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تحليل فاقد المياه ومؤشراته

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الملخص

يعتبر فاقد المياه هو المشكلة الرئيسية في نظام توزيع المياه. لقد زاد الاهتمام بهذه المشكلة في العقد الأخير. من خلال المقارنة، نجد ان نسبة الفاقد في الدول النامية أعلى نسبيا من الدول المتقدمة، ولكن الإثنتين تعانيان من نفس المشكلة. تحتاج شركات التزويد بالمياه ليس فقط الى خفض وإدارة الفاقد، بل الى طرق وتكنولوجيا معينة لزيادة الكفاءةأيضا. لذلك، فإن الهدف هو تقليل الفاقد الى الحد الأدنى في كل شبكات التوزيع. وتستخدم تقليديا عدة مؤشرات الأداء لمقارنة الفاقد مثل نسبة الكفاءة وغيرها كمؤشرات معروفة، ولكن توجد مؤشرات حقيقية عند المقارنة. في هذه الأيام، تستخدم مؤشرات دولية مثل ILI, ELL, NRW (انظر الاختصارات) ومن السهولة بمكان المقارنة بين الدول. لا بد من تحليل المؤشرات الإقتصادية والفنية لفقدان المياه. ومن أجل ذلك فإن هذا البحث يهدف لنقل وإثراء المعلومات والتكنولوجيا والخبرات بسبب نقص البحوث في ذلك المجال.

ABSTRACT

Water Losses Analysis and Its Indicators

The water loss is the main problem at water distribution system. Water losses cannot be completely avoided, but they can be managed so that they remain within the economic limits. It is increasing of interests during last decade. The water losses percentage is relatively high in developing countries, as compared to developed countries, but both have the same problem. Water suppliers have not only a need to reduce and manage their losses, but they also have the methods and technology to do so effectively. Therefore, water losses in all water supply firms should be minimized as a target in the water distribution networks. Traditionally, several different performance indictors to compare water losses, percentage of system input volume or metered water ratio, and per km of mains per day, appear to be the most common, but these are reliable indicators for comparing performance. Nowadays, the international water losses indicators are using like: ILI, ELL, NRW (see Abbreviations), which are easy to compare among different countries. The actual economic and technical indicators of water

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losses in water distribution system should be analyzed. This paper aims to transfer and enrich the knowledge, about the technology and experiences in this field because of the lack of researches.

Abbreviation:

ALC: Active Leakage Control
BABE: Background and Bursts Estimates
ELL: Economic Leakage Level
FAVAD: Fixed and Variable Area Discharges
ICI: Industrial, Commercial, and Institution
ILI: Infrastructure Leakage Index
IWA: International Water Association
NRW: Non-Revenue Water
UARL Unavoidable Annual Real Losses
UFW: Unaccounted for Water

Keywords: Water losses, real losses, apparent losses, water losses indictors, NRW (Non-Revenue Water)

1- Introduction:

The water loss is the main problem at water distribution system. It is increasing of interests during last decade. The water losses percentage is relatively high in developing countries compared to developed countries, but both have the same problem. **Economical Problems of Water:** The water losses percentage is relatively high, making losing potential revenue in such water supply firms.

2- Methodology:

- Analysing the actual economic and technical indicators of water losses in water distribution system.
- Analysis of the current theories and indicators of water losses, especially ILI and ELL;
- Updating the data and models of water loss and its indicators, as well as the case studies;
- Using the (micro) economic models to do analysis as concepts and tools in order to calculate ELL in Short-Run and Long-Run;
- Collecting and studying data from many references in water losses and economics from famous international water organization, and famous water journals;
- Reviewing the Latest research papers of pioneers of water losses.

3 - Water Loss in General:

Water loss occurs in all distribution systems, but the volume of loss varies. This depends on the characteristics of the pipe network and other local factors, the water company's operational practice, and the level of technology and expertise applied to controlling it. With the demands of growing populations, however, realization of the limits on our natural resources and increasing costs form regulations and customer demands have made it increasingly unrealistic to allow water loss to be ignored. It is now evident that the world's water suppliers have not only a need to reduce and manage their losses, but also have the methods and technology to do so effectively. Therefore, water losses in all water supply firms should be minimized as a target in the water distribution networks. Water losses cannot be completely avoided, but they can be managed so that they remain within economic limits. The problems associated with water loss are numerous. High real losses indirectly require water suppliers to extract, treat, and transport greater volumes of water than their customer demand requires. Leaks, bursts, and overflows often cause considerable damage and inflate liability for the supplier. It is evident that reducing water loss would not only improve water supply operations, but would also result in increased revenue. Sound water loss management, therefore, usually generates a direct and rapid payback to water utility. For the vast majority of water distribution systems, leakage is something which can not be eliminated completely. There will always be a level of leakage which has to be tolerated, and which has to be managed (*Farley and Trow, 2003, Trow and Farley, 2001).*

Traditionally, several different performance indictors to compare water losses, percentage of system input volume or metered water ratio, and per km of mains per day, appear to be the most common. However, these are reliable indicators for comparing performance. Some countries use "per property per day", or "per service connection per day", or "per kilometer of system (main plus services length) per day". The IWA Task Force on Water Losses, with nominated representation from the American Water Works Association, has been considering best practice internationally, and their conclusions strongly suggest that there are more reliable and meaningful performance indicators than percentage of system input and per km of mains. *(Trow and Farley, 2001)*

3.1 Types of Water Losses:

The International Water Association (IWA) defines two major categories under which all types of supplier water loss occurrences fall:

1. **Real Losses**: It is the physical escape of water from the distribution system including leakage and overflows prior to the point of end use. i.e. Water lost for the distribution system through leaks, tank overflows, or improperly open drains or system blow-offs.
2. **Apparent Losses:** which occur at the customer destination, penalize the water supplier at the retail cost- a rate usually much higher than production cost. Water that reached a customer or other end use (including beneficial and unauthorized use) but is not properly measured or tabulated. It is essentially "paper" losses and consist of customer use, which is not recorded due to metering error, incorrect assumptions of unmeasured use, or unauthorized consumption.

$$\text{Water loss} = \text{water produced} - \text{water consumed} \qquad (1)$$

3.2 The Occurrence and Impact of Lost Water

Apparent losses do not carry the physical impact that real losses impart. Instead, they exert a significant financial effect on suppliers and customers. The economic of apparent losses is often relatively much greater than real losses, since the marginal costs of apparent losses occur at the retail rate charged to customers, while the baseline marginal cost of real losses is the production cost. Apparent losses occur at the "cash register" of the water utility and directly affect the water supplier's revenue stream, yet many systems have such unstructured water accounting and billing practices that they cannot even show that such loss is occurring. Therefore, sound water loss management, usually generates a direct and rapid payback to water utility *(Trow and Farley, 2001)*

3.3 The Actions to Reduce Water Losses :

Water audits and loss control programs will only be successful if the operator and the utility are willing to accept what they find and act on it. Therefore, it is critical that system operators understand the extent and impact of water loss, and that the control of water loss be considered of paramount importance throughout the entire organization. Due to number of dramatic changes in the water supply business model worldwide. The need for a new breed of water system operator has been created by pressure from stakeholder groups who will no longer tolerate abuse and inefficient use of natural water resources. These include the environmental community, which has been successful in raising grass-roots consciousness to the level of environmental regulation at the national and international levels. Consumer advocates now carefully monitor the value of service per unit cost paid by the customer, expecting the utility to provide quality service at reasonable cost. Competitive forces have also increases, focusing utilities on improving both technical and business efficiency. The awesome power of the Internet, the media, and other communication forums has helped to accelerate all of these forces, which are mandating that water loss not be tolerated or overlooked as it has been in the past.

British water companies were privatized and reorganized along watershed boundaries in 1989. They also fell under a heavy regulatory burden at that time, which focused on effectiveness and the imparting of company operations and cost to the customer. The ability of water companies to pass costs along to customers is greatly limited by this structure, which ties approval for increased rates or tariffs to company performance. Consequently, innovation was accelerated as companies sought to improve performance, cut costs, and increase profits, *(Cihakova et al, 2001, Farely, 2001, Thornton, 2002).*

3.4 Program Requirements for Water Loss Control and IWA International Standard

A complete loss control program is often referred to as a water loss optimization program. Optimizing basically means doing everything possible to improve the technical and financial performance of the water system, whether it is a public, private, or demand-side system. Optimization usually entails reduction of operating overhead and enhancement of revenue streams. Table (1) shows a typical optimization graph. In this case, it can be seen that the profitability in the beginning is low, as the cost of the water loss project is being borne on a performance basis.

Table (1): IWA standard international water balance & terminology (Lambert et al, 2001a)

<table>
<tr><td rowspan="9">System input volume (SIV)</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed authorized consumption</td><td>Billed metered consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed un-metered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption</td><td>Unbilled metered consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled un-metered consumption</td></tr>
<tr><td rowspan="5">Water losses</td><td rowspan="2">Apparent losses</td><td>Unauthorized consumption</td></tr>
<tr><td>Customer metering inaccuracies</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakage on transmission and/or distribution mains</td></tr>
<tr><td>Leakage and overflow at utility’s storage tanks</td></tr>
<tr><td>Leakage on service connections up to point of customs metering</td></tr>
</table>

Water loss optimization programs may be implemented in four phases:

1. Water audit and analysis using performance indictors,
2. Pilot study to demonstrate initial recommendations of the water audit analysis in the field,
3. Global Intervention,
4. Ongoing maintenance of the loss control mechanism.

Water loss optimization is usually a highly cost-efficient endeavour, since so many water supply systems currently suffer excessive water loss. The greatest challenge for today's progressive water manager is to change dated mindsets that view water as infinite and inexpensive. Once policy and decision makers understand the true value of water, implementing intervention techniques can be a relatively straightforward undertaking. *(Thornton, 2002)*

3.5 IWA International Standard of Water Balance and Losses

Table (1) explains briefly about components, particularly of water losses and NRW, which consists of unbilled authorized consumption, and water losses. Apparent losses can range from almost zero to 10% of system input volume. Widespread international use of the IWA standard water balance is being encouraged, as the first step in calculation the IWA "best practice" performance indicators. The IWA standard water balance is gaining rapid acceptance, and has already been adopted or promoted. It usually relatively easy to re-allocate the components of any 'national' or 'local' water balance into IWA standard approach, before calculating the annual volumes of losses and the 'best practice' performance indictors.

NRW = Unbilled Authorised + Water Losses (2)

Water Losses = System Input Vol. - Authorised Cons. (3)

Water Losses = Apparent Losses + Real Losses (4)

Apparent Losses = Unauthorized Cons.+ Metering Inaccuracies (5)

Because of widely varying interpretations of the term 'Unaccounted for Water' (UFW) worldwide, the IWA Task Forces do not recommend use of this term. If the term UFW is used, it should be defined and calculated in the same way as 'Non-Revenue Water' in Table (1) (*Lambert et al., 2001c*).

3.6 Assessment and Management of Unbilled Authorised Consumption

Authorised Consumption, in the IWA terminology, includes items such as fire fighting and training, flushing of mains and sewers, cleaning of suppliers' storage tanks, filling of water tankers, water taken from hydrants, street cleaning, watering of municipal gardens, public fountains, frost protection, building water etc. These may be billed or unbilled, metered or unmetered, according to local practice. Unbilled Authorised Consumption is normally only a small component of the water balance. Wherever feasible, such volumes should be metered. In other situations, simple but effective methods of documenting and estimating such uses are strongly recommended; they often show that volumes of Unbilled Authorised Consumption are unnecessarily high, and can be managed down to lower annual volumes without influencing operational efficiency or customer service standards *(Lambert et al., 2001a and c, Trow and Farley,2001).*

3.7 Assessment and Management of Apparent Losses

Apparent Losses consist of Unauthorised Consumption (theft and illegal use) and Metering Errors. Calculations of these volumes are preferably based on structured sampling tests, or estimated by a robust local procedure (which should be defined for audit purposes). Some quoted figures for Apparent Losses in the Country Reports (as % of System Input Volume, SIV) are: in Malaysia, Apparent losses 9% of SIV and in Australia, Apparent losses 1% to 3% of SIV *(Lambert et al., 2001c).*

3.7.1 Why Apparent Losses Occur?

Apparent losses of water can be perceived as occurring in three primary ways:

1. Errors in water flow measurement
2. Errors in water accounting
3. unauthorized usage

Many water suppliers have chosen to incorporate customer water meters at the end-user premises and gather regular meter reading for the purpose of billing per unit volume of actual water used. Customer meters also allow users to monitor their own water usage and provide customers the option to exercise restraint against excessive use and identify waste. Outwardly, this approach seems to follow the norms of typical free-market commodities: charges are based on the volume of product or service delivered. In England and Wales, traditionally only the industrial, commercial, and institution (ICI) population was metered *(Thornton, 2002).*

3.7.2 Assessment and Management of Unauthorised Consumption

Unauthorised Consumption occurs to a greater or lesser extent in most systems worldwide – the England & Wales estimate is 0.36% of System Input Volume. The Australian, Moroccan and USA National Reports specifically mention this component of Apparent Losses, which is generally associated with misuse of Fire Hydrants and Fire Service connections, and illegal connections *(Lambert et al 2001c).*

3.8 Assessment Real Losses

3.8.1 Why Real Losses Occur?

Apparent losses include no physical impropriety, as the water has reached the destination of an end user: but this successful supply function lacks either a full and accurate accounting and revenue capture, or the use of the water was unauthorized. Leakage is the most common form of real losses for water suppliers, and occurs for a number of reasons, including:

- Poor installation and workmanship
- Poor materials
- Mishandling of materials prior to installation
- Incorrect back-fill
- Pressure transients
- Pressure fluctuations
- Excess pressure
- Corrosion
- Vibration and traffic loading
- Environmental conditions such as cold
- Lack of proper scheduled maintenance

Real losses (largely leakage losses) typically account for the greatest volume of water "lost" by suppliers, although not necessarily at the greatest cost. Considerable research work has been conducted in the past decade on the nature and impact of leakage, and highly effective practices and technologies have been implemented around the world. It is in the interest of all water suppliers to evaluate closely the leakage occurring in their systems and to take advantage of these methods, which may be considered best practice in controlling leakage losses *(Thornton, 2002).*

3.8.2 Assessing Real Losses from Water Balance

This is the most basic and widely used method. The volume of Real Losses (Table 1) is assessed as the component remaining after Authorised Consumption and Apparent Losses volumes have been calculated, and deducted from System Input Volume. Volumes of Real Losses calculated from a 'Top-Down' Water Balance are always subject to some calculation error, because of errors in the individual components. Some of the most recent international applications of the IWA Standard Water Balance include the facility to calculate the 95% confidence limits for the assessed volume of Real Losses, given 95% confidence limits for the other volumes entered in the water balance.

The disadvantages for relying only on Water Balance for assessment of Real Losses are:

- Water Balance gives no indication of the individual components of Real Losses, or how they are influenced by Utility policies.
- Water Balance normally covers a 12-month retrospective period, so it has limited value as an 'early warning' system for the occurrence of new unreported leaks and bursts.

For these reasons, Real Losses should preferably also be assessed by additional methods, namely:

A- Component Analysis of Real Losses (see section 3.8.3)

B- Analysis of night flows *(Lambert et al 2001c).*

3.8.3 Component Analysis of Real Losses

The general principle of assessing some components of Real Losses from repair statistics is well known. Annual numbers of repairs are assumed to represent the annual number of new leaks and bursts; these are then classified into different categories, with different typical flow rates. If average duration of each category of leak or burst is logically assessed, then the annual volume lost from different categories can be assessed. In 1993, an internationally applicable overview concept known as 'Background and Bursts Estimates' (BABE) was developed from this basic building block, for calculating components of Real Losses based on the parameters which influence them *(Lambert et al 2001c).*

3.8.4 Modelling components of real Losses using Breaks and Background Estimates (BABE) Concepts

In BABE analyses, components of Real Losses are considered to consist of:

- Background leakage at joints and fittings, flow rates too low for sonic detection if non-visible
- Reported leaks and bursts – typically high flow rates but short duration
- Unreported leaks and bursts – moderate flow rates, average duration depends on method of active leakage control.

By considering average duration of detectable leaks and bursts to consist of three components– *Awareness, Location and Repair time*– these concepts can be used to model any Utility policies and standards of service. Typical burst flow rates are specified at a standard pressure, and adjusted to actual pressure using appropriate assumptions for FAVAD N1 (Fixed and Variable Area Discharges) values. The typical parameters which would be assumed to influence components of Annual Real Losses in different parts of the Infrastructure. *(Lambert et al., 2001, Thornton, 2002).* The BABE annual model was first calibrated and tested successfully analysis to assess the economic frequency of Active Leakage Control (ALC) intervention, and since then has been used in many countries *(Thornton, 2002).*

3.9 Analysis of Night Flows

Night flow measurements are used to calculate leakage in the distribution system (distribution mains, service connections and fittings), after subtracting customer night leakage. To convert night leakage rates to daily average leakage, the night leakage rates must then be multiplied by an 'hour-day factors' which allows for the variation of average pressure over from midnight to midnight *(OFWAT, 2002a).* Night flows measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of unreported leaks and bursts. However, continuous night flows can also be used for assessing Annual Average Real Losses. Night flows in individual Sectors must be measured continuously throughout the year. Customer night consumption must be assessed and deducted, and the average night leakage (in m^3/hour) must be multiplied by a 'Night-Day Factor', which depends upon the 24-hour variation of average pressure in the sectors *(Lambert et al 2001c).*

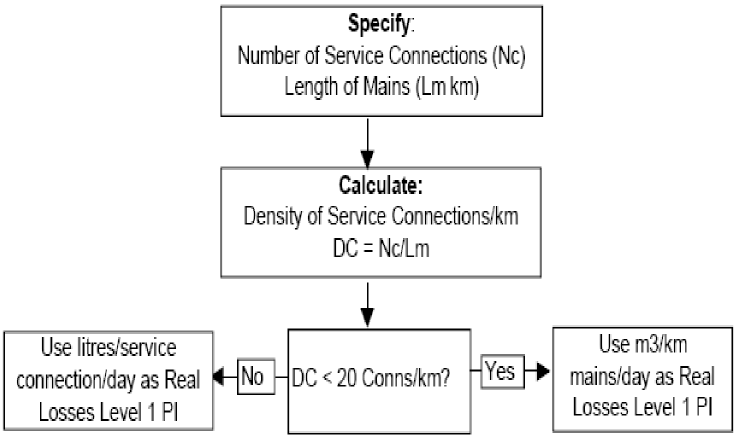
3.10 Where do the Largest Components of Real Losses Occur?

Analyses of components of Real Losses assist in identifying where the largest components occur in any individual system, and how these components are influenced by Utility policies. The large number of joints and fittings on service connections between the main and the edge of the street result in a relatively high value for background leakage in this part of the infrastructure. Although average burst flow rates are higher for mains than for service connections, when typical proportions of unreported bursts, and average durations of different types of bursts, are taken into account, it is evident that in most systems the largest volume of Annual Real Losses generally occurs on service connections. This accords with most operational experience world-wide (*Lambert et al 2001c).*

3.11 The Best Practice Basic Performance Indicator for Operational Management of Real Losses

Figure (1) shows this selection process for IWA PI Op24 in the form of a decision diagram. As most distribution systems have density of connections more than 20 per km of mains, 'per service connection' should logically become the predominant basic operational PI for Real Losses in future.

Figure (1): Process to determine Level 1 PI for Operational Management of Real Losses *(Lambert et al 2001c).*



In the case of systems subject to intermittent supply, Op24 is expressed as 'litres/service connection/day when the system is pressurised'. The annual volume of Real Losses is divided by the equivalent number of days that the system is pressurised, rather than by 365 days *(Lambert et al 2001c).*

4- Water Losses Analysis

Traditionally, several different performance indictors to compare water losses, percentage of system input volume or metered water ratio, and per mile of mains per day, appear to be the most common. But are these reliable indicators for comparing performance? Why do some countries use "per property per day", or "per service connection per day", or "per kilometer of system (main plus services length) per day"? The IWA Task Force on Water Losses, with nominated representation from the American Water Works Association, has been considering best practice internationally, and their conclusions strongly suggest that there are more reliable and meaningful performance indicators than percentage of system input and per km of mains *(Thornton, 2002).*

4.1 Comparisons Water Losses Indicators

4.1.1 Performance Indicators and Target Setting

There are many possible performance indicators (PIs), but some are better than others, and many are unsuitable for some purposes, IWA reports. When monitoring night flows to identify the presence of unreported leaks, the measurement is usually taken in litres/second or m^3/hour. The night flow rates would traditionally be converted to one of the following measures and compared:

- Percentage of average daily flow (some US suppliers, French International practice)
- M^3/km of mains/hours (typical of current German and Japan practice)
- Litres/property/hour (typical of recent UK practice)
- Litres/service connection/hour.

The fact that theses simple measures are based on use of some convenient easily identifiable parameter, however, does not necessarily mean that parameter forms a suitable basis for making decisions on when to intervene to look for unreported leak *(Bundschuh, 2000, Fareley, 2001).*

4.1.2 Non-Revenue Water (NRW): Financial Performance Indicators

Performance Indicators for water supply services: IWA Manual of Best Practice contains 133 different performance indicators for different function. The IWA 'best practice' level 1 performance indicator for non-revenue water (NRW) is: "Volume of non-revenue water as percentage of system input volume. NRW (or UFW) has, for many years, been quoted only or principally in % terms *(Bundschuh, 2000).* International date for percentages of NRW by volume typically show the percentage of NRW varying from less than 5% to over 50%. There are many reasons for this wide range of variation, other than simply management efficiency and infrastructure condition:

- Economic NRW management policies depend upon the cost and availability of water
- High consumption decreases % NRW, and low consumption increases % NRW
- Intermittent supply reduces the length of time the system is pressurized and leaking, but is not good practice as it reduce infrastructure life
- Apparent losses are influenced by type of meters, and weather customers are supplied by direct pressure or via roof tanks
- Average operation pressure vary from less than 20 m to over 100 m, and average real losses vary approximately linearly with pressure for leakage systems with mixed pipe materials
- Some systems include transmission mains and services reservoir real losses, others do not
- Real losses may include leakage on customers private pipes, depending on ownership and maintenance responsibility for different sections of the service connection, and customer meter location *(Farley, 2001).*

Countries with relatively low consumption can appear to have high losses when expressed in percentage term. In contrast, percentage losses for urban areas in developed countries with high consumption can be equally misleading. When consumption decreases, the percentage of real losses increases even if the volume of real losses even remains unchanged. When consumption increases, the opposite effect occurs.

4.2 The Four Basic Methods of Managing Real Losses

In figure (2), suppose that the area of the large rectangle represents the Current Annual Real Losses **(CARL)**, in m^3/year, for any specific system. CARL volume is constrained by four leakage management activities shown. As the system ages, there is a tendency for a natural rate of rise of real losses through new leaks and bursts, some of which will not be reported to the utility. This tendency is controlled and managed by some combination of the four primary components of Real Losses Management, namely:

A- Pipeline and Assets Management
B- Pressure Management (which may mean increases or decreases of pressure)
C- Speed and quality of repairs
D- Active Leakage Control, to locate unreported leaks.

The lowest technically achievable annual volume of real losses for well-maintained and well-managed system is the UARL, represented by the smaller rectangle.

Primarily long-term pipeline management influences the number of new leaks arising each year. Pressure management can influence the frequency of new leaks, and the flow rates of all leak and bursts. The average duration of the leaks is limited by the speed and quality of repairs, and the Active Leakage Control (ALC) strategy controls how long unreported leaks run for before they are located. The extent to which each of these four activities is carried out will determine whether the volume of annual real losses increases, decreases or remains constant.

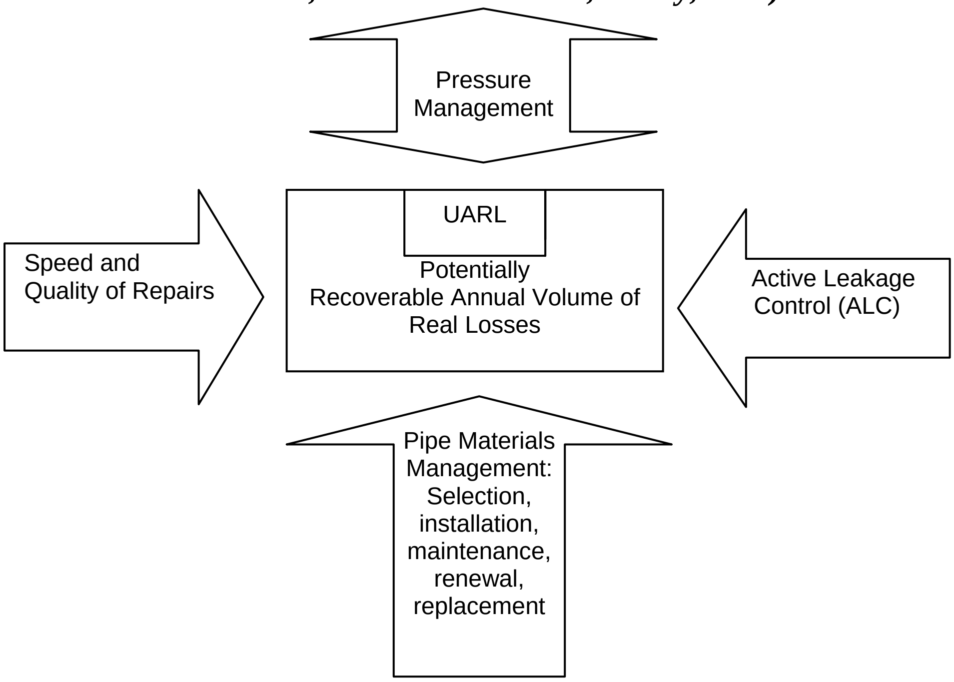
The ‘unreported’ events will need to be identified by some method of active leakage control. Therefore, in the simplest terms, ALC represents the management of the duration of unreported leaks. There are several different methods of Active Leakage Control, and many different levels of activity for each method. Selection of the most appropriate method and level of activity for an individual supply system becomes a matter of efficiency and economics, given that the numbers of new unreported leaks and bursts from one year to the next is unlikely to vary greatly in the short term.

This type of analysis can be assisted by considering the average duration of particular types of leaks to consist of 3 components :

• ‘**Awareness’** from the start of the event to the time the Utility is aware that a new leak exists.
• **‘Location’**, the time taken to locate the event once the Utility is aware of it

• **'Repair'**, the time taken to repair or shut-off the leak or burst once it has been located.

Figure (2): The Four Basic Methods of Managing Real Losses. ***(Lambert et al 2001b, Lambert et al 2001c, Farley, 2001).***



Using the above approach, the average duration of any type of unreported leakage event can be assessed, and related to any particular Active Leakage Control policy, level of activity, or standards of service. Once leaks are located – whether they are reported or unreported events – the 'Repair' element of the overall duration should be monitored against realistic target times. Methods for assessing the economic level of specific active leakage control methods are mentioned in the Norwegian, UK and Taiwan National Report. Some of these methods require knowledge of the numbers of new unreported leaks each year – which can only be truly known once intensive active leakage control, has been implemented for several years *(Lambert et al 2001c).*

Real Losses cannot be eliminated totally. The lowest technically achievable annual volume of Real Losses for well-maintained and well-managed systems is the Unavoidable Annual Real Losses (UARL), represented by the smaller rectangle in figure (2) System-specific values of UARL can be calculated using the component-based methodology developed by the Water Losses Task Force. The difference between the

UARL (small rectangle) and the Current Annual Real Losses (CARL) (the large square) is the potentially recoverable Real Losses. The ratio of the CARL to the UARL is the Infrastructure Leakage Index (ILI). CARL is always tending to increase, as the distribution networks grow older. This increase however can be constrained by an appropriate combination of the four components of a successful leakage management policy.

ILI = CARL / UARL (6)

The ILI measures how effectively the infrastructure activities in Figure (2) - *repairs, active leakage control and Pipeline/Assets Management* – are being managed at current operating pressure. To obtain Potentially Recoverable of Real Losses (PRPL) is by using the following equation:

PRPL = CARL – UARL (7)

(*OFwat,2002c*) has another name of CARL, which calls Technical Indicator for Real Losses (TIRL)

TIRL = l/service connection/day (when the system is pressurized)

UARL (measured in l/service connection/day) represents what could be achieved at current operating pressures assuming the following:

- No financial or economic constraints,
- Good infrastructure,
- Intensive state of the art active leakage control (ALC),
- All detectable leaks and bursts are repaired quickly and effectively.

Therefore, UARL does not directly address the scope for reductions in leakage due to pressure control. It is similar in concept to the lowest technically possible policy minimum level of leakage. The UARL calculation takes the existing pressure as given. This is not necessarily the optimum pressure and consequently there is a danger of underestimating potential leakage reductions. For each of the four activities, there is some economic level of investment and activity, which needs to be calculated or assessed, depending upon the marginal value, in local currency/m^3, placed on the Real Losses. Depending upon local circumstances and practice, the marginal value placed on Real Losses may be low – perhaps power and chemicals cost only – or high, and this profoundly influences the economic management policies for controlling Real Losses *(Lambert et al 2001c, Liemberger, 2002, OFWAT, 2002b, Trow et al)*

4.3 Unavoidable Annual Real Losses (UARL)

4.3.1 Calculation UARL

$UARL_{total}$ calculates by adding background leakage, reported bursts and unreported burst. The following components of UARL in Table (2).

UARL is useful concept as it can be used to predict, with reasonable reliability, the lowest technically achievable annual real losses for any combination of mains length, number of connection, customer meter location and average operating pressure- assuming that the system is in good condition with high standards for management of real losses.

Table (2): Components of UARL *(Lambert et al, 2001c)*

Infrastructure Component	Background Leakage	Reported Bursts	Unreported Bursts	UARL Total	Units
Main					Liters/km mains/day
Service Connection					Liters/Connection/day
Underground pipes					Liters/km u.g. pipe/day

In the above table, we put the data and figures. Then, we do calculating the $UARL_{total}$ by adding each figure, according to the type of infrastructure component.

$UARL_{total}$ =Background Leakage+ Reported Bursts+ Unreported Bursts (8)

The following components of UARL are:

On mains: 18 litres/km mains/day/metre of pressure

Plus On service connections: 0.8litres/service connection/day/metre of pressure

Plus On service connections 25 litres/km/day/m of pressure

UARL is calculated as:

UARL (liters/day) = $(18 \times L_m + 0.8 \times N_c + 25 \times L_p) \times P$ (9)

Where:

L_m = mains length (km)

N_c = number of service connections

L_p = length of unmetered supply pipe in km

P = average operating pressure (m)

The UARL calculation has an accuracy of ±20%, which, it is claimed, is well within the likely range of error in assessing real losses from water balances on systems with low leakage *(OFWAT, 2002b)*.

UARL is a useful concept as it can be used to predict, with reasonable reliability, the lowest technically annual real losses for any combination of mains length, number of connections, customer meter location and average operating pressure – assuming that the system is in good condition with high standards for management of Real Losses *(Lambert et al, 2001)*.

4.3.2 Analysis of UARL

Lambert explains about calculation of UARL as the following equations:

UARL (litres/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P (10)

or

UARL (litres/service conn./day) = (18/DC + 0.8 + 25x Lp/Nc) x P (11)

or

UARL (l/service/day/m pressure) = (18/DC + 0.8 + 25 x Lp/Nc) (12)
or
UARL (litres/km mains/day) = (18 + 0.8 x DC+ 25 x Lp/Lm) x P (13)
or
UARL(litres/km mains/day/m pressure= (18 + 0.8 x DC)+ 25 x Lp/Lm) (14)
Where is:
Lm = mains length (km);
NC = number of service connections;
Lp = total length of private pipe, property line to customer meter (km);
P = average pressure (meters);
DC = density of connections/km mains *(Lambert et al, 2000).*

5- Economic Aspects and Economic Indicators of Water Losses

In recent years, there has been substantial technical progress in methodologies to calculate economic levels of pipe materials investment, pressure management, active leakage control and speed and quality of repairs. However, the application of these methodologies has been limited by the problem as to how an appropriate valuations on Real Losses in different circumstances. In many cases, unless the water is purchased as a bulk supply, or supplies are limited, Real Losses have been valued, only at the short-run marginal cost of production (power & chemicals). This situation is changing. As natural water resources become scarcer, higher values will be placed upon source waters, leading inevitably to greater investment in management of Real Losses. Selection of the most appropriate combination of management techniques for individual situations will be a considerable challenge to the International Water Industry *(Lambert et al, 2001c)*

5.1 Non-Revenue Water: Financial Performance Indicators

We have discussed the mentioned indicator (See section 4.1.2).

5.2 Economic Aspects of Water Losses

5.2.1 Diminishing Returns

In an ideal world, every water supplier would like to eliminate leakage from water distribution systems. Leakage will add to the cost of producing and distributing water. It will add to the capacity requirement for storage systems, treatment works, and main sizing. For the vast majority of water distribution systems, leakage is something which can not be eliminated completely. There will always be a level of leakage which has to be tolerated, and which has to be managed.

When considering alternative ways of bridging the gap between the future need for water into an area, and the current availability of water, there are usually two principal methods:

- Supply augmentation. This may mean adding reservoir or pumping capacity;
- Reducing the future need for water by leakage reduction and demand management.

Each of these methods will increase the forecast 'headroom' i.e. the difference between the available supply and the projected demand, and therefore reduce the risk that supplies will become insufficient to meet customer demand *(Farley et al, 2003).*

Figure (3): Diminishing returns from leakage management measures *(Farley et al, 2003)*

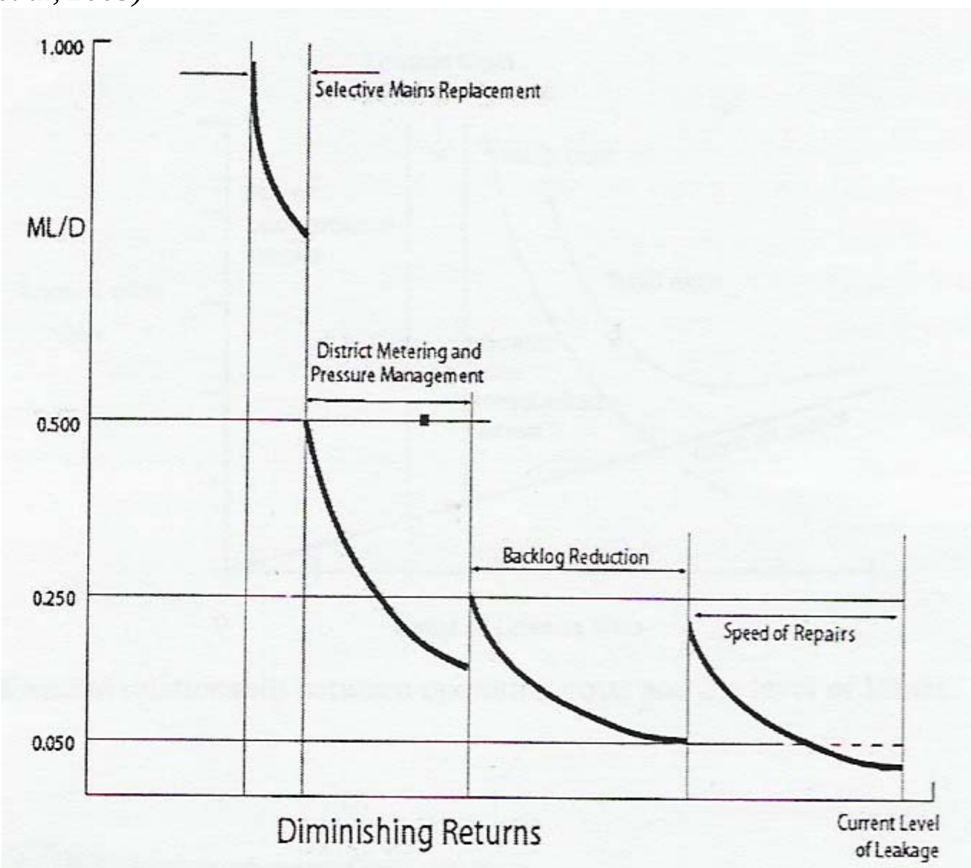


Figure (3) shows how each leakage management option can be implement at a relatively low unit cost per Ml/d, but the unit cost increases the more each measure is used. The diagram show a typical relative order for using each measure, but this order may vary depending on local circumstances. Although each option is illustrated with a set start and end level leakage, in practice there will be some degree of overlap, where a mixture of measures is used at any level of leakage to make further reductions, *(Farley et al, 2003, Trow and Farely, 2001).*

6- Water Losses Indicators

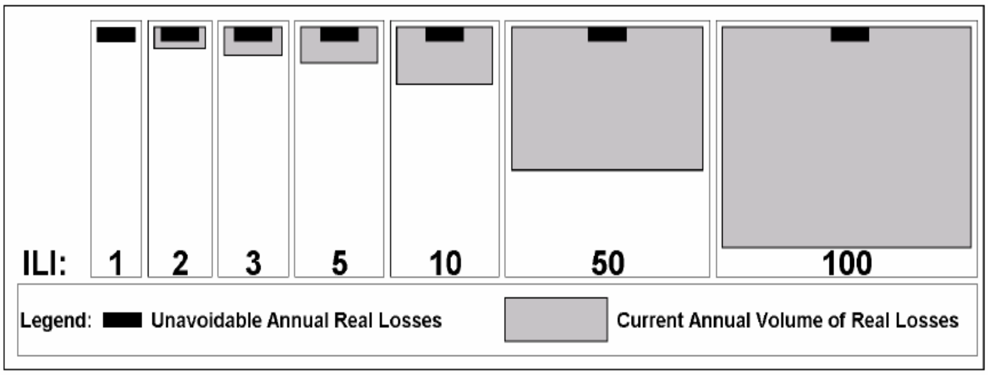
6.1 The Infrastructure Leakage Index (ILI)

The Infrastructure Leakage Index (ILI) is a measure of how well the system is being managed for the control of real losses, at the current operating pressure. and how effectively the three infrastructure activities - *speed and quality of repairs, active leakage control (ALC) and pipe materials*- are being managed, at the current operating pressure.

The ILI is a new, and potentially very useful performance indicator. Being a ratio, it has no units, so it facilitates comparisons between countries that use different measurement units (metric, US). An Infrastructure Leakage Index (ILI) close to 1.0 represents near-prefect technical management of real losses from infrastructure, at actual operating pressures, and demonstrates that all aspects of a successful leakage management policy are being implemented by a water utility. However, typically it will only be economical to achieve an ILI close to 1.0 if water is very expensive, scarce, or both. Economic value of ILI depends on the system-specific marginal cost of real losses, and typically lies in range 1.5-2.5 for most systems *(Cabrera et al, 2001, Lambert et al., 2001a, Lambert et al, 2001c, Thornton, 2002).*

Figure (4) below tries to visualise ILIs from 1 to 100 - maybe a possible way to demonstrate long-term improvement or targets to media and politicians. The ILI is a purely technical performance indicator and does not take economic considerations into account. In the beginning of international data collection for developing the ILI methodology, it was a common understanding that an ILI of 5 would be already very ‘poor’ performance. Meanwhile the ILI methodology was tested around the world, and ILIs of more than 30 do not come as a surprise anymore. Taking this into consideration, a utility with an ILI of 5 would be shown to have quite good performance in a truly international competition *(Liemberger, 2002).*

Figure (4): Graphical Visualisation of ILI from 1 to 100 ***(Liemberger, 2002)***



6.2 Economic Leakage Level (ELL)

For any water distribution system is a level of leakage below which is it not cost effective to make further investment, or use additional resources, to drive leakage down further. In other words, the value of the water saved is less than the cost of making the further reduction. This point is known as the economic leakage level (Farley et al, 2003). Leakage targets based on ELL must therefore be specific and dynamic.

6.2.1 Definition of ELL

In 1994, defined the ELL as "that level of leakage where the marginal cost of active leakage control **equals** the marginal cost of the leaking water". In other words, when the cost of reducing leakage by one cubic meter **equals** the value of that same or equivalent cubic meter of water(Farley et al, 2003).

$$mc\ (ALC) = mc\ (leaking) \qquad (15)$$

where:
mc : marginal cost
ALC : Active Leakage Control

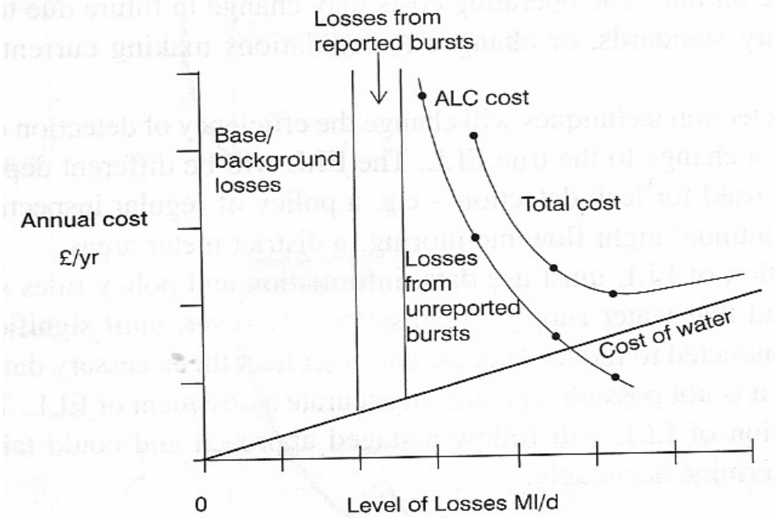
$$\text{Cost } 1m^3 \text{ reducing leakage} = \text{value (cost or price) } 1m^3 \qquad (16)$$

Notice: in equation (16) value means cost of water related to Water Company or price of water for a customer (or consumer).

Later, the definition of (ELL): The level of leakage at which it would cost more to make further reductions in leakage than to produce the water from another source. Operating at ELL means the total cost to the customer of supplying water is minimized and companies are operating efficiently. In determining this, it is important to include consideration of environmental and social costs as well as other costs *(OFWAT, 2004, OFWAT, 2003, OFWAT, 2002 a-c, OFWAT, 2001 a- d).*

Figure (5) shows the generalized relationship between expenditure on leakage management operations, and the unit production costs of water as a function of the level of losses. In order to understand the estimation of ELL, it is necessary to appreciate how water is valued. This will vary from one region to another, and also within areas of the same region *(Trow and Farley,2001).* For more detail, see the second research "Calculating ELL (Economic Leakage Level) in Short-Run and Long-Run as an Indicator of Water Losses".

Figure (5): General relationship between operating costs and the level of losses *(Farley and Trow, 2003).*



6.3 Economic Leakage Index (ELI)

6.3.1 Calculation of ELI (ELI - Economical Leakage Index)

What is the most important for the operator of the water systems is to determine the economically acceptable values of water losses indicators. These are values the further reduction of which is not economically efficient for the operator. The Economical Leakage Index (ELI) values can be determined using the following simple relation.

ELI = EI. LI (17)

Where is:

EI - **Economical Index**: can reach the following values:

(1,5) - water in the audited system is treated in a two-stage process and pumped to a minimum height of 50 m of water column.

(1) - water in the audited system is treated in a two-stage process but it is conveyed to the system by gravity, the water for the audited system requires only disinfecting, i.e. simple treatment, but it must be pumped into the system

(0,5) - water in the audited system requires only disinfecting i.e. simple treatment and it is conveyed to the system by gravity.

(LI) – Losses Index

From the equation (18), (LI) Losses Index is based on the following relation

$$LI = \frac{JUVNF}{3600} \qquad (18)$$

Where:

The JUVNF valued is calculated according to the relation (equ. 17).

The JUVNF = 3600 [m^3/km/year] value represents the recommended value of the unit leakage indicator for networks that are in a very good technical condition *(Tuhovcak, 2005).*

6.3.2 Evaluation of ELI

For evaluating water losses using the ELI indicator, the following simple methodology was prepared;

If **ELI > 1,3** it is a pressure zone where the water losses cause significant economic operating losses and where it is desirable that the operator should focus intensively on their reduction.

0,8 <ELI<1,3 it is a pressure zone where the present water losses do not cause any major economic operating costs

ELI < 0,8 it is a pressure zone where the water losses are adequate in technical and economic terms and execution of further measures focusing on losses reduction would not be economically efficient (Tuhovcak, 2005).

6.4 Economic Network Efficiency (ENE)

To calculate (ENE) indicator, there are 4 steps as following:

Step 1: Determination of the Current Annual Real Losses (CARL)

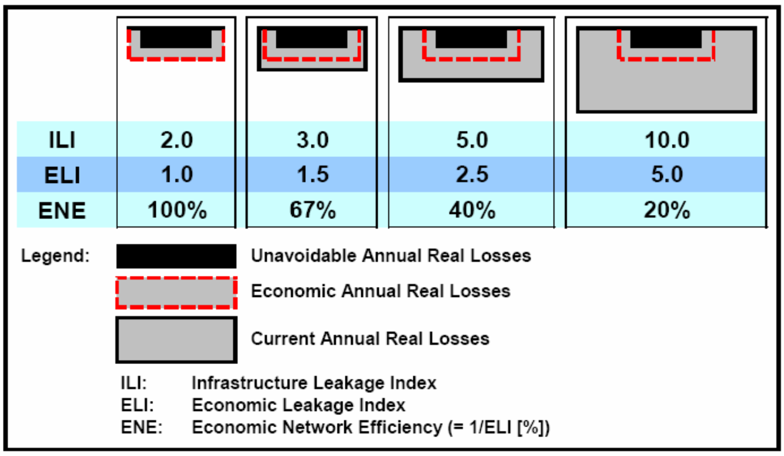
Step 2: Establishment of the Economic Level of Leakage (ELL);

It is well understood that this is a very complex issue and further research is needed to develop a simple 'cookbook' procedure and software

Note: ELL means Economic Annual Real Losses

Step 3: Calculation of the ELI, the Economic Leakage Index, similar to the ILI but replacing UARL by the Economic Annual Real Losses (EARL)

Figure (6): The Economic Network Efficiency *(Liemberger, 2002).*



ELI = CARL / EARL (19)

This indicator should be good enough for the industry, but for media and politicians the next step is recommended.

Step 4: Calculation of the Economic Network Efficiency (ENE):

ENE [%] = 1 / ELI (20)

Figure (6) shows how ILI, ELI and the ENE are related. Is this the way forward? This remains to be seen. New indicators always have their enemies - for various reasons. But hopefully the need for a 'media friendly' indicator will be understood by the various task forces and committees in the IWA, the AWWA and other relevant organizations *(Liemberger, 2002).*

7.0 Long-Term Benefits from Leakage Reduction by Network Rehabilitation Programs

It is economically benefit to replace or to rehab water network to save water and reduce water losses? i.e. to compare between water saving happened from leakage & losses, and new water cost of such a project to replace or/and rehab network. There are drinking distribution systems with about half of the water production reaching the consumption taps. As pipelines get older, the frequency of beaks and the amounts of leakage tend to increase. At some critical level, the amount of water losses cannot be tolerated any more, for economic reasons as well as from a consumer point of view. For budget allocation, it is necessary to assess future pipe replacement needs. Monitoring the number of failures and the amount of water losses helps to decide whether to go on with network rehabilitation.

However, investments for leakage reduction need economic justification in a comprehensive cost-benefit framework. The result will depend on the full cost of replacement or renovation of pipelines on the one side, and on all direct and indirect benefits resulting from reduced leakage and failures on the other side. Theses benefits are a function of the water tariff. While investment costs accrue at the beginning and are evenly distributed over a defined financing period, benefits from reduced leakage and repair extend over a longer period and tend to diminish towards the end of the pipe's service life *(Herz and Lipkow 2003, Herz and Lipkow, 2002, Herz, 2001).*

7.1 Mains Renewal and Rehabilitation to Reduced Leakage

Most water supply organizations regularly carry out work to renew or rehabilitate their water distribution networks. If they did not, the pipe network would continue to age and deteriorate, resulting in increasingly higher maintenance costs to carry out repairs, on order to maintain levels of services to customers. However, age alone is not a reliable indicator of the need to replace a section of main. If a pipe network is, an average 50 years old, and the aim is to prevent it aging further, then at least 2% of the network will have to be rehabilitated each year.

The primary justification for main renewal and rehabilitation is usually one of the following:

- The internal condition of the main is affecting the quality of the water delivered though it.
- The internal bore of the main has reduced due to corrosion or a build up of deposits, so that it is no longer capable of carrying sufficient flow.
- The pipe wall has weakened and is no longer capable of withstand the internal pressure of water, or it has insufficient beam strength to withstand traffic loading.
- Some external factor has resulted in the main being unable to fulfill its current duty *(Herz and Lipkow 2003, Herz and Lipkow, 2002, Herz, 2001).*

RESULTS: CONCLUSION

- It should take into consideration the economic aspects of water to solve the water losses in water distribution system in whole supplying water firms.
- Limitation of water losses in all water networks by analyzing the problem and using the international standard to measure the water losses.
- Water losses occur in any water distribution system in the world. Therefore, the best management of water distribution system is to minimize these losses.
- The efficiency of water network is not the only indicator to compare between water firms or countries, but also with other indicators like: ILI, CARL.
- Some experts consider the 15% of water losses as accepted standard in this decade, but one expert considers 10% of water losses as maximum in the next decade.
- Other experts consider the efficiency of water network as an old indicator and should be neglected, and replaced by the new developing indicators.
- ELL is a new indicator to measure water losses and should be considered in Short-Run, which is usually used for one year, while ELL in Long-Run is used for more than 5 years.
- ELL is considered as more economical to replace/rehab the water network in a city or a zone and more in the same city.
- ELL is comparing between the costs of rehab in water network in such zone in a city with economic cost water losses in the same zone in the same city. If we reach the balance point that the cost of rehabilitation equals the water losses in the specific place, means ELL.
- The decision for water rehabilitation is up to the management of a water supply firm that can decide to rehab, if the cost of rehabilitation is less than the water losses and leakage of the one zone in a specific city.
- ELL is not the same in such country and differs between system and other, from a country to another. It takes many years to accomplish and use it as a standard indicator to be considered as international indicators.
- ELL in short-run and long-run should be taken into consideration as indicator of water losses together with others.

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