipeline can be determined. If the actual loss is above this figure a water loss control programme will be required. This actual flow can be obtained by making use of reservoirs and accurate bulkmeters.

METHODS OF APPLYING A LEAK DETECTION PROGRAMME

Local authorities usually prefer to conduct their own leak detection programmes once the decision to undertake such a programme has been made. Occasionally a private concern is contracted for leakage control in a section of the network, or for a survey of the large pipelines, while the local authority trains its own employees to continue the programme.

Personnel and equipment selection is very important to the success of the programme.

Accurate Documentation

The quality of the network documentation plays an important role in any leakage control programme.

Maps of the network must be accurate and up to date, showing all mains, intersections, valves, fire hydrants, connections and very important, stubs for future service extensions. If development of new areas is slow, it is often easier to lay new connections than to locate the original stubs and if these abandoned stubs later develop leaks a very perplexing detection problem may arise.

Obviously, if the network documentation is not as comprehensive as it should be then additional effort will be necessary. The knowledge and experience of operators can be invaluable when it comes to updating network maps.

Leakage detection

A lot of careful planning is necessary before embarking on a leak detection programme. Basically such a study involves delineating the water supply network into better manageable discrete zones or sections and sub-sections, from plans and field investigations. Ideally such a section would comprise not more than 2 km of mains serving some 200 consumers, but this would depend on the size of the town, availability of manpower, the urgency of the programme and the nature of the area.

All the valves and fittings, hydrants, taps, meters etc in the section have to be located, inspected and repaired, if necessary.

A series of 24 hour continuous flow measurements into and out of the section establishes the ratio of average daily consumption and the minimum night flow. As a rule higher ratios are usually indicative of a very good pipe network system. If the ratio should fall, problems exist and the leak control programme must be pursued. Typical ratios are established for each section based on local experience. Night flows generally reach a minimum between 02h00 and 04h00. By adopting this method of elimination, the extent of the detailed survey can be substantially reduced, but care must be taken as the existence of a number of large consumers in the section can make the ratio difficult to interpret correctly.

Once the sections of abnormally high flow have been identified, an intensive search for individual leaks can be undertaken, or the section can be further subdivided.

The section of the network under survey must be completely isolated, possibly necessitating the installation of additional isolating valves (boundary valves), and fed through a single feeder pipe separately metered with an accurate bypass meter.

Total leakage is determined by closing *all* of the stop-cocks to consumer premises and observing the meter on the feeder pipe. Losses of up to about five per cent of the average daily flow are considered "satisfactory". Above 20% serious problems exist and urgent action is required.

Location of individual leaks is invariably achieved using one or other sonic device. Water leaving a pipe at high pressure loses energy to the pipe wall and the balance is dissipated to the surrounding soil. The sound waves thus created are well within the audible range and can easily be picked up by means of electronic transducers. From this information a trained operator can determine not only the location of the leak but the relative size of the leak as well.

Sound waves generated in the pipe wall are in the 500 — 800 Hz range and can be transmitted a considerable distance from the point of leakage. Systematic testing of valves, hydrants etc is necessary to pinpoint the actual location of the leak.

Sound waves generated in the soil are in the 20 — 250 Hz range and are limited to the immediate area of the leak and are therefore important for pinpointing the leak for excavation and repair. In order to generate sufficient sound waves for detection a mains pressure of at least 100 kPa is necessary.

Often a method of proportionality, using direct contact microphones can be successfully utilised. If a leak can be isolated between two similar points on the same pipeline (e.g. two valves or two hydrants or exposed sections of pipe) then the ratio of the strengths of the signals picked up is proportional to the distance along the pipe from each microphone.

Operator experience also plays an important role as steel, PVC and asbestos cement pipe materials all generate and conduct sound waves differently. Sound waves are amplified at bends, at reducers and at fittings in the pipeline and if errors in pinpointing are to be avoided these locations must be known to the operator of the sounding devices. Depth of cover must also be known.

Alternative Methods

Other methods of leak detection (apart from the obvious method of observing surface wetness) involves the use of soluble tracer gases such as nitrous oxide. Because of expense and other practical problems this method is not often used. For most other tracer gases the pipeline has to be dewatered before the gases can be injected. Salt solutions or vegetable dyes have also been used.

A method developed in Sweden uses a differential liquid manometer connected to taps along the pipeline to measure friction gradients from which graphs on both sides of the leak are drawn.

Once the leak detection programme on a section of piping has been completed the stop valves to consumers can be systematically opened. In this manner leaks on consumer premises can also be identified and the householder informed.

A STUDY OF METHODS OF PREVENTION AND CONTROL

Investigations indicated that, in general, pipe materials were of a good quality and that SABS approved material should be used wherever possible.

Contract specifications for the installation of pipes were found to be satisfactory and there is not much room for improvement. However, it would be of considerable help if a standard specification could be drawn up for the country as a whole.

The standard of installation of pipes can definitely be improved upon, especially as far as bedding is concerned. Supervision by the contractor and the supervision authority must also be improved if there is to be a significant drop in the UAW.

In future network design, consideration should be given to the possibility of allowing for leak detection, once the network is operational. Due consideration should also be given to limiting working pressure in pipes to pressures in the order 270 — 400 kPa. This could possibly lead to larger pipe diameters being used in some instances.

The effectiveness of water loss control is not influenced by accurate meters or regular meter maintenance. Accurate meters do however assist in determining at what level the UAW is running.

Leak detection involves the tracing of leaks usually by means of sonic sounding devices. Water loss control incorporates other methods like waste detection meters and visual surveys as well as sounding and pinpointing of leaks. Therefore, a successful and effective programme will include the aforementioned methods of monitoring and control.

Pipe materials and construction methods

Existing pipe materials are of a high quality. This aspect does not, therefore, have any real economic implications. The same can be said of contract specifications.

It is not clear whether the cost of installation will increase if the standard of supervision is raised.

Water losses at various centres

The UAW was determined for various centres. Seeing that the UAW consists of four components, it is not clear what the actual economically reparable leaks amount to. If the general metering condition of a centre is satisfactory meter losses can amount to about 3%. Unavoidable losses in a well-maintained network will always amount to some 5%. Therefore, if a centre has a 15% UAW it can be argued that if the metering system is correct then the economic implication will be about 7% of the total supply. The unit value of this loss should be estimated somewhere between the purchase and sale price.

CONCLUSIONS

Meters

- New meters are generally accurate and conform to the standards laid down by the Division of Weights and Measures of the Department of Customs and Excise.
- The accuracy of meters after a number of years in use is not satisfactory.
- A regular maintenance programme based on local conditions, flows and water quality does much to improve meter accuracy.
- Bulkmeters in particular, must be serviced at regular intervals if their accurarcy is to be maintained. Consideration should be given to the use of meters which can be readily serviced or replaced.
- A high standard of meter accuracy does not reduce the actual losses in a network but gives an indication of what the losses amount to.
- Network metering and the determination of the UAW is not the most successful method of water loss control.

Pipes, materials and construction methods

- It is the duty of the design engineer to choose the most suitable pipe material for a specific task.
- Pipes and fittings should conform to the standards laid down by the SABS.
- New and alternative materials for pipes and fittings should be investigated and installed if more suitable than traditional materials.
- The specifications for the installation of pipes that were examined were found to be satisfactory.
- Handling, transportation and installation of pipes on the construction sites could be improved. This can be brought about by a higher standard of supervision by both the contractor and supervising authority.

Water losses at various centres

- It would appear that the UAW for some of the centres investigated is unrealistically low. Incorrect, under-registering bulkmeters could be responsible for this situation.
- In the determination of the UAW, it is essential that accurate bulkmeters be used.

Leak detection methods and devices

- There are various methods of leak detection and control with a combination of visual, sounding and waste detection meters being the most successful.
- The nitrous oxide method is not suitable for use in South Africa.
- A variety of sonic leak detection devices are available in South Africa or can be imported. The prices for these devices vary considerably.
- UAW and its components could be expressed in $\ell\ min^{-1}\ km^{-1}$ and is generally independent of the pipe diameter. This method of expressing UAW is suitable for individual networks as well as for a complete supply system.
- Sophisticated sonic water leak locating equipment, is essential for leak detection in central business districts.
- Leak detection is most successful when carried out during the quiet conditions prevailing at night.
- The UAW for new networks is considerably lower than for older networks.
- Actual losses that are economically reparable were found to be low probably because the test period was only three months.
- Unavoidable losses appear to be more serious than the actual losses. If these losses become too high, consideration must be given to the possible replacement of the pipe network as a whole. Unavoidable losses are acceptable if they do not exceed 5% of the total.
- Losses due to slow consumer meters appear to be extremely serious in some of the networks surveyed. Low per capita consumption can distort the meter losses. A regular maintenance programme will reduce losses considerably.
- Unmetered draw-offs can be ignored in the UAW equation, especially for built-up residential areas.
- A reduction in network pressures does result in a reduction of the UAW. By reducing the pressure for one test area from 1 000 kPa to 400 kPa the minimum night flow (MNF) was reduced from 11 200 ℓ/h to 4 800 ℓ/h.

Methods of leak prevention and control

- The quality of pipe materials in South Africa is generally high, especially if the material is in accordance with SABS requirements. The most suitable pipe material must be selected for given soil and other conditions.
- Specifications for the installation of pipe networks and fittings were generally found to be satisfactory. However, consideration should be given to the publication of a national standard specification for this purpose.
- The installation of pipework according to specifications should result in the virtual elimination of leaks.
- High standards of supervision are necessary for any construction project. To be able to maintain these high standards, only well qualified personnel should be in charge of operations.
- Due consideration should be given to the establishment of firms specializing in construction supervision. These firms could also assist in the training of personnel.
- The possibilities of incorporating leak detection control areas in the design of future networks, should be considered. Such areas would consist of a pipe length of between 5 and 15 km or 200 — 500 stands, whichever is most suitable.
- Regular meter maintenance does not decrease the actual water loss through leaks, it does however give an indication of what the UAW amounts to.
- The most suitable water loss control system involves the use of various methods of leak detection. Certain sections of a supply network will require more attention due to the age of the pipes, soil conditions and change in external loads applied to the pipes.

- Measurement and documentation of survey results are used as guides for future control work by comparing new measurements with previous figures.

- Benefits, both long and short term are obvious, but programmes must be commenced and sustained on a continuing basis and should be repeated at frequent intervals of one to five years depending on local conditions. Pipe materials, soil conditions, pressures and age all determine the frequency of surveys.

Economic implications

- Economic implications can only be determined if a prolonged water loss control programme is maintained.

- The economic benefit of a water loss control programme is the amount of water that is saved over and above the unavoidable losses.

- Accurate bulk as well as stand metering is essential if the economic implications of water saved or lost is to be determined for a supply system as a whole.

- An economic study can only be carried out on a properly designed, constructed and operated system.

Initial survey costs are high due to the preparatory work associated with it. Subsequent surveys cost very much less.

RECOMMENDATIONS

- All consumer connections should be metered.

- Meters must be maintained; especially bulkmeters which measure large volumes of water. The economic implications of a water loss control programme can only be determined when high meter accuracy is maintained.

- General specifications for the installation of pipes and fittings should be drawn up for the country as a whole. The training of technical personnel in this field should incorporate such specifications.

- Specialized construction supervision should be encouraged.

- Control of water losses from pipe networks should be improved in all centres in South Africa and a better understanding and knowledge of this problem should be developed by the various authorities and persons responsible.

- The possibility of establishing an organization specializing in the water loss control field should be considered. Such an organization could possibly create a psychological stimulus in this field which is sorely needed.

- A UAW of eight to ten per cent for a centre can be considered as acceptable. If this figure rises above 15% it becomes essential to initiate a water loss control programme.

- Unavoidable losses as well as losses resulting from leaks which are economically reparable, should be expressed in $\ell\ min^{-1}\ km^{-1}$. Values for unavoidable losses as indicated in Table 9 are recommended.

- High priority should be given to an investigation into allowable maximum and minimum pipe network pressures.

- Research is necessary in the field of water losses on private properties; control measures should be based on the results of such research.

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