An Overall Dynamic Approach in Water Loss Reduction.

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Abstract
Many action plans for reducing NRW fail for various reasons. The authors have analysed a large sample of successful and unsuccessful actions plans. One of their main findings was that the non-consideration of the dynamic nature of the water losses is a frequent cause for failure. Based on that finding, the authors have developed a specific approach called the dynamics of water losses that has already been presented in the frame of the Apparent Loss Initiative launched by the IWA WLTF. In the current paper the objective of the authors is to show how risky it is to develop an action plan without taking into account the whole range of real and apparent losses, their dynamic nature, the interactions between them and, in some cases, the migration of a category of loss into another one. The authors propose new concepts and tools such as monitoring software based on the dynamic approach promoted in the paper.

Keywords: non revenue water; dynamics of water losses; apparent loss; loss migration

DYNAMICS OF LOSSES – THE SCHEME

The dynamic water loss scheme (Figure 1 below) shows the various types of causes and corrective actions that are commonly applied in the reduction of real losses (leak repair, active leak detection, pressure control, pipe replacement) and apparent losses (meter errors, unauthorised consumption, incorrect estimate of unmetered consumption and errors produced by the data acquisition cycle itself).

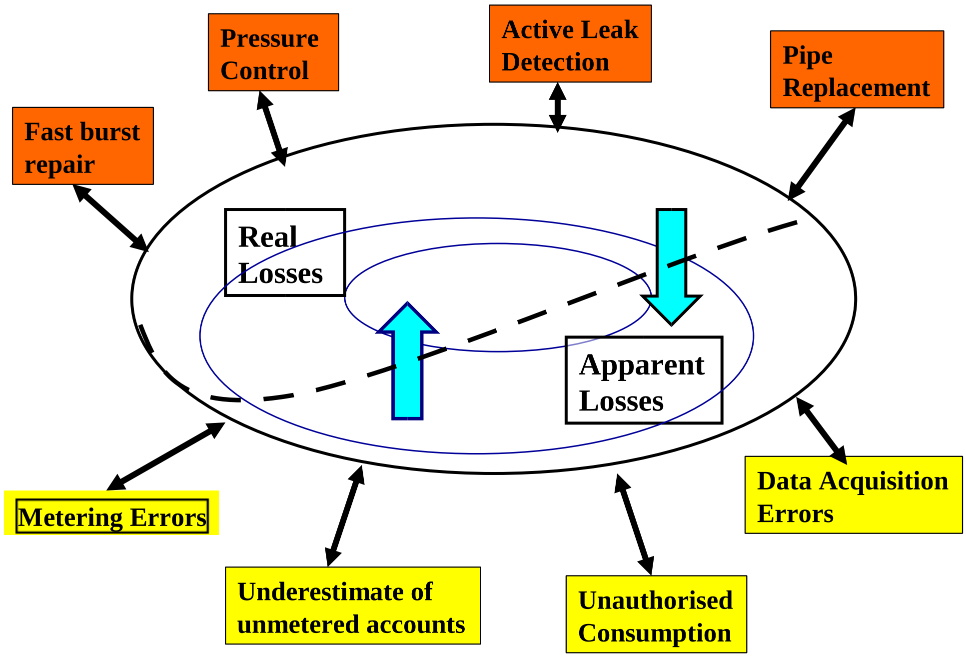

Figure 1: Dynamics of Water Losses

The central ellipse represents the water loss, divided into real losses and apparent losses. The 8 external arrows are the symbols of the actions that can reduce or increase the losses. They are 2way arrows: oriented toward the centre they represent the components of the action plan itself and they contribute to reduce real or apparent losses; oriented in the opposite external way they contribute to increase real or apparent losses.

But the dynamics is not so simple. The two additional blue arrows are responsible for moving the boundary between real and apparent losses and they demonstrate the possible migration of real losses into apparent losses or conversely. In other words some loss migration may appear as collateral effects of the main actions to reduce real or apparent losses. This point is developed hereafter.

DYNAMICS OF LOSSES – THE FORMULA

As demonstrated in former papers (Carteado, 2006; Vermersch, 2008), any action plan to control for Non-Revenue Water consists in a variety of actions, correctly scheduled and coordinated. The overall action plan may include “n” specific actions called “i”. For instance “i=1” refers to leak detection in distribution network, “i=2” refers to leak detection and repair in service connections, “i=3” refers to massive meter replacement program, “i=4” refers to resizing campaign for large meters and “i=5” refers to detection and regularisation of unauthorised consumption. This list is not exhaustive.

Each action is supposed to generate real water savings in volume or increase in water billed, i.e. reduction in NRW. But the NRW reduction is the result of 3 components: (i) action planned to reduce the loss (ii) the coefficient of return of anomaly (CRA) that is often out of control and (iii) some exceptional occurrences (EO) that are difficult to assess and that includes some migration attributes of the loss as described later. As far as real losses are concerned, the CRA is known as the natural rate of rise (NRR), but similar concepts may be used with respect to apparent losses: it is, for instance, the natural aging of the meters that increases the metering errors over time and the “natural” development of low income areas in the suburban areas of the large cities that increase the unauthorised use of water.

The total Vt volume that will be saved in the frame of an action plan during a given period of time is given by the formula.

$$Vt = \sum_{i=1}^{i=n} \left[V_i - (VCRA_i + VEO_i) \right]$$

(Formula n°1)

Where:

The action plan consists in i corrective actions numbered from i=1 to i=n; i also refers to a specific field of activity and to related losses.

V_t is the total water saving (or NRW reduction in volume)

V_i is the water saving directly produced by the corrective action i

$VCRA_i$ is the natural loss increase generated by the CRA related to i
VEO_i is the additional loss generated by exceptional occurrences that may occur in the (i) field and amongst which one may find some unexpected loss migration

The formula is an algebraic; it means that some terms may be negative. It also means that the sum of the negative terms may exceed the sum of the positive terms: this explains the failure of many programmes to reduce NRW: despite many corrective actions the total volumes of savings (V_t) may be nil or even negative.

On the contrary, when a detailed analysis of the terms of the formula is carried out at the stage of the preliminary water audit, it enables the utility or the consultant to point out the main issues and to determine what the conditions for a successful action planning are.

DYNAMICS OF LOSSES – SOME SIGNIFICANT EXAMPLES

The following examples are classified from very simple cases to more complex ones with an increasing involvement of the "migration" concept. They enable to better understand the meaning and the possible application of the formula.

Example 1: Corrective actions should at least compensate the natural coefficient of return of anomalies (Vi > VCRAi)

Much has been written on this matter in terms of leakage (Lambert et al, 2005) but a similar approach may be developed for the apparent losses. The overall undermetering due to the aging of the meters will not be reduced if the savings due to the replacement of some old meters does not compensate the "aging loss" generated by the remaining meters. In a similar way the apparent loss generated by unauthorized consumption will not be reduced if the number of detection and regularisation is lower than the number of unregistered consumption in the low income areas of the city for instance.

Example 2: Geographical planning: the gain in one area may be compensated by the losses in others areas

The water utilities often split their action plan into various geographical areas due to the lack of funds for instance. The project starts in some pilot areas first but, at the end of the program, it often happens that the level of loss for the all city does not reflect the good results obtained in the pilot areas. It simply shows that the savings obtained in the pilot areas are lower than the losses generated by the CRA in the other sectors of the city. Was it better to use the pilot area approach or to focus first on the metering issue for the whole city?

Example 3: Benefits generated by a given category of actions are hidden by losses in another category

In this case, the water utility has a good policy to reduce physical losses but does not take care of the customer meters because the practitioners are not aware of how the impact of the meter ageing may be. The real loss of the distribution network is over estimated because the apparent loss due to under metering is under estimated. The overall result may be nil because the savings in real loss are compensated by the increase in undermetering losses.

Example 4: When real losses migrates into apparent losses.

This case often happens when not all service connections are metered or when there are significant low income areas that are not under control. This does not happen only in some developing countries. It is frequent, in those cases, that the high level of loss is attributed to leakage and the bad status of the distribution network. The apparent loss issue is underestimated for management or political reasons and the priority is given to leak detection campaign. But the effect is not the expected one: leak repair leads to better pressure of service and increased consumption and wastage by the non-metered customers and those in the low income areas. The real losses savings are automatically transformed into apparent losses by underestimate of the real customer's consumption without any economical and financial advantage for the utility.

Example 5: When apparent losses migrates into real losses

This example is more or less the opposite of the former one. In some water utility – often in developing countries – there is a high rate of unmetered service connections. Experience shows that their average consumption may be twice or three times higher than the consumption of the metered service connection, when there is no water restriction or pressure management. This is generally due to high level of wastage when there is no consumption control. When these nonmetered areas are metered there is a dramatic decrease in customers' consumption, which leads to higher pressure in the pipes and increases flow rate of leakage.

Example 6: Effect of non pressurized network

When a water utility has to deal with water shortage and needs to develop a rationing policy, the network is not always pressurised. This has poor consequences for the life expectancy of both the distribution network and the customers' water meters. When the situation is back to normal it becomes very difficult to make a clear distinction between real and apparent loss. It is often necessary to develop a comprehensive rehabilitation program.

Example 7: Low income areas, slums, red areas, favelas

Those are the different names given in different countries to these areas where the water supply is not fully under control for various reasons such as low income, violence and security. This is not the focus of this paper to present how to manage these areas but one of the basic solutions is to install zone meters and provide an appropriate pressure of service to give the consumers a fair quality of service and reduce both, leakage and wastage that cannot be distinguished in these unmetered areas. In the countries where the number of low income areas is significant, the implementation of this policy may completely change the pressure in the rest of the network and therefore leads to a modified breakdown between real and apparent losses.

Example 8: Collateral effect in water pressure control

Pressure control appears as one of the most effective way to control real losses. However, it may also produce collateral effects such as a significant reduction in the customers' consumption and related increase in terms of apparent losses. Pressure reduction generates a change in the customer's consumption patterns, mainly at night. Some specific water usages may be affected by the pressure drop. At night, some other consumption may drop down under the minimum flow rates of the water meters; in that case, relevant volumes may be accounted for as apparent losses. The Legitimate Night Flow Initiative of the IWA is presently surveying this issue and aim at developing a matrix which will be the basis for calculating legitimate night use under any operating regime in any geographical location (Fantozzi, under preparation)

DYNAMICS OF LOSS – DETAILED ANALYSIS

The formula (1) presented above is a very general formula that shows which issues need to be addressed and which strategy needs to be implemented to meet the targets in terms of NRW. In order to be more effective, it would be necessary to show how to calculate every component, i.e. V_i, $VCRA_i$ and VEO_i. for each category of loss. Is it possible to provide such detailed formulas?

As far as real losses are concerned, there is an abundant literature about the natural rate of rise (NRR). However no general formula is provided for obvious reasons: detailed surveys and assessment of the utility records and additional field experimentation are necessary to make a model of the real losses (Lambert, 2005).

As far as apparent losses are concerned, meter ageing formulas are based on laboratory experimentation. There is no universal formula; each utility or country has to carry out their own laboratory trials that will differ based on many factors such as type of meter, conditions of service, condition of meter installation, quality of water etc. Date of replacement will also depend on cost of meters and cost of water (Arregui et al. 2006)

The other types of apparent losses, such as the unauthorised usages are deeply dependant of the local context: type of management of the utility, social and cultural background, juridical background etc. No serious analysis and prospective can be carried out without former field experimentation based on pilot areas or samples of consumers. Finally, the low income areas need to be surveyed on a case by case basis.

As a conclusion, it is clear that, due to the nature of the losses itself, the general formula cannot be used and no reliable forecasts can be carried out without implementing preliminary field and laboratory surveys. These surveys must be part of the preliminary water audit. Forecasts should be based on a calibrated model approach.

DYNAMICS OF LOSS – APPLICATIONS AND SOFTWARE

Apart from the utility records, the main tools that can be used to better define the terms of the formula are (i) the water distribution hydraulic model and (ii) the NRW project management information system.

Water distribution hydraulic model

The water distribution hydraulic model shows how water flow rates and pressure of service will be distributed under certain circumstances and scenarios. In particular, it is also very useful to design sectors and district metered areas (DMA) in order to get the NRW under control. But this tool must be used very carefully.

The model needs to be correctly calibrated, which is often not the case. In many cities around the world there is water shortage and water is rationed by the Utility in order to share it equitably between the consumers. One understands easily that calibrating a model in such conditions is not an easy task.

Another difficulty to calibrate hydraulic models is linked to the level of loss and the breakdown between real and apparent losses. When the volume of losses is around 20% of the water input it generates no big error to distribute the losses at the nodes as directly proportional to the consumptions. But when there is a 50% loss or more, this hypothesis may lead to a wrong distribution of flow and pressure over the distribution network. For instance, in many megalopolis, very low-income areas concentrate high level of real and apparent loss: these losses needs to be concentrated in the model too and not distributed on pipes and nodes in other areas, which is a very common mistake.

Too often, poorly calibrated model are used to take strategic decisions and the authors would like to stress that hydraulic model should not be considered as magic tools. However, a well calibrated model – or a model that has been well calibrated under certain circumstances – may be very helpful to detect possible migration from real loss to additional consumption, additional real losses or additional apparent losses.

Non-Revenue Water planning model

Programmes to control for NRW are complex because they comprise many actions in various fields of activity such as water production, water distribution, water metering and customer management. In such cases, it is very difficult for the management of the Utility – and for the manager in charge of the NRW project – to have a clear overall view of the effectiveness of each individual action. Which department does not act properly? Which component of the programme does not produce the results initially forecast? What are the interactions between the various components of the programme? Which action jeopardizes the impact of others? How to correct or to modulate the programme in order to meet the final targets?

To answer these questions, it is recommended to build a model, based on Formula (1). The objective of the model is to simulate the dynamic evolution of the losses when going from the current level of loss to the targeted one.
At the outset, the model needs to be built on the basis of a very detailed audit of the operation of the water utility that includes the following:

- the main causes for water losses have been identified and quantified
- the water balance has been established
- cost-benefit analyses have been carried out
- In addition - last but not least – the risks of migration of losses has be carefully analysed and quantified.

The pertinence of the model and the actions to reduce NRW depends largely on the correct diagnosis of the NRW situation of the Utility and the values used for the different ratios. Therefore, it is important for these two elements to receive the greatest attention and preferably the support from specialists.
The main objective of the model is to compare - as often as possible – the actual value of the loss (i.e. the one that results from the direct measurement of water input and consumption volumes)

and the calculated value of the loss (i.e. the one that results from the algorithms and hypothesis of the model).

Next figure n°2 describes the structure of the model.
The model includes various modules. Each module refers to a component of the action plan. For instance:L1 leak detection and repair on primary distribution network; L2, leak detection and repair on secondary network; L3, leak detection and repair on house connections; (L4), large meter resizing campaign; (L5), unauthorised connection detection campaign; (L6), fraud detection campaign and L7, other specific actions.

For each module (or action), the calculation of the impact in terms of loss reduction results from one positive and one negative factor such as:
- positive impact Vi: what is due to the action itself: leak repair, meter replacement, etc.
- negative impact VCRAi: natural deterioration and coefficient of return of anomaly (CRA)
- positive or negative impact VEOi due to exceptional occurrences

The results obtained from the different modules are added together with the previous losses to produce the "Modelled Loss Vt" that can be compared to the measured value of the loss Vm.

Action Plan	**Action 1**	**Action 2**	**Action 3**	**Action 4**	**Action 5**	**Action 6**	**Action 7**	**Total**
Initial Loss Wbo	L1o	L2o	L3o	L4o	L5o	L6o	L7o	**Vto**
	minus	minus	minus	minus	minus	minus	minus	
Actions	V1	V2	V3	V4	V5	V6	V7	
	plus	plus	plus	plus	plus	plus	plus	
NRR (natural rate of rise)	VNRR1	VNRR2	VNRR3	VNRR4	VNRR5	VNRR6	VNRR7	
	plus/minus	plus/minus	plus/minus	plus/minus	plus/minus	plus/minus	plus/minus	
EO (exceptional occorences)	VEO1	VEO2	VEO3	VEO4	VEO5	VEO6	VEO7	
	equals	equals	equals	equals	equals	equals	equals	
Current Loss WB	L1f	L2f	L3f	L4f	L5f	L6f	L7f	**Vt**
Modelled loss Vt	**L1f + L2f + L3f + L4f + L5f + L6f + L7f**							**Vt**
Actual loss Measured Vm Calibration Vt vs Vm								

Figure 2: Dynamic NRW Model used to monitor a complex action plan

As any other model such as distribution network model or aquifer model, the NRW dynamic model requires calibration. This can be done at the audit level but also during the implementation of the programme through the continuous comparison between actual losses and calculated losses.
The main items to be considered to calibrate the model are aspects such as the predicted impact of each action and the values of the coefficient of return of anomaly. The analysis of the evolution of the NRW value from the Model and the comparison with the actual value allows not only the calibration of the model but also highlights possible anomalies that require correction.
It is recommended to test the model in pilot areas in order to estimate some specific impact such as the migration factors.

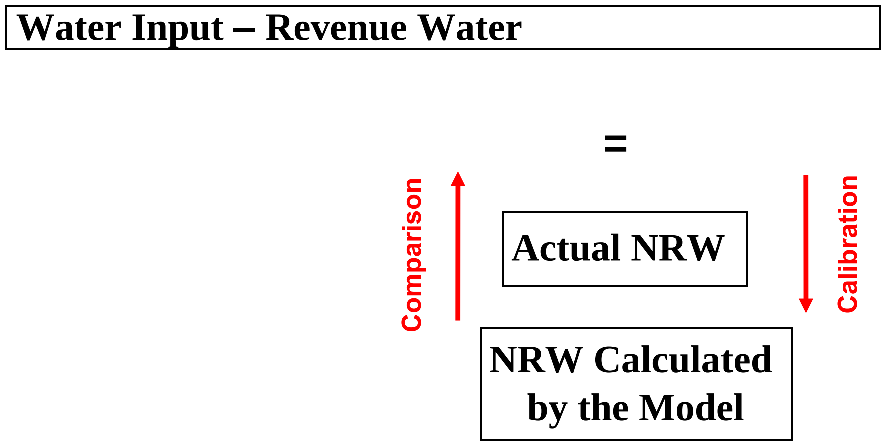

Figure 3: Flowchart calibration of the Dynamic Model

DEVELOPED AND DEVELOPING COUNTRIES

In this paper, the authors have stressed some specific issues that are often very important in developing countries such as lack of metering, water shortage and extensive poor areas. Therefore, one may believe that this paper does apply to developing countries only.
In fact, the frequent distinction between developed and developing counties is not always appropriate: there are very developed utilities in developing countries and poorly developed utilities in developed countries.

Developed utilities and undeveloped utilities face the same issues: they need to fully understand and control the loss production and transformation mechanisms. When a developed utility has a very low level of loss and the regulator asks for additional loss reduction, the utility needs to carry out further analyses on the loss breakdown and the margins of error of the water loss ratios; then, the utility can decide if there is a need for prioritising leak detection or metering policy, for instance. The proposed dynamic approach may be very useful in such framework.

CONCLUSION

The dynamics of water losses aims at reaching a better comprehension of the water loss mechanisms, including transformation from one kind of loss into another one. The lack of consideration of the dynamics of water losses is a very frequent cause for failure in action planning for reducing water losses.

The authors have tried to show how important it is to consider the dynamics of losses at any stage when designing and implementing any NRW-related action plan. This paper only shows the basics and there is still much to do to establish a complete methodology to tackle the issue. Nevertheless, the authors do believe that the dynamics of losses will gradually become a full and unavoidable component in the water loss reduction planning.

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